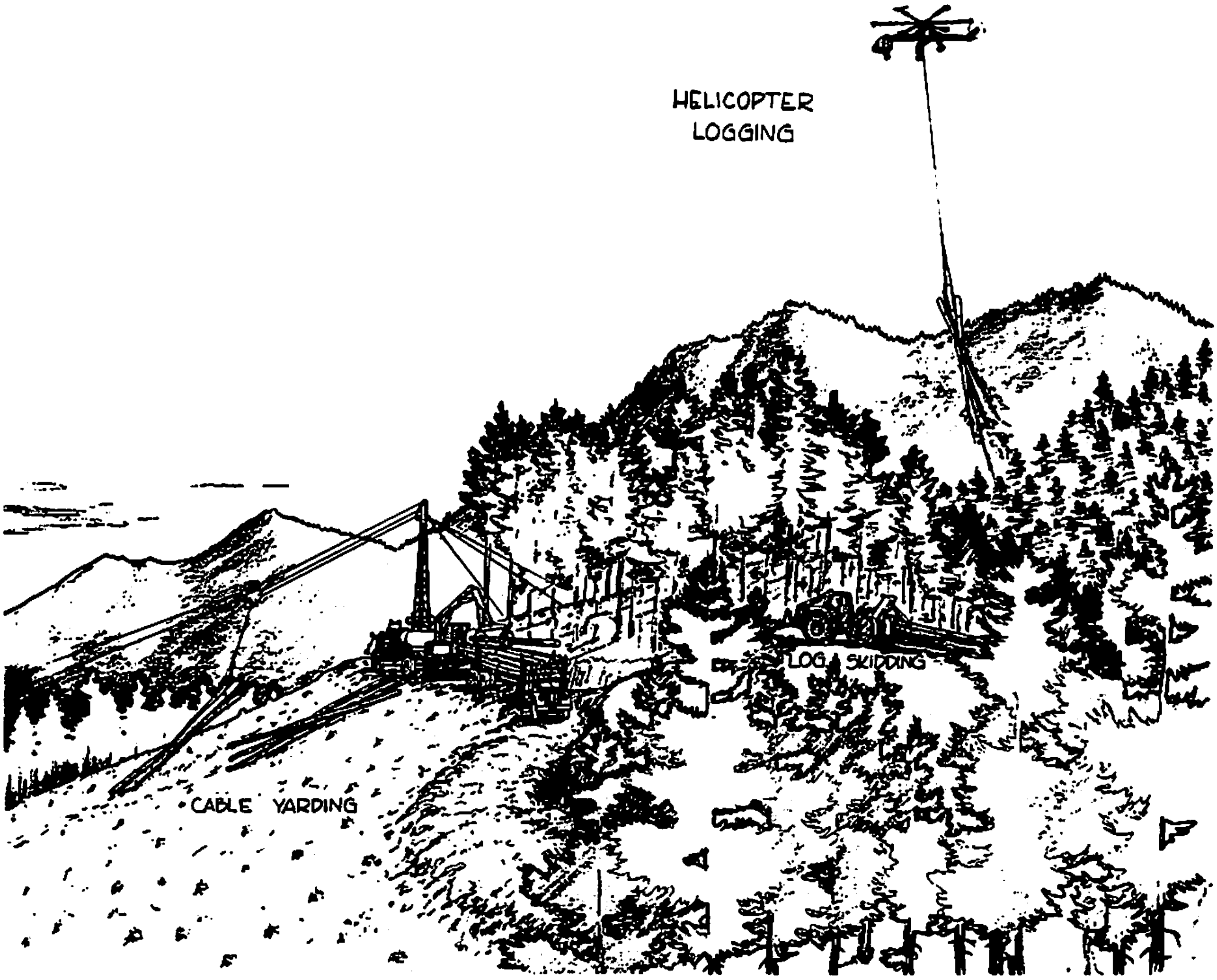
FOREST OPERATIONS IN POLITICALLY AND ENVIRONMENTALLY SENSITIVE AREAS

A Proceedings of the Council on Forest Engineering



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Forest Operations in Politically and Environmentally Sensitive Areas[1]

Gerald Partain[2]

To discuss a topic like "Forest Operations in Politically and Environmentally Sensitive Areas" you've certainly come to the right place in the right state. I just hope you've all brought with you the phone numbers of some bright lawyers well-versed in environmental laws. You may need to call on one before you've completed your meeting. You probably didn't need an environmental impact report before you scheduled this meeting, but don't count on it. I've been wrong about that before.

Actually it's a great honor to be invited to be your keynote speaker--not only an honor but a serious responsibility. A keynoter must set the stage for the whole conference--develop a note of confidence and optimism not only for the success of the conference itself, but for wrestling with the subject at hand after you return to your real world afterward.

Lately, there hasn't been a lot of room for optimism for conducting forest operations in politically and environmentally sensitive areas in California. We continue to be challenged seemingly at every turn by groups of activist citizens in league with the courts and the legislature as well as with county governments and other state agencies. Our motives as forestry professionals, to say nothing of our methods and procedures, seem to be distrusted to such an extent that open dialogue is often made quite difficult. Without question, however, most of our critics are formidable antagonists. They have energy and zeal fostered by the assurance that somehow most of the angels are on their side. You can see where that consigns the rest of us.

But I'm not here to recite a litany of all the problems that most of you already know too well. My role is to build hope for the future, and of one thing I'm quite certain, there is a bright future. We may have to mend some of our ways. We will certainly have to learn how to communicate with the public as a whole. That much is necessary and we all know that necessity can beget the means of accomplishment.

In my opinion, there are two related strategies we need to employ as we look ahead. Both involve a rather active stance toward the future. First, forestry professionals and others responsible for maintaining forest productivity must do more now than in the past to set the agenda for forest policy discussions. Forestry professionals, I believe, need to communicate more effectively their values and priorities to various concerned publics and gain these individual's support for forestry programs.

Secondly, the forestry community must also learn to anticipate better the type of policy issues that will be raised from outside the community. Many issues only indirectly related to our profession can severely affect us if they become fixed in law or custom. We must learn to foresee outside concerns before they surface in the media, or in the Legislature, or in the courts. If we don't catch some issues early, viewpoints may already have become polarized, and we will have lost our opportunity to influence subsequent decisions.

I would like to illustrate what I mean by using some examples drawn from our experiences with forest practice regulation. First, however, I should back up a bit and explain some of the historical background for those of you from outside California.

The impetus for regulation came first from the federal level. Several regulatory bills were introduced into Congress as early as the 1920's as part of a general attempt to accomplish the development of scientific, sustained yield forestry on all timbered land ownerships. None of these bills passed, but the idea of federal regulatory laws stayed alive and again became an issue during the administration of Franklin Roosevelt. Under these continuing pressures, California adopted its first Forest Practice Act in 1945.

California's 1945 Forest Practice Act resulted from a bill sponsored by the Forest Products Industry and was based on the concept of self-regulation. The stated purpose of the legislation was to "...encourage, promote, and require ... adequate supplies of forest products ... for the needs of the people and industries." Rulemaking under the act was left primarily to district committees composed of industry representatives and landowners.

The 1945 Act made no mention of values such as soil conservation, watershed protection, or wildlife habitat which are now commonly included in many forest practice programs. This was a cause of some concern to California's environmental and professional communities. Nevertheless, the Act survived with only limited modification until 1971. In that year, however, an appellate court struck down the law on constitutional grounds.

Ruling in the Bayside Timber Case, the court found the rulemaking provisions of the Act unconstitutional on two counts. First, it held that the act had failed to provide adequate guidelines for the making of rules. Second, and more to the point, a violation of due process was seen in the makeup of the State Board and the Regional Committees, since a majority of the members each had a "pecuniary" interest in the matter before them. In other words, too many industry representatives and not enough public. The invalidation of the 1945 Act created something of a battleground as the Legislature scrambled to develop new legislation. Controversy arose between the timber industry, organized labor, and Governor Regan's administration on one side who wanted minimal changes in the new law, and the environmentalists, led by the Sierra Club on the other who saw an opportunity to broaden the purpose of the regulations and to strengthen the means of enforcement.

Two years later the Z'Berg-Nejedly Forest Practice Act of 1973 emerged. It was a composite of two competing bills, both of which had been amended considerably from the form in which they had been originally introduced. Governor Regan signed the law which had been passed unanimously by the Legislature.

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[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985

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The intent section of this new law went considerably beyond the 1945 Act in recognizing the values furnished by forests in addition to timber products. While legislation clearly values timber production above other outputs, it requires that consideration be given "to values relating to recreation, watershed, wildlife, range and forage, fisheries, and aesthetic enjoyment." Individual section of the act further reinforce and make specific the legislative concern over adequate control of soil erosion and protection of the beneficial uses of water.

The Z'Berg-Nejedly Law broke new ground by requireing that a Timber Harvesting Plan be prepared by a Registered Professional Forester and approved by the Department before any logging takes place. With the exception of minimum post-logging stocking standards, the task of adopting specific rules is vested in the Board, which now has just three industry members on the panel of nine. Since 1973, the Board has developed a lengthy package of rules covering such elements as clearcut size, watercourse and lake protection, logging practices and erosion control, fire safety, and road and landing construction.

On the surface and in practice, the 1973 Act represents a major intervention into the activities of private forest landowners in California. It has been called the most stringent and comprehensive in the nation, as it covers a broad range of environmental and public good values. However, the Act reamins controversial and continually subject to change depending on political or judicial winds.

The administration of this new Forest Practice Act has become a very complex undertaking. It is an act with which no one seems to be particularly pleased, aside perhaps from some of our professionals.

Our environmental community continues to try to make the Act and the rules adopted to implement it more responsive to public interest-type values. Working primarily through provisions which allow county governments to request special rules from the State Board, environmentalists have recently gained a number of new regulations. Since 1982, five highly urbanized counties have requested and received rules from the Board. In these counties, in addition to all the other rules, there are now controls on hours and dates of logging and hauling, noise limits, bonding for maintenance of private and county roads, more protection of aesthetics, and more public notice and participation.

Previously, counties had had the authority to regulate timber harvesting through ordinances that were stricter than state law. Certain of these counties had begun to be more restrictive than intended by legislative policy, leading the Legislature to withdraw that authority. In its place, a process for the counties to request special rules from the Board was enacted. Not satisfied with their recent gains, the environmental groups and counties also last year brought six lawsuits against the Board and the Department. These suits challenged state law on a variety of constitutional and statutory grounds. At base, however, the suits appear to be an expression of certain groups' desire to all but eliminate timber harvesting in the more urban sections of the state.

From industry's standpoint, the Z'Berg-Nejedly Act can be a source of great disdain. In essence, many of our industrial landowners are frustrated by the bureaucratic plan approval process and by having to incur costs for which they see no commensurate return. The question of additional costs is a real one, although the estimates of the actual costs of regulation vary greatly. It seems clear though that our Act and its various provisions has in effect transferred a variety of rights of property from private landowners to the public sector or to neighboring landowners with little or no compensation. The courts have supported this transfer by not-very-generous reading of the doctrine of compensation.

To date, the effect of our Act on industrial behavior is not clear. A Department sponsored study has found that over a million acres of California industrial land has been offered for sale in the last five years. However, almost all of this land has been purchased by other corporate groups. Industry would appear to see a continuing place for itself in California, apart from all the problems it faces.

The Legislature has taken some limited steps to brace up the rights of timber landowners to improve the state's climate for private forestry investment. The 1982 bill amended our timber tax law and made clear that our timberland zoning program was designed to encourage production and not to have lands set aside as reserves. Also, as I mentioned earlier, county authority to unilaterally impose forest practice rules has been limited by the State Legislature. But these acts have hardly altered the trend to impose constraints on the activities of private landowners

The administration of Governor Deukmejian is committed to improving the climate for business in California and to stabilizing our regulatory environment. But we have no plans to throw truly necessary controls out the door. In a recent speech, our Secretary of Resources, Gordon Van Vleck, made this point quite strongly. His comments contain some sage advice for participants of this conference. I quote:

> "The State, through its many regulatory agencies, can assure even-handed enforcement of rules and regulations for all users of our natural resource base. However, I have a caveat for the industry: You must realize that today's laws and regulations are a product of public opinion.
>
> "In our political framework, the power to demand regulation in any area of government rests with the voters, and today that power resides in our major metropolitan centers.
>
> "Tomorrow's regulations of forests, air quality, fish and wildlife, toxics and costal land uses are more likely to be based on the perceptions--accurate or not--of urban voters in Oakland or Los Angeles who have never seen a steelhead, a sea otter, or walked in a forest, than on the knowledge of experienced managers, scientists or government officials."

Taking this situation into account, I think it becomes clear that the primary way forestry leaders can continue to conduct forestry operations in today's sensitive political and environmental circumstances is to create a broad public understanding of the benefits of forest management. In other words, if we are to gain a balancing of the costs and benefits of regulation and to define a stable land base then we must have open communication and planning capabilities.

Effectively communicating with the public is a difficult endeavor for most forestry professionals. In fact, as I know you are aware, many of our critics would say that it is our biggest fault.

However, it is also true that the long-running Smokey the Bear Campaign has been very successful, and foresters have been largely responsible for it. In California, we have recently worked with Smokey and some of our professional sports teams to produce TV ads and posters that have been quite effective. We need to work very hard to produce a set of messages on forest management in general that can appeal to the public in the same way. Equally important, we need to learn how to talk more openly among ourselves. Of course, we also need to get better at anticipating how various outside factors can and do affect us. At the heart of my talk today has been an appeal to forestry professionals to get out ahead of the issues before viewpoints become polarized or intractable. Above all, we need to make sure the public understands the role that forestry plays in meeting basic national and regional economic requirements. For example, California's forest industry remains the second largest in the United States, providing 15 percent of annual national softwood lumber production. Activities of the industry translate into jobs, payrolls, tax contributions, and purchases of services and materials in over 30 of our rural counties. In Humboldt County, as an example, the local wood industry provides about 90 percent of the manufacturing-based employment. I think a broad cross-section of the public can find meaning in this economic activity generated by forestry.

A second argument for continuation of forest management also relates to its economic importance. In recent years, I have noted a change in the stance of some rural county planners, development agencies, and local entreprenuers towards natural resource based operations. During the 1960's and 1970's, many rural counties sought to diversify their economic base by attracting high tech or light industrial firms. These industries seemed preferable to the older smokestack variety which keyed rural development but were suddenly viewed as dirty and old-fashioned. Today, while diversification is still an important goal and while the timber industry remains in a slump, many rural counties are coming to see the long-term advantage of maintaining their traditional industrial base.

Quite honestly, I think the main reason for this change in thinking is that most communities have not been successful in attracting new firms. But beyond that, many local officials have come to see that timbering and ranching offers an opportunity to maintain the rural character of their communities. High tech firms, on the other hand, tend to bring gridlock and other urban problems with them. This is an important factor in rural counties as they become more dependent on retirees, second-home owners, and recreationists who are willing to spend dollars to live or play in rustic environments.

Forestry professionals will do well to take advantage of this new attitude and to work more closely with local planning officials, particularly if markets for forest products improve or can be expanded.

A third advantage of the forestry sector relates to the various nonmarket and environmental benefits that lands under management can provide. We have paid lip-service to these values for years, but public remains largely ignorant of the environmental role of forest lands. I think the public would be interested to know how forests function in the total environmental cycle. After all, forests act as vital watersheds almost everywhere. Many important wildlife species live on or near forests. Moreover, many of our citizens, perhaps as many as one-fifth, annually use privately owned forests as sites for recreational activities, such as skiing, hiking, and camping. Such activities would be threatened if active forest ownerships are converted to residential or agricultural use.

Along with the various regulatory programs I have mentioned, the California Department of Forestry is also developing an assessment program, modeled to some degree on the Forest Service's Resource Planning Act Program. Our program is beginning to provide comprehensive information and analyses on trends affecting forestry in this state. In addition, we have been working closely with the Forest Service and our universities to attempt to institutionalize something like a futuring process within our community. I know the Forest Service and a few other states have also begun a similar process. It's what I mean by getting "out in front," and I recommend it to all of you.

To conclude, I hope that I haven't left the impression that foresters in this state are overwhelmed by the situation they find themselves in. The state contains a very productive timberland base and there are some excellent economic opportunities for substantial expansion of intensive forest management on private lands.

California's Board of Forestry is celebrating its first 100 years of existence with an in-depth look at forestry issues and development of a plan to begin addressing these issues as it enters its 2nd century. I believe that our Board will be around to celebrate its second centennial in 2085 and that forestry professionals will still be playing an important social role. However, I do think that these professionals will have had to master a whole new set of communicative, analytical, and social skills. Our future and their future is likely to depend on how well we employ all the tools that are available to us--the market, government, politics, and most importantly, our intellectual and inner strengths. That will be true not just in California but over the entire nation.

Tahoe National Forest: A Case Study of Forest Operations in Politically and Environmentally Sensitive Areas[1]

Robert G. Lancaster[2]

Abstract: The Sierra Nevada Group of the Mother Lode Chapter of the Sierra Club has recently opposed the harvesting of timber in the area adjacent to the Rock Creek Nature Trail. This paper provides background information regarding the trail and the logging history of the area.

Purpose for the Nature Trail

The Rock Creek Nature Trail was built on the Nevada City Ranger District in 1969 as an educational trail, interpreting the forest environment and man's interaction with it. The trail was located in the Rock Creek drainage for several reasons:

1 - It is close to town, with easy access.

2 - It provides a gentle walk suitable for both young and old visitors.

3 - It is a scenic area adjacent to a creek.

4 - There are opportunities to explain and interpret both a variety of vegetation types and the use and management of forest resource.

The trail is especially popular with local residents. Over 2,000 visitors used the trail in 1983.

A brochure describes various features along the trail that are marked with numbered posts. It points out both the natural environment and also man's activities in the area including the remains of an old cabin and a former logging site.

Logging History of the Rock Creek Area

The area has an extensive logging history. It was clearcut during the Gold Rush era. Most timber in the sale has naturally regenerated since the 1850's and 1860's. As mentioned previously, the brochure points out a logging site which was used 70 years ago. Evidence of this can be seen north of the trail at marker 19. Since 1968, almost nine million board feet of timber have been harvested from the area, including the following:

Rock Creek Sale (1968)	557,000 BF
Grave Timber Sale (1969)	2,000,000 BF
Five Mile Sale (1972)	2,000,000 BF
Blue Tent Sale (1973)	830,000 BF
Youth Camp Sale (1975)	3,000,000 BF

Evidence of logging is apparent as one drives down the Rock Creek Road and along the Washington Camp Road. In addition, 1,500 cords of firewood have also been removed from the area since 1980.

Management Direction

The current management direction for National Forest System land in the vicinity of the trail is described as General Forest Zone--which is one of the most important sources of commercial timber in the Forest. In addition, multiple use coordinating requirements call for providing interpretive facilities to further public understanding.

Five Mile Sale

Two units of the current Five Mile Sale are located across the road from the Nature Trail and are at the heart of the controversy.

The Environmental Assessment was completed in 1978. The sale was originally offered twice in 1981. Both of these were opposed by the timber industry because of the high development cost and poor market conditions at the time. In 1982, the sale was reprepared after reducing the expenses involved in harvesting and hauling the timber. The sale was again offerred in June 1983. It was awarded to Bohemia, Inc. as the high bidder ($40.00/MBF). The sale involves 13.2 MMBF on 496 acres, two-thirds of which will be tractor logged and the other third skyline logged.

The two units nearest the Nature Trail (#15 and #20), contain 23 and 15 acres. respectively. They will be logged using a short span skyline system. The logs will be transported upslope away from the Nature Trail area, minimizing any impacts along Rock Creek. The short span skyline logging fully suspends one end of the log, greatly reducing ground disturbance and, subsequent erosion.

The skyline method is relatively new to the Tahoe and has only been used since the mid-1970's. When the trail was built, skyline systems were not available, and therefore logging on sideslopes, such as the Rock Creek area, was not practical. The comment from an outdated version of the Nature Trail brochure illustrates the fact that the logging methods available when the trail was first constructed could not protect the stream resources properly and therefore, logging at Rock Creek would not be done.

Protecting the Trail's Scenic Quality

Although two of the cutting units are located across the road from the trail, their visual impact on hikers should be minimal. The vegetation surrounding the trail is quite dense. Often at noon, many spots on the trail are shady, due to the dense forest canopy. This tangle of vegetation between the trail and the road will provide a substantial screen, making it difficult to see the units from the trail.

Unit 20 will be visible from the parking lot. However, the harvested site will add to the educational experience that the trail provides. Current logging methods can be compared with those used 70 years ago. The visual disruption as seen from the parking lot will be short-term since the area will be replanted with tree seedlings.

Overall harvesting activity disturbance will last about 10 days for each unit. The logging plan, however, will minimize disturbance to the Rock Creek Trail as logs will be yarded upslope away from the area and transported using the upper road. This will diminish visual impact and noise around the trail.

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[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

[2]Former Supervisor, Tahoe National Forest, Nevada City Ranger District, Forest Service, U.S. Department of Agriculture, Nevada City, California.

Pileated Woodpecker

Since harvesting of timber has occurred in the area for the last 16 years, the Five Mile Sale should not eliminate the pileated woodpeckers from the area. The nesting tree of concern is adjacent to the nature trail, is not in any harvest unit and will not be eliminated.

The Forest contains approximately 25,000 acres of land capable of sustaining over 1,200 pileated woodpeckers, which is four times the amount needed to insure a viable population on the Tahoe. This species prefers old growth and requires trees of substantial size and age suitable for cavity nesting. Stands of 70-80-year old trees can meet this requirement as long as they are distributed throughout the Forest.

Clustered Lady Slipper Orchid (*Cypripedium fasciculatum*)

This species of orchid is found along the road bank and in Unit 15. It is not Federally listed as threatened, endangered, or sensitive. It is, however, listed by the California Native Plant Society as a species that may become vulnerable.

Forest Service specialists have walked Unit 15 and have identified stands of this orchid. Its habitat will be protected by delineating areas where the orchid is found, as well as adjacent areas of similar habitat. These areas, which total approximately three acres, will not be harvested.

Summary

Although the timber harvest activities may cause some disruption for Nature Trail visitors for a three-week period, the overall impact will be minimal. Due to the dense vegetation, the scenic quality along the trail will remain. The harvesting is not expected to eliminate pileated woodpeckers from the area, and the habitat of the Clustered Lady Slipper will be maintained. Loggind activities in this area will provide an excellent and accessible opportunity to better explain resource management and logging operations.

SUPPLEMENT

This supplement provides additional information and mitigation measures regarding the harvesting of timber in the Rock Creek area. It should be read in conjunction with our previous "White Paper."

Mitigation Measures

To mitigate some of the concerns raised by the Sierra Club and others, a 200-foot buffer strip will be left along the road in Unit 20. The vegetation in this strip will screen the harvest area from the road and parking lot.

In addition, a 2- to 3-acre no-harvest area will be maintained in Unit 15. This will protect the known *Cypripedium fasciculatum* (Clustered Lady Slipper Orchid) plants and adjacent area with similar habitat. As was mentioned in the previous white paper, this orchid is not listed as threatened, rare, endangered, or sensitive. The decision to delineate a no-harvest area is considered adequate to protect this population by agency biologists, as well as botanists from other agencies. Due to the speculative nature of the timber harvest impacts to the nearby habitat of the orchid, a difference of opinion exists among professional biologists and botanists as to the size of the buffer zone needed.

Logging History

The Rock Creek area has been used for resource production for over 100 years. In addition to the logging history noted in the previous white paper, an old lumber mill was located on what is now the Nature Trail site. This mill was operated from 1879 to 1905. It was then moved upcanyon where it was operated until 1928. The site has undergone extensive alteration and does not contain virgin timber. The land in this area was acquired as part of the National Forest System in the 1940's because of its potential timber production.

Logging Methods

The clearcutting issue is at the heart of this controversy. Using the technological advancements available today, foresters believe that clearcutting can be completed on certain forested land, as in the Rock Creek area, without damaging long-term productivity. Some members of the public, however, are opposed to this method of harvesting timber.

Opposition to clearcutting was expressed during the development of the Tahoe National Forest Timber Management Plan. The preferred alternative, formulated after consideration of these comments, was approved in 1978. This plan calls for intensive timber management of 305,000 acres of the Forest. Within these timber emphasis areas, clearcutting and shelterwood harvesting are planned on about 5,600 acres per year to accomplish this goal. Multiple use management, including wildlife, recreation, and watershed is part of the management direction for these lands as well as for the remaining 508,000 acres of National Forest lands within the Tahoe. By intensively managing about one-third of the Forest for timber, production can be maximized, waste reduced, and impacts of intensive timber production on the remaining of the Forest's lands lessened.

Based on the results of early day harvesting techniques, "clearcutting" is a word that evokes an emotional response from many people. Rarely will additional information or factual material alter these emotional reactions. Tahoe National Forest personnel are always available, however, to discuss this issue and forestry practices in general.

Summary of Information Presented in the Original White Paper and this Supplement

The Rock Creek area has had an extensive logging history. Past harvesting is partially responsible for the condition of the site as it now exists. The purpose of the Nature Trail was to interpret both natural features and man's use of forest resources. The trail is a popular interpretive facility and there are no plans for its removal. The harvest is not expected to reduce the scenic quality of the trail experience. A buffer strip will be left to screen harvest activities in Unit 20 from the parking lot and access road.

The nest tree of the pileated woodpecker is adjacent to the trail and is not in any harvest unit. After the Five Mile sale, biologists anticipate that the woodpecker will remain in the area because of the continued presence of suitable habitat.

The population of the *Cypripedium fasciculatum* (Clustered Lady Slipper Orchid), which is found primarily on a disturbed road bank and irrigation ditch, will be protected from logging. A no-harvest area will protect the individual plants and adjacent areas with similar habitat.

The Sierra Club has submitted an appeal on the Revised Decision and Finding of No Significant Impact signed by Forest Supervisor Robert G. Lancaster on May 9, 1983. The appeal was forwarded to Regional Forester Zane G. Smith, who dismissed the appeal as untimely on October 23, 1984.

Most of the timber sales in the Tahoe National Forest are located in inaccessible areas. The Five Mile Sale provides an opportunity for the public to see and learn about timber harvests and logging techniques. The harvest near the Nature Trail provides an increased educational opportunity for the public.

Logging, Politics, and Regulation in the East: Status and Prospects[1]

Frederick W. Cubbage, William C. Siegel, and Kevin P. Raney[2]

Abstract: A model of politics is adopted that helps explain the recent proliferation of state and local laws that regulate logging. The status of logging regulation in the eastern United States is reviewed--both state forest practice statutes and local ordinances. Prospects for further regulation are discussed.

The theme of this meeting "Logging in Politically and Environmentally Sensitive Areas" is particularly relevant in the 1980's. Public regulation of private forestry practices have proliferated since the early 1970's. In those years, major state forest practice acts were enacted in the West. Then, in the late 70's, local regulatory efforts began in earnest in both the West and East. Today, logging is regulated in some respect by virtually every modern ordinance governing rural private landowners' property rights. We will examine the scope of these statutes and the reasons for their enactment.

POLITICAL PROCESSES

Enactment of laws governing logging practices may be viewed essentially as a political process. A political system serves as a means to allocate resources, to arbitrate disputes, and to establish institutions, programs, and rules under which market transactions take place. Politics are pervasive, and often undeservedly carry a negative connotation. At least in the United States, politics are relatively open to all interested participants, operate in a reasonable environment, and seldom use violence as a recourse to unsatisfactory outcomes.

A belief that a system is fair, however, provides little solace to persons adversely affected by political decisions. In order to explain how political decisions are made, a number of authors have developed models of politics. For discussion here, a model developed by Anderson (1979) will be adapted to help explain the recent spate of laws regulating logging.

The Model

Anderson describes six steps in the policy process--problem formulation, policy agenda, policy formulation, policy adoption, policy implementation, and policy evaluation (fig. 1). The first step in the process involves identification of a problem, which may be defined as "a human need, deprivation, dissatisfaction, self-identified or identified by others, for which relief is sought" (Jones 1970). Essentially, a problem means that some person or group is not satisfied with the current policy (status quo) regarding some matter. Jones notes that one person's problem is another person's profit. Problems result from events that affect people differently.

Problems usually become public when large numbers of people are involved and relief is sought from a

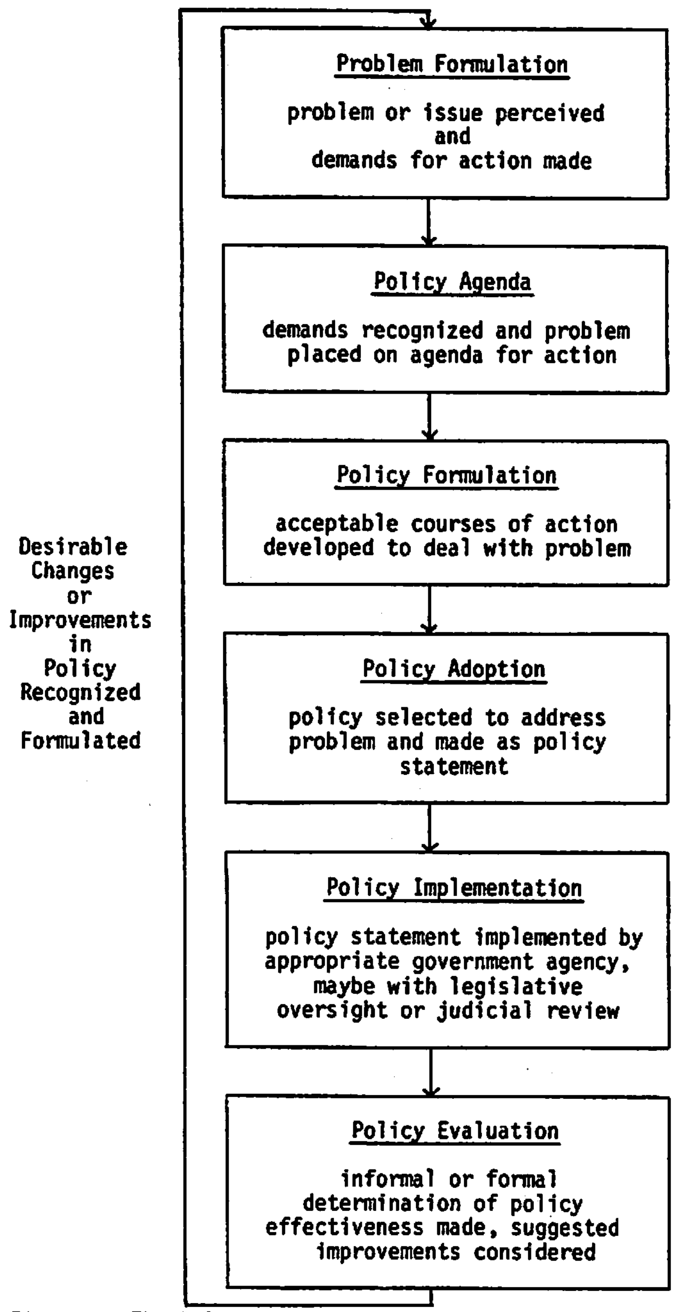

Figure 1--The Policy Process

Source: Adapted from Anderson (1979).

[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

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government. People who perceive a problem demand action from the actors who have authority to make changes. These policy makers include legislators, judges, agency heads, and local government officials. Public policy involves deciding which problems to address and what methods to use.

People demand government action for thousands of problems. However, only a fraction are recognized by policy makers and receive serious attention. These comprise the second step in the policy process--achievement of agenda status. Then the third step, termed policy formulation, begins. It involves developing acceptable courses of action to deal with the public problems on the agenda.

Policy adoption, the fourth step, occurs when policy makers accept a particular solution to a problem. New policies may either be adopted by government agencies operating within their legislative mandates, or by specific legislative or judicial action. Policy adoption implies that the government intends to follow a new course of action regarding a specific problem or issue.

Once a policy statement (law, rule, or order) is adopted, government must implement the policy over time--the fifth step. The content and effect of public policy may change greatly during implementation, which is usually accomplished by either legislation or administrative rule. Policy is usually implemented by administrative agencies, but legislative bodies and the courts are also often involved in natural resource issues. Courts do not enact legislation, but they often interpret the meaning of the sometimes vague rules and laws.

Once implemented, policies should be evaluated, which is the sixth step. Did the policy work? What are the costs and returns from the programs? Systematic evaluation will help to quantify the social impact of policies and the extent to which stated objectives are met.

By merely adding a loop to this process, one can add utility to the model. Policy formation and adoption are usually circular in nature. Seldom do problems or issues merely appear from nowhere. Rather, they are based on some prior policy--that is, a course of action followed by a political actor or set of actors. Perhaps people's opinions or values changed or perhaps natural events triggered concern about existing policies, but for some reason a previously acceptable policy may now be perceived as a problem by some people. The process often begins anew and ends with a new policy or problem resolution, and perhaps policy evaluation.

A Logging Application

The applications of such a model in logging are fairly obvious. Forest harvesting is rife with opportunities to create problems or issues. Cut-over stands look ugly to many people; wildlife habitat may be harmed; soil may erode; undesirable brush may invade the site; local roads, culverts, or bridges may be damaged; slash fires may occur; equipment and truck noise may be intrusive; debris may be littered on the site; and neighboring owners' trees may be cut. Detrimental logging practices in the early 20th century led to concerted efforts in the 1920's, and again in the 1940's, to federally regulate private forestry operations. The state forest practice statutes enacted in those years were largely in response to the federal initiatives and to ensure that satisfactory regeneration occurred. More recent state laws and revisions focus more on environmental damage. Local ordinances, on the other hand, are often concerned with protecting neighbors' rights, amenity values, or wildlife. All of these laws regulate some aspect of logging as their principal concern.

Clashes in values between ex-urbanites and rural residents have led to many recent logging issues. Former urban residents often still work in cities, and do not depend on the land to produce income. Rather they own it for amenity purposes (Raup 1978); they act soon and effectively when these values are threatened by neighbors' actions. Even many long-time rural residents have become less tolerant of poor logging practices. Cavalier attitudes and responses by loggers, especially when conversing with public officials, only exacerbate problems.

At both the local and state levels, demands for action are made by officials or citizens who perceive a problem. Such demands may be placed on a local town or county agenda and enacted within weeks or months. State-wide regulation is considerably more difficult to place on the legislative agenda, let alone enact.

A simplified local government scenario will illustrate the politics of logging regulation. Perceived problems with logging may prompt demands for action. Local governing bodies often consider various solutions, including logging permits or notification requirements. Legislative research is generally very limited. Ordinances may be developed after consultation with legal counsel or adopted from other jurisdictions. Hearings may be held and other input considered, or the matter may be simply adopted at the next meeting. County or town officials, probably most of whom are not familiar with logging, will enforce the ordinances in either a desultory or enthusiastic fashion. Changes are usually made based on informal evaluation--complaints by loggers that the law is too strict or by local residents that it is too lax.

LOGGING REGULATIONS

The legislation in the East that has resulted from such political processes may be divided into state forest practice laws and local laws. Most of the state statutes were enacted in the 1940's, primarily to ensure adequate regeneration. Most local laws have been enacted in the last decade to prevent logging damage.

State Forest Practice Laws

In the 1930's and 1940's, ten eastern states sought to discourage federal legislation regulating forest practices by enacting forest practice laws of their own. Most principally addressed adequate regeneration after harvest by mandating that an adequate number of seed trees be left. Some of these laws still exist.

Initial legislation in the East ranged from mere exhortation to modest requirements for the leaving of seed trees. Enforcement was minimal, as were the impacts on logging practices. The strictest seed tree law was passed by Virginia. Still being enforced, it now requires leaving of 2 14-inch tulip poplar trees and 8 14-inch or greater pine trees per acre after logging of these species.

Two states in the East enacted new forest practice legislation in recent years. Maryland enacted a seed tree law similar to Virginia's, which requires the leaving of pine seed trees to ensure future regeneration. Then, in 1982, Massachusetts substantially amended its Forest Cutting Practices Law, considerably increasing its regulation of forest practices. This legislation was passed with the support of foresters and loggers who felt that foresters did not have enough input into logging regulations promulgated under the Massachusetts Wetlands Law, and who wanted to forestall proliferation of local ordinances. Forest industry was well represented on the committee that drafted the law (Smith 1984).

The new statute requires landowners to notify the Massachusetts Division of Forests and Parks and their town's Conservation Commission, and to submit a cutting plan before timber can be harvested. They must also notify abutting owners within 200 feet of the area being cut unless separated by a public way. The Division of Forests and Parks must issue a final work order and a cutting practices certificate to the landowner within 10 days after receiving the notice of intent to cut, or else operations may automatically begin--except in wetland areas. Landowners must post the certificate in plain sight from the highway at the entrance to the cutting area.

The Division of Forest and Parks is to inspect operations during and after harvest to determine whether the harvesting has been carried out in accordance with the plan and practices. When logging is complete, landowners must notify the Department of Environmental Management regional office. After final inspection has determined performance to be satisfactory, the Department issues a certificate of compliance.

Information in the cutting plan is required on erosion control measures, buffer strips along public ways and water bodies, and means of controlling mud on public highways. If critical wetlands or steep slopes (over 30 percent per 200 feet) are involved, supplemental information is required. The cutting practices law also stipulates that timber harvesters obtain a license. The cost is $10 per year for state residents and $20 for nonresidents, with a penalty of up to $500 per violation for noncompliance. The timber harvester is required to follow the cutting plans and must have a copy of the final work order on the site whenever work is done. The Division of Forests and Parks may issue a stop work order for any operation that fails to follow the law or the cutting plan, and it remains in force until the deficiency is corrected. If not corrected, the Division of Forests and Parks may hold a hearing to consider revocation of the operator's license.

Although it does not have a forest practice law per se, Maine strictly regulates forestry operations via its statewide Land Use Regulation Commission (LURC). LURC controls timber harvesting, slash disposal, and road construction in about one-half the land in the state--especially near streams, other water bodies, and recreation trails; on slopes greater than 60 percent; at elevations above 2700 feet; or in scenic or scientific areas (Pidot 1982). Its statewide zoning rules require notification of harvesting on certain classes of land throughout the state. Generally the law only requires permits for sensitive areas. The latest regulatory legislation in the state was enacted in 1981, and regulates nonpoint source pollution from logging roads.

Local Regulation

Many counties, townships, and municipalities in the East also regulate the harvest or transport of timber. Most such ordinances have been enacted in the last decade. Even the South has seen some regulatory activity in the 1980's.

The Northeast

Regulation in the Northeast has been prompted primarily by concerns about logging and its effects on water quality, wildlife, or aesthetics. Forestry practices are regulated at the local level in one of two ways. Regulation may occur directly via a separate distinct ordinance, or indirectly via concealment in a related ordinance. Application to harvesting may not be apparent in the verbiage. For example, an existing or new ordinance that regulates extraction of natural resources may be intended or construed to apply to timber cutting. The enforcement and interpretation of local laws is often the responsibility of the town building inspector or transportation official (Provencher and Lassoie 1982).

Depending on one's source, New York town harvesting ordinances have existed either since the 1960's (Provencher and Lassoie 1982) or since 1977 (Wolfgram 1984). Similarly, the number of ordinances in 1984 ranged from 24 (Wolfgram 1984) to 29 (Goodfellow and Lea 1984) out of approximately 1000 towns in the state.

Most local ordinances in New York encourage desirable practices and require loggers to obtain a permit before logging a tract. They are designed to protect border properties, streams, and soils; to maintain haul roads adequately; and to control the slope of haul roads. The permits allow the town to gather information on the type of cut (i.e. clearcut, shelterwood, diameter limit), the location and number of acres to be harvested, dates of the operation, and measures for ensuring soil stability and stream protection. "Informational" ordinances may require only a permit coupled with a few minor regulations in order to let the town know when and where logging will occur (Provencher and Lassoie 1982).

At least 20 of Connecticut's 169 towns have enacted regulations or ordinances pertaining to forestry operations, and another 11 have recently considered adopting such regulations (Youell 1984). Hogan (1984) reports that numerous former urban residents in New Jersey now live in rural areas. Many of these politically active newcomers demand protection when their hard-earned, quiet surroundings are shattered by the noise of chainsaws and skidders. As a result, many local ordinances were enacted that have been upheld in the courts. Hogan writes:

> "The exodus to rural areas is not the only factor contributing to local regulation: the maturation of previously unmanaged woodlands; harvesting of timber on smaller tracts, reduced road maintenance, the strong home-rule status of New Jersey municipalities and the 'new federalism' which encourage legislation in areas heretofore left to State and federal governments, all contribute to the proliferation of local anti-logging ordinances in New Jersey. At last count, over 100 of New Jersey's 567 municipalities had such ordinances."

In Vermont, under an agreement with the state's Water Quality Bureau, the Vermont Timber Truckers and Producers Association makes initial responses to sedimentation complaints. An association representative meets with the logger and attempts to negotiate corrective and preventive actions. If the discussions fail, the Water Quality Bureau then initiates enforcement action (Irland 1985).

The South

Despite their traditional conservatism, some states and local governments in the South have also enacted logging or regeneration regulations. Logging practices are regulated in order to protect water quality or prevent damage to local roads. State highway departments and county governments are the principal proponents of logging regulations in the southern states. Highway departments, in addition to their continual concern with truck weight limits and safety, also attempt to prevent damage to state roads and shoulders from logging trucks and harvesting equipment. Rural county governments are usually concerned with damage to their roads, shoulders, culverts, and bridges, rather than with cutting regulations per se. Urban counties are apt to have similar concerns, but also are likely to regulate logging in order to prevent unsightly clearcuts, eliminate trash-covered logging sites, and protect aesthetic values.

The Virginia Highway Department began enforcing permit and performance bond requirements for temporary forest road entrances to state maintained highways in 1984. The law has existed for over 30 years. However it was not "vigorously enforced" until a recent court ruling declared that the state could be sued if an accident occurs as a result of an unsafe log-road entrance to a state highway (American Tree Farmer 1984b). A permit and a performance bond are required for each log road entrance. This can be done on either an individual road, or on a "blanket" basis, and is administered by the Resident Engineer's office in each county.

Leon Brown, Associate Director of the Georgia Forestry Association, has written that the list of local ordinances affecting forestry and related business in Georgia is growing:

> "What's frustrating is that most of this legislation could have been avoided simply through communication. It's time for us to start talking to local governments, because clearly they are starting to talk to us (American Tree Farmer 1984a)."

A current count in Georgia indicates that at least 12 out of 159 counties have considered or enacted ordinances affecting either logging or log trucks. Several of the counties with legislation are urban ones that are attempting to minimize cutting and protect aesthetic values by zoning law. Others utilize rural ordinances focused on roads. At least one rural county has adopted a zoning ordinance.

PROSPECTS

As observers of forest practice legislation, it is easy to conclude that logging regulation in the eastern United States will increase. Local laws are increasing in many Northeastern states, prompting some of them--most notably Connecticut, Pennsylvania and New Jersey--to consider state legislation similar to that recently enacted in Massachusetts. Regulation will also increase in the South, albeit more slowly than in the Northeast. However, southern laws will generally be milder than those in the North and probably not greatly affect operations that are already being performed in a reasonable manner.

The model of politics described by Anderson well describes how these laws evolve. Shoddy logging practices have always been viewed as a problem by some people. Now, influential community members are making demands to regulate or even prohibit logging. Elected and appointed government officials are responding accordingly with new policies which manifest themselves in the form of legislation or ordinances.

Can loggers, foresters, and timber owners prevent the proliferation of such laws? The answer is sometimes, but not always. As the model suggests, avoiding problems or issues is crucial to success. Participants in this conference are discussing a host of environmentally sound methods and machines for logging. This is a start. Adoption of these approaches by loggers must be the next step. Such acceptance will help to avoid much potential regulation. If legislation appears unavoidable, rational participation in the legislative process is likely to lead to balanced, livable regulations. In heavily urbanized areas, logging simply may be unacceptable to local residents. In most areas, however, responsible actions, good communications, and political participation can ensure a reasonable forestry operating environment.

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Impacts of Forest Practice Regulation in California[1]

Donald P. Gasser[2]

Abstract: California's complex system of forest regulation is the most stringent in the nation. A survey of key foresters and timber operators was made to attempt to characterize and quantify the types of impacts involved. Direct logging cost increases due to regulation in 1981 averaged from $6-30/MBF cut, depending on site specific factors. The avoidance of stream impact in steep areas produced the highest overall regulatory cost increases. Nonindustrial private landowners are the owner group most affected by high regulatory costs.

California's Forest Practice Act prescribes a series of rules that are the most demanding in the nation (Arvola 1976). The financial and human impacts of this system are substantial, and these are affecting the viability of forest management on private lands. This paper addresses some of the direct and indirect short and long term impacts associated with the California regulatory environment. While benefits of regulation clearly exist, they are not treated in this paper.

This assessment was developed over a 6-year period. It is based on real costs as well as on factors that are difficult to accurately quantify. An interview survey of over thirty key foresters and timber operations in California was conducted in 1979-81 to develop major areas of concern as well as to gain financial data. Additional information has been gathered and verified since the survey, with the original data allowed to age to allay industry fears of presenting sensitive material.

BACKGROUND

California has had a forest practice act since 1945. This original act was declared unconstitutional in 1971, due to the industrial makeup of the regulating body (Bayside Timber 1971). The California legislature put into effect the Z'berg-Nejedly Forest Practice Act (FPA) on January 1, 1974. This Act has as its primary intent the "restoration, enhancement, and maintenance of the productivity of California timberlands" (Z'berg-Nejedly 1973). It provides for a system of rules to regulate management on over 7-1/2 million acres of private forestland. The regulatory environment encompasses a total of 16 State and 13 Federal agencies, boards, departments, and commissions (Trzyna 1981) which can get involved in an aspect of timber harvesting on privately owned lands. In actual fact, most timber operations deal with only one, the California Department of Forestry (CDF), the State body which also oversees fire protection, service forestry, and other forest resource matters on private lands.

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REGULATORY ADMINISTRATION

The rules and regulations provided by California law are both detailed and complex. The FPA provides for a Board of Forestry composed of nine members appointed by the governor, only three of which are from the forest industry, with one from the range livestock industry, and five from the general public. The FPA also provides for at least three districts within the state (currently three, with two subdistricts). A Coastal Protection Area and a Lake Tahoe Protection Area also have been designated by subsequent legislation. The three forest districts, Coastal, Northern Sierra, and Southern Sierra, each have a technical advisory committee (DTAC) appointed by the Board of Forestry, and the criteria for membership as well as the quotas for representation are the same as for the Board itself. The DTACs work to advise the Board in the governance of timberlands and in the creation or change of rules. The Board of Forestry has the responsibility to propose and to promulgate new rules, which then have the force of administrative law. Violation of the rules can be punishable by work stoppage until the problem areas are corrected, by fines, or by revocation of a timber operator's license and/or the license of a Registered Professional Forester.

The FPA also mandated that a Registered Professional Forester (RPF) be required to prepare a Timber Harvest Plan (THP). An RPF is licensed to practice forestry, and a license may be applied for after committee approval of seven years of experience and an extensive written examination. The THP details the harvest and silvicultural systems to be used on an area. In addition, the THP provides maps for locating the placement of roads and landings, notes the existence of endangered species, archeological sites, stream protection zones, erosion hazards, timing of operations, fire control plans, and other specifics relating to the where, when, and how of operations. A THP must be written and signed by an RPF for commercial timber harvesting on all private lands larger than 3 acres in size or with a cut greater than ten thousand board feet.

The THP, once written and planned on the ground is sent into the CDF for review team approval. Following a public review period, this review team analyzes the plan for completeness, feasibility, appropriateness, and the potential impacts on land and people. The review team may have on it representatives from the Department of Fish and Game, the State Water Resources Control Board, and may also call on representatives from the Air Resources Control Board, the Department of Parks and Recreation, the Bureau of Mines and Geology, or from other agencies who may be concerned with the regional, archeological, ecological, or health aspects of the proposed plan. This system was declared the functional equivalent of the state mandated environmental impact statement (CEQA) in 1976 (Natural Resources 1980). The review team may ask for more information, may approve the plan, or may reject it. An on-site visit may be made prior to approval. If rejected, the decision may be appealed to the Board of Forestry. The ultimate power over approval or disapproval of a plan is vested solely in the director of CDF. Mitigation measures may be proposed by the review team, the director, the Board of Forestry, or by the RPF proposing the plan. If approved, a site visit to the area will probably be made on at least two other occasions by representatives of CDF--during and after operations. At each visit, the plan may be altered, operations halted, or mitigation measures called for. Rule violations may take the form of:

1. Impaired timber productivity, including "unnecessary damage" to the residual stand, operating outside of the silvicultural prescription, or excessive timber breakage.

2. Impairment of site productivity, including excessive soil movement, improper road and landing location, improper construction methods, lack of cross drains or appropriate drainage structures on roads and skid trails, unacceptable increases in compaction and disturbance, and inadequate closure techniques employed at season's end.

3. Impairment of water quality, including excessive removal of streamside canopy, damage to unmerchantable streamside vegetation, trees or slash felled or skidded into the stream, soil movement in the Stream and Lake Protection Zone (SLPZ), impairment of fish passage, or disposal of petroleum waste products where they could enter streams.

4. Lack of fire prevention equipment, plans, notices, or actions, including the post harvest existence of snags near roads and ridgetops.

5. Loss of wildlife habitat, including inappropriate removal of snags, nest trees, roost trees, dens, or the disruption of endangered species.

6. Insect or disease hazards, including inadequate slash treatment, poor utilization of merchantable wood, or improper tree selection.

7. Violations of public safety, including the leaving of snags near roads, excessive dust from hauling, and in urban areas, the hauling of logs during rush hours.

8. Impairment of scenic qualities through improperly treated slash, inappropriate placement of earthwork, high stumps, or clearcuts greater than 40 acres.

In addition, the law relating to the level of tree stocking states that any site, whether even or unevenaged, will have a stocking level of 300 points per acre after a five-year period following harvest. Seedlings are worth one point, while larger trees may count up to six points.

COSTS OF REGULATION

The categories of regulatory cost due to regulation can be divided into direct and indirect, both of which have short and long term impacts. Direct costs are often reasonably clear and relatively easy to document. Indirect costs are regulatory functions which resulted in lost values or opportunities, and include externalities which were not easily anticipated when the act was developed. Numbers shown herein are only estimations of actual costs, but are representative of statewide conditions. While the dollars spent were not directly related to lumber market conditions, they have been converted to dollars per thousand board feet ($/MBF) because of this common measure of comparison.

Direct Costs

Direct costs include those dollar figures which can be related closely to operations. The dollars are clearly costs to different entities, and reflect an actual exchange of funds.

Governmental

The administration of the State's regulatory program, with over 80 direct employees, has become a budgeted part of the State government. "Table 1" shows the fiscal year budget, the total harvest volume, and the number of THPs filed (by calendar year). These are combined to show several general conclusions. A portion of the budget in any given year includes work done on THPs filed but not completed in previous years, cost per unit is difficult. Nevertheless, a general figure for direct government functions in the regulatory process is about $2/MBF cut, or just about $2700 per filed THP. A 1981 estimate by Green et al. (1981) places this value at less than $1/MBF, or $1150/THP.

Preparatory

The cost to the landowner for the preparation of a THP by an RPF varies from a low of about $250 to many thousands of dollars per plan. Typical personnel costs industry-wide range from $1.50-2.00/MBF for development and review of a THP.

Cost variances can be quite large, since a THP must be fairly complete whether the planned cut is 200 thousand board feet or for 20 million board feet. Costs are highly dependent not only on size of projected cut, but also on site characteristics and silvicultural prescriptions. Those plans requiring road construction in steep terrain normally require larger time inputs in both field and office.

Vaux (1981) attempted to develop a cost for THP preparation and estimated a $.20 cost per acre per year for industrial owners, and $.40 per acre per year for nonindustrial owners. If these estimates are factored by the relative proportions of the 7-1/2 millions acres of private land (78 percent industrial, 22 percent

Table 1--Direct governmental regulatory cost (normalized to 1981 dollars).

Year	Regulatory Budget (millions)	# THPs Filed	Volume Cut (MMBF)	Governmental Cost/THP	Regulatory Budget/MBF cut
1981	$3.346	1379	1,736.	$2426.	$1.93
1982	3.389	1128	1,543.	3004.	2.20
1983	3.462	1249	1,932.	3772.	1.79
Three year Total	$10.197	3756	5,211.		
		Three Year Average		$2715.	$1.96

Source: Department of Forestry / Board of Equalization nonindustrial) (Bolsinger 1980) then an annual cost to all landowners can be developed at $1,862,000/year. The cost per THP preparation using Table 1 data is approximately $1500/THP. Green (1982) estimated a $3000/THP preparation cost for landowners, without including a preharvest inspection or subsequent negotiations.

Preparation is clearly a significant cost to the landowner. There is no guarantee that a plan prepared will be approved, so that preparation can be regarded as a sunk cost that may or may not be recovered.

Operational

Operational regulatory costs will vary by location, equipment, silvicultural system, topography, and by the mitigation measures called for in the THP. The cost of operations can be broken into several categories, but the separation of regulatory costs from the normal operations can be arbitrary unless the regulatory work is contracted. Costs which were obvious increases soon after the FPA was initiated have become internalized into the operations and are difficult to directly assess as operators gain proficiency in regulatory compliance.

Operational costs increases cited by interviewed foresters and loggers are shown in the categories in "Table 2". Costs are normalized to 1980 dollars based on statewide survey representing 16 separate THPs. The low cost range is normally found on the pine flats of the Sierras, while the upper end of the range is found in steep North Coast drainages which contain high value timber and which can command unusual harvest practices. While 16 THPs represent less than 2 percent of the THPs filed in a year, those were chosen to be representative, and certainly give a flavor of statewide norms. Most foresters interviewed agree that per MBF costs are lowest when clearcutting to the maximum area allowed. Both slashing and ditching costs are quite sensitive to silvicultural prescription. As an extreme example, some foresters claim that operating in steep stream protection areas can add as much as $40-50/MBF for combined tree jacking and stream cleaning:

Table 2--Operational costs.

Harvest Activity	Cost/MBF cut (1978-1982)
1. stump height restrictions (12" maximum on uphill side)	$ .10-.75
2. slash disposal	1.50-4.00
3. ditching (closing skid trails)	1.50-3.50
4. directional falling	0-6
5. stream cleaning	0-20

Other direct costs exist, but are difficult to quantify.

An area of direct cost increase in logging practices has involved road interactions with water quality. Specifically, stream crossings and road locations or relocations to avoid water contact has resulted in cost increases of substantial proportions. Both planning and construction to protect water quality have had major influence on logging costs on many sites. This type of operational decision is so difficult to assess, owing to site specific prescription, personal judgement, and long term processes, that no further attempt is herein made to quantify it.

Another major impact, also not well documented or estimated, is the change in equipment necessary to log within the regulatory framework. The cheapest skidding methods are often not allowed due to expected impact, steep slopes, or erosive soils. Cable systems, often requiring substantial road relocation in areas formerly ground skidded, double to triple the cost of yarding logs in addition to road construction costs. This change in harvest system approach affects large areas with substantial increases for operations. Here again, steep areas combined with water make for expensive combinations.

Stocking rules require the planting or reestablishment of cut areas which may or may not be considered a regulatory cost. Certainly, more areas are planted following cutting than was the case before 1974. Stocking rule tend to alter regeneration strategies. Brush control and seedling survival are given much greater attention, since compliance with the law for 300 well established points/acre is required within five years following harvest. Industrial foresters disagree among themselves as to appropriate practices, and some of the prescribed activities would undoubtedly be undertaken regardless of mandated compliance with regulatory procedures.

While rules are district-wide and State mandated, the lack of communication between forest practice inspectors and operators may make a timber sale take substantially longer and cost substantially more than would otherwise be the case. A forester's professionalism is often called for in heated exchanges which may occur in harvest inspections, as the translation of written rules into on-the-ground activities demands a forester's full capabilities. The THP has become an important tool for communication and for proper management, yet it can be used as a lever by environmentalists during the review process to hamper, delay, or prevent proposed timber operations.

Summarizing quantitative estimates is restricted to those costs about which a clear estimate can be made. These may be a small portion of the real costs involved.

Direct preparatory and operational costs would most affect a timber owner, rather than the logger or the sawmill. The logger has successfully passed on most of the increases associated with regulation. Operations in the pine region of California had an average logging cost increase for regulatory practices in 1978-82 dollars of $6-8/MBF, while direct coastal cost increases average $20-30/MBF. Several coastal operations were documented with additional costs at over $50/MBF. These estimates are generally higher than those 1982 observations of Green who places the increase for coastal district between $15-20/MBF. Vaux in 1981 estimated statewide costs at $10-$40/MBF, with a $20/MBF statewide average.

Indirect Costs

While direct cost categories may be relatively easy to specify, although difficult to closely pin down, the indirect effects or lost values have probably had more impact on forest management or at least on forest managers than have the direct costs.

One pervasive impact is the loss of expertise that has occurred in the areas of forest production. While the knowledge, desire, and capabilities to more fully utilize California's forestlands exists, the time and money do not, partly because of the large commitment that regulation demands. Creative talent and money that would otherwise be available is spent on attending meetings of the Board of Forestry, the DTACs, the CDF, the Water Quality Boards and the public. The requirements for form filings, inspections, public notifications and other related demands take time, energy, and expertise. The person-hours spent in these activities is staggering, when taken in total. Meetings at which attendance records are kept are a virtual Who's Who guide to forestry in the local area or the State, depending on the magnitude of concerns under discussion. Travel time and meeting time together add up to several person-years spent by medium-sized industrial firms each year.

Numerous foresters have been hired by industry as well as government to cope with procedural compliance as specified by law and rule. One large firm estimates that each forester on the staff spends greater than 60 percent of their time on regulatory related matters. Several firms have regulatory foresters whose sole job is to keep track of current trends of regulation and to inform their management of these. Many chief foresters have essentially become professional meeting-goers rather than land managers. Resource attention and emphasis has necessarily shifted away from intensified management to satisfaction of rules.

Violations must be looked at as a potential cost factor, as a $10,000/day fee for violating clean water standards can scarcely be ignored. Many violations carry the threat of dollar fines, legal action, or even criminal proceedings. In addition, the loss of professional license is continually possible, and by 1981 two RPFs had their licenses revoked. (One was subsequently reversed, at great cost to all involved parties.) A concern to loggers has been the implied threat by the State to charge fees for simple accidents. A tree felled into a creek is of benefit to no one, yet it has occasionally been true that the logger has had to clean up the mess, accept the loss of production, and pay a fine - for a mistake.

Additional Impacts

In addition, there is another human type of indirect cost which is hard to quantify - the loss of "esprit de corps" among foresters and loggers in the state. Professional foresters and loggers practiced at doing their jobs have been brought up short and seriously questioned in their applications and approaches. A vocal public has managed to capture the process at times, because the application of general rules to specific sites has caused confusion, confrontation, and lack of credibility on both sides of the regulatory front. Adversarial positions have been created and cooperation at times runs thin between forestry professionals whose desires for quality land management are similar.

The pressures brought to bear on resource workers and professions has had its effects on organizational development. In 1980, a professional organization, the California Licensed Foresters Association, was formed. This gives the RPF an avenue for communication, as well as a larger voice when dealing with regulations and other problems. It more than likely would not have come into existence without the advent of forest regulation. The Associated California Loggers formed in 1973, has responded as much to insurance and safety problems as to regulatory concerns.

LONG TERM IMPACTS

While dollar cost increases exist as shown, these are not the major impacts affecting California forest management. The shift in emphasis that has occurred goes beyond increased costs and lower profits. This shift has affected land ownership and land use.

Costs associated with forest regulation are not passed on to the consumer. The timber operator or mill cannot attach a premium for selling wood from regulated lands, since the timber economy is almost perfectly competitive. The trees from California lands hold no increased values for society once the boards are cut. Therefore the real dollar loss for regulation is to the landowner or stumpage holder. Stumpage price continues to be a residual value that initially has all other costs subtracted. This effect on stumpage acts as a disincentive for timberland ownership, since land appraisals specify real values, and buyer and seller alike are adversely affected.

The inflationary rise of stumpage values (1974-79) masked this effect for a number of years, but the large areas of California currently for sale are partly a reflection of this decreased value. Of course other factors act to intensify this effect, including the depressed lumber market and the decline in old growth timber volumes available. Nevertheless, at least one large progressive industrial firm has chosen to avoid operations in California, while numerous companies have ceased to operate in California land ownership.

Nonindustrial private landowners are those most heavily affected. With no staff to assign to regulatory matters, the small landowner is often in the dark about rules and must pay a consulting forester to create a THP and to become educated. These owners tend to cut small volumes of wood and have small acreages, so that the fixed costs of regulation have a greater impact per thousand board feet cut. A small landowner has a much higher regulatory cost/MBF than do industrial ownerships due to high fixed costs and low volumes cut. In addition, the uncertainty of future regulation must act as a risk factor for profitability analysis. The ability to act quickly in response to market opportunity is greatly decreased by the time-demanding process of THP filing. A small landowner who is unfamiliar with the process may miss such an opportunity altogether.

THE CONTINUING PROCESS

The forces which are currently active in the State's regulatory processes are not in remission, but are continually questioning and refining their effects on wildland management. In the ten years since implementation of the FPA the initial confusion has resulted into a workable system, but one in which many changes are still taking place. Industry and agency continue to work out differences, although early polarization in each camp argued for extremes which ranged from abolishing all rules to nationalizing the logging industry. The participants in regulatory debate usually have an attitude of teamwork that only occasionally degenerates into an adversarial relationship of diverse ideologies. The CDF has generally managed to maintain its lead role in resolving differences, despite the problems of agency regulators who have different goals.

The process is still poorly understood by the public, many of whom see a need for greater controls. At any given time since 1973, one or more bills to replace the current FPA have been pending before one or both houses of the State legislature. In addition, boards, commissions, and county governments continue to attempt to develop more involved rules for regulating practices.

Rules for increased stream protection and road and landing placement and construction have recently been created by the Board of Forestry, while rules regulating hardwood removal are currently under review. The addition of hardwood legislation could put another 15 million acres under the jurisdiction of the FPA (Hardwood Task Force 1983).

As we increase our understanding of human productivity, it becomes obvious that ten years of public skepticism and intense analysis has taken its toll on human capital, as well as on financial capital. A change of goals focusing on the protection of nontimber values away from timber production has left many foresters frustrated at the discrepancy between societal goals and employer goals.

California is the second largest lumber producing state in the nation (Howard 1984), with timber the principal economic product in 16 of its 58 counties (Board of Equalization 1983). As the California timber economy matures and California faces problems of small wood handling, the total value of wood at the landing site will become one-third of the former value, while harvest costs have already more than doubled. The regulatory climate in California may act as the straw which breaks landowners out of timber production and away from productive ownership. Its marginal cost adds an element of uncertainty to those interested in harvesting timber.

SUMMARY

Regulation of forest practices has had impacts far beyond those envisioned for environmental quality. California's history of regulation has been both involved and complex, resulting in the 1973 Forest Practices Act and continuing in major issues today and into the future. Direct costs may average $20/MBF cut, but these are minor when compared with indirect impacts and long term effects. While not based on strictly quantified costs, these are nevertheless real and result in disincentives for ownership and management. The California forester continues to face the challenges presented by a regulatory environment in a state where trees and forests are regarded as metaphysical resources. The persistence and drive of these foresters combined with California's fine forests may turn this into a positive situation over time, but the impacts of regulation will be long felt in California's forest industry.

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Using a Computer-Aided Planning Package to Assess the Impact of Environmental Restrictions on Harvesting Systems[1]

Stephen E. Reutebuch and Glen E. Murphy[2]

Abstract: A case study is presented that examines the effects that three hypothetical levels of environmental restrictions would have on the equipment mix and road system needed to harvest a small drainage. The drainage, located in the East Coast region of New Zealand, was originally reforested in the early 1960's as part of a successful attempt to slow severe erosion and flooding, which had been accelerated by deforestation of the area in the early part of this century.

A map-based harvest plan was developed for each of the hypothetical restriction levels using a computerized planning package. These map-based plans were field checked and revised as needed. It was evident from the study that the level of environmental restrictions incorporated in future harvesting of this drainage will have very large financial and operational impacts and, in some instances, could preclude harvesting activities altogether.

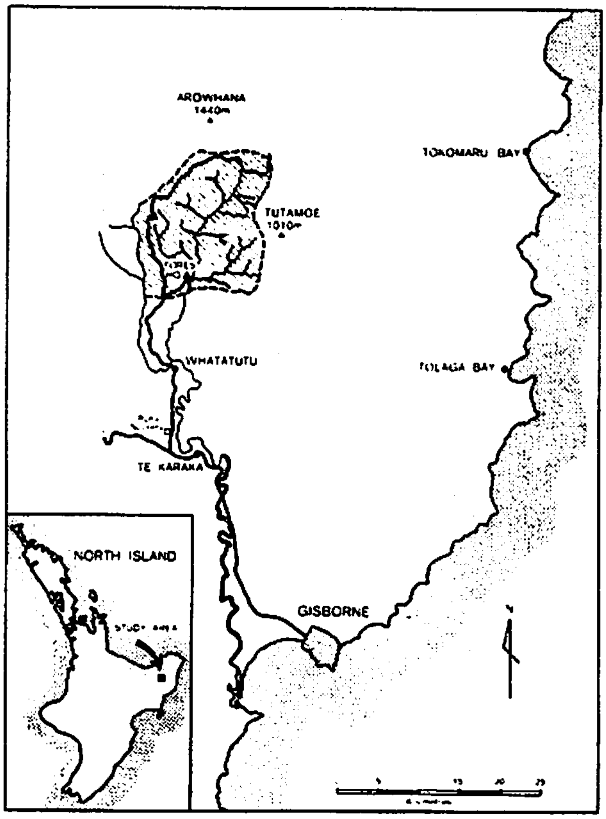

Figure 1--Location map. Hatched portion indicates Mangatu State Forest (Gage and Black 1979).

HISTORICAL BACKGROUND

Early records indicate that flooding has always been a problem in the East Coast region of New Zealand (fig. 1); however, damage caused by flooding increased dramatically from 1910 through 1950. This flooding resulted when the stream beds in the area became clogged with sediment and debris. In May 1948 during a major flood, it was estimated that in one day 12 million cubic meters of sediment were discharged into the ocean at the mouth of the Waipaoa River. Beds of minor streams had been raised as much as 30 meters in some places, making it necessary to raise the level of bridges. Stream beds had also widened dramatically--from 60 meters to 360 meters in one instance (Allsop 1973). Particularly hard hit by this flooding were the intensively farmed flats of the Waipaoa River in the vicinity of Gisborne. These farm lands were repeatedly inundated, which resulted in huge losses of livestock and damage to property. Some pastures were left in an unproductive state for up to 2 years following each flood; or worse yet, completely buried under sediment and debris.

The Poverty Bay Catchment Board, the local soil and water conservation authority, began flood control works in the lower reaches of the Waipaoa River in the early 1950's. It was recognized, however, that control of the source of sediment in the headwaters of the Waipaoa would be particularly critical for the success of this downstream flood control scheme. A large portion of this headwaters area had been converted from native forest cover to pasture between 1890 and 1920. Within 10-20 years of land clearing, large-scale erosion, in the form of earthflows, slumps, slides, and sheet wash, was underway. This erosion continued to accelerate unchecked until the late 1950's when the first attempts were made to reforest the most spectacular and devastating instances of mass wasting in this critical headwaters area. This area is now part of Mangatu State Forest.

EROSION CONTROL THROUGH REFORESTATION

Since the first plantings in 1958, Mangatu State Forest has grown to its current size of approximately 12,000 hectares. Monterey pine (Pinus radiata D. Don) was the principal cover type established although a wide variety of species were planted on a limited basis.

By 1970 these plantings had been successful, to a large extent, in controlling mass wasting in the area (Allsop 1973). Black (1981) states that "the stabilization effect of the forest has been to reduce debris movement on the slopes and to remove stored sediment from the smaller channels .... Associated with the improvement of the channels is the increased slope-stability such that roads can now be maintained where previously it was thought impossible due to the activity of the wet, moving ground. The overall result is to reduce the rate of erosion back to the natural state such that any sediment removed from the slope can be accommodated within the normal sediment transport system."

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Major problem sites, such as the Tarndale-Mangatu Slip complex still exist; however, the bulk of the forest area now supports a well-established forest cover that is growing at a fast rate. Many of the early plantings will soon be of a size normally considered suitable for harvest. It is recognized that, if the problems of mass-wasting and flooding are not to be repeated upon harvesting, it is imperative that a better understanding of the interaction between the forest cover and the local geology be established.

FOREST COVER/SLOPE-STABILITY INTERACTIONS

Extensive investigations of slope stability in the headwaters region of the Waipaoa River were undertaken in the mid-1970's by Gage and Black (1979). It was found that, although the geology of the area had predisposed it to mass-wasting problems, forest cover played an important protective role in stabilizing the area in recent geological times. A brief and simplified description of the geology of the area is provided below.

Rocks in the Mangatu area fall into two distinct geological groups of strata as shown in figure 2. The upper strata are composed of well-cemented sandstones and mudstones of the Mid-Tertiary. These materials are less susceptible to weathering and breakdown than are the underlying strata. The underlying strata are of the Late Cretaceous-Early Tertiary (Paleocene). This material is composed of severely crushed, sheared, and distorted sandstones and shales that exhibit an exceptionally low shear strength and a marked tendency to break down mechanically under the influence of water (Gage and Black 1979). Overlaying these two strata is a mantle of volcanic ash deposited at various intervals over the last 28,000 years. Gage and Black (1979) provide a detailed geological map of the Mangatu area which figure 2 is based on.

The entire East Coast region of New Zealand has been rising over the last few tens of thousands of years. This has resulted in a general down cutting of the Waipaoa River. Associated with this down cutting has been a regrading of the river valley slopes as the rock material making up these slopes seeks its natural angle of repose. This regrading process is particularly pronounced in areas where the severely crushed and sheared Cretaceous-Paleocene strata are at or near the surface, as is commonly the case in the headwaters region of the Waipaoa. In most recent times (the last 11,000 years) the protection provided by the volcanic ash mantle and the native forest cover has tended to retard this regrading process by decreasing water infiltration and surface erosion and by adding shear strength through the root system.

The presence of this protective mantle has resulted in present-day hillside slopes that are at an angle greater than the natural angle of repose of the underlying rock in many parts of Mangatu. Old slumps and alluvial terraces in the area show that this regrading process has been active in the past when the protective vegetative cover was disturbed by climatic change. The felling and burning of the protective vegetative cover by the early settlers once again triggered this regrading process, but on a much grander scale than had occurred from natural causes.

SLOPE-STABILITY CLASSIFICATION

Gage and Black (1979) devised a slope-stability classification system intended for use by forest land managers in the Mangatu area. This system is unique to the headwaters region of the Waipaoa River and is based on a classification of surface material and evidence of previous mass-wasting behavior. The system has yet to be field tested for harvest planning activities. The system contains the following eight terrain stability types:

1. Stable surfaces on Tertiary strata;
2. Stable surfaces on Cretaceous-Paleocene strata;
3. Very deep slumps on Tertiary strata;

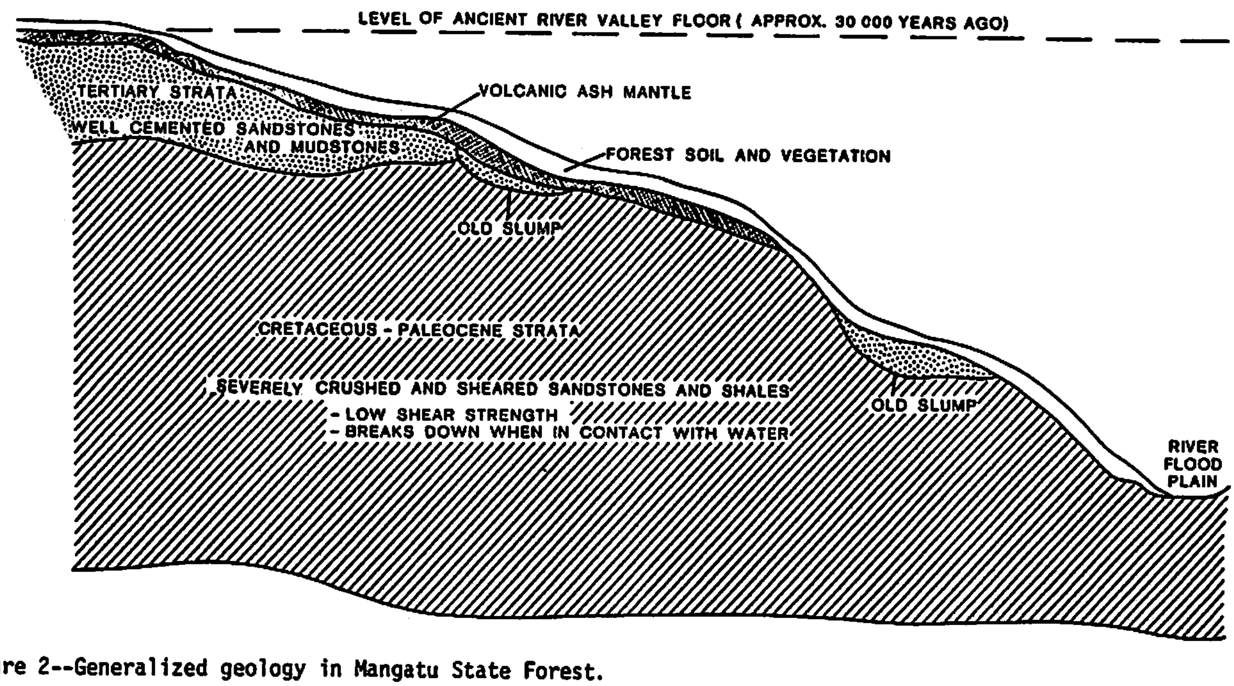

Figure 2--Generalized geology in Mangatu State Forest.

4. Older, moderately deep flows and slumps on Cretaceous-Paleocene strata;

5. Younger, moderately deep flows and slumps on Cretaceous-Paleocene strata;

6. Active flows, slumps, and eroding gullies;

7. River flood-plain accumulations, and debris fans; and

8. Stream terraces and dissected fans.

Gage and Black (1979) provide a terrain stability map of the Mangatu area that incorporates these terrain stability types.

Terrain types 1 through 6 are in order of decreasing stability. Types 3-6 constitute active erosion and sediment transport zones. Terrain types 4, 5, and 6 pose the greatest danger of slope failure and comprise over 70 percent of Mangatu State Forest. Terrain types 7 and 8 are sediment deposition and impact zones and represent only a small portion of the area. Type 7 terrain is often flooded during periods of heavy rain fall.

In addition to developing this slope-stability classification system, Gage and Black (1979) make the following recommendations:

> On types 1, 2, and 3 terrain, forest operations should employ methods that have been found safe and effective in normal soft rock or fractured sandstone terrain with regard for steepness of slopes and runoff. Replanting should be completed as soon as possible and burning of slash should be avoided.
>
> On type 4 terrain, care must be taken to ensure that the protective vegetative cover and ash mantle are not seriously disturbed and that surface water is not allowed access to stabilized old slumps and flow material.
>
> On type 5 terrain, additional road work should be kept to a minimum. Logging methods that can be conducted predominantly from within adjoining, more stable terrain are preferred.
>
> On type 6 terrain, protection forestry, rather than production forestry, should be practiced.

PLANNING HARVESTING ACTIVITIES AT MANGATU

A loss in local employment in the farming sector occurred with the creation of Mangatu State Forest. Forest establishment and tending increased local employment opportunities; however, it was hoped that future harvesting on more stable sites and the ensuing replanting would provide continuing employment and economic growth opportunities for the region. Harvesting is to start on a small scale (10-100 hectares per year) in 1986-91. From 1991 until 2010, the harvest volume is to increase until a harvest area of about 400 hectares per year is reached and will be sustained thereafter. At present, clearcutting is the planned method of regeneration.

It is important to make estimates of the types and quantities of logging equipment and road construction that will be required.

Discussions concerning the planning of harvesting activities for Mangatu State Forest have been ongoing for several years, most notably the Mangatu Forest Case Study presented in the Tactical Planning Seminar held in Rotorua, New Zealand (New Zealand Logging Industry Research Association 1981). Many approaches to harvesting have been proposed, but very limited analysis of these approaches has occurred, and no generally accepted guidelines for harvesting in the Mangatu area have yet evolved. This is understandable given the lack of past operational experience and minimal research conducted in logging and roading on this type of terrain (Bryan and others 1985). Harvest planning guidelines will be evolutionary in nature as each new site harvested provides more information on how the sensitive slopes of Mangatu react to the removal and reestablishment of the forest cover.

Given the steepness of the terrain and the difficulty of building roads in the area, it is likely that a large portion of Mangatu Forest will have to be logged using cable systems. Planning an area for harvest by cable systems involves a large number of complex and repetitive calculations. Ground profile information must be collected from available topographic maps and field surveys. The performance of different cable systems must be estimated for each unique setting. A road system that connects each landing site must be located. Estimates of production and costs must be made.

In such a dynamic environment, it is anticipated that harvest plans will need to be repeatedly modified or redone as planners attempt to incorporate new knowledge concerning slope behavior into each logging operation. Planners will need a methodology that enables them to quickly and rationally evaluate the impact of evolving planning guidelines on future harvesting operations. Traditional manual techniques for performing these calculations are available; however, computer-aided harvest planning techniques allow the planner to carry out this analysis in a fraction of the time.

Several computer-aided harvest planning packages for cable operations have been developed. Carson (1975) developed several computer programs for skyline planning, which were implemented on a small microcomputer facility. Lemkow (1977) demonstrates that wide area planning of cable logging operations could be more efficiently carried out when topographic information from maps is first converted to a digital format or digital terrain model. As microcomputer technology improved, Twito (1982) expanded on Lemkow's concept and developed an operational harvest planning package known as the Preliminary Logging Analysis System (PLANS). In New Zealand, Reutebuch and Evison (1984) developed a package, known as the Cable Hauler Planning Package (CHPP), that allows the planner to work from both digitized topographic maps and field survey data when planning cable logging operations. Because CHPP and PLANS utilize a digital terrain model as a source of terrain data for the planning process, areas can be modified or completely replanned very quickly. Twito and McGaughey (1984) found that the use of digital terrain models reduced the time needed to analyze harvesting options by up to 80 percent when compared to other computer-aided planning methods that did not incorporate a digital terrain data base. For this reason, packages such as CHPP and PLANS are particularly well suited for problem areas such as Mangatu Forest where flexibility in planning and the ability to react to rapid changes in planning guidelines are needed. CHPP was selected for use in the following case study because of its local availability and compatibility with conditions and terminology in New Zealand.

HOMESTEAD CREEK CASE STUDY

To illustrate how a computer-aided harvest planning package such as CHPP could be used for planning in environmentally sensitive areas such as Mangatu State Forest, a small watershed was selected and a planning exercise was carried out. This watershed, which was planted between 1960 and 1961, drains into the Homestead Creek, which flows to the west into the Waipaoa River near the Forest headquarters. The watershed is rectangular in shape, approximately 500 to 600 meters wide and 1750 meters long, and covers 93 hectares (fig. 3). It is bounded on the north and south by ridges running east-west. An actively eroding gully of about 3 hectares is located in the middle of the unit. An existing road runs through the southern edge of the area. Most of the watershed is gently sloping (15 to 30 percent). This makes the area not well suited for cable logging because of the lack of deflection. Sixty-one percent of the watershed is type 6 terrain, 23 percent is type 5, 7 percent is type 3, and 9 percent is type 1. With regard to topography and soil stability, there are many areas in Mangatu Forest that pose more severe problems.

Collection of Available Maps, Photos, and Stand Data

The following maps and photos were collected:

- Topographic map with a scale of 1:5,000 and 20-foot contours (see fig. 3).
- Aerial photos with a scale of 1:20,000 taken in 1958 before planting.
- Aerial photos with a scale of 1:10,000 taken in 1977.
- Stand boundary maps with a scale of 1:10,000.
- Stand inventory permanent sample plot records for the area.

A terrain stability map at a scale of 1:30,000 was available for Mangatu State Forest (Gage and Black 1979). It did not, however, have sufficient detail for this planning exercise. The area was remapped at a scale of 1:5,000 using the preplanting photos and field data (see fig. 4).

Formulation of Planning Guidelines

Because no planning guidelines exist that incorporate soil stability considerations for the area, it was decided to plan the area using three different levels of restrictions based on the slope stability classification developed by Gage and Black (1979) and to develop three alternate harvesting plans.

The following levels of planning restrictions were selected for this exercise:

Level 1 - No restrictions whatsoever--just good harvesting practices. (Assumes no restrictions on roadbuilding and extraction operations as a result of soil stability problems.)

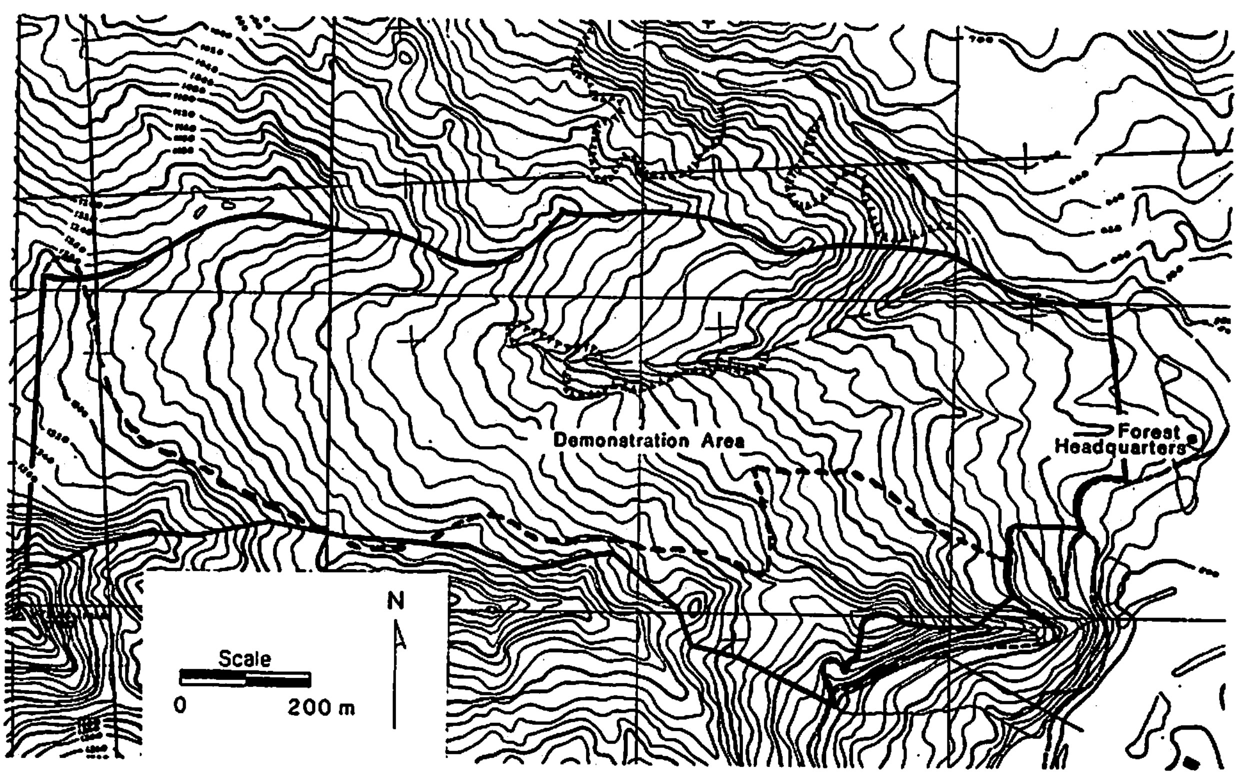

Figure 3--Topographic map of study area, Mangatu State Forest.

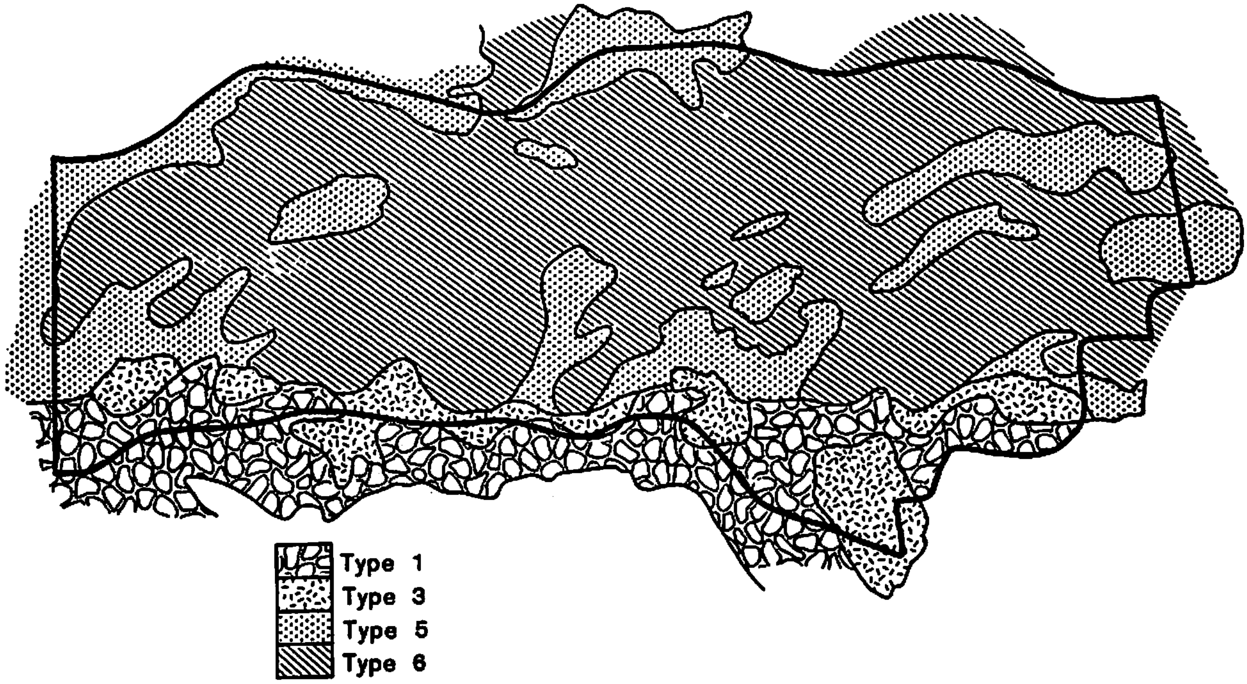

Figure 4--Soil stability classification map for study area.

Level 2 - Minimize roadbuilding on types 5 and 6. Keep landings as small as possible. No ground extraction machinery on types 5 and 6.

Level 3 - Minimize roadbuilding on type 5. No roadbuilding on type 6. No landings on type 6. Buck at the stump on type 6. Full suspension of logs over type 6 and deep gullies. No ground extraction machinery on types 5 and 6.

It should be noted that these three restriction levels are not based on operational experience. They were formulated simply to show how restrictions of varying intensities affect the selection and placement of logging equipment and how a methodology that incorporates computerized planning tools can be used to aid in the harvest planning process. Much more work is needed to determine what effect a variety of logging and roadbuilding operations will have on these different soil stability types (Bryan and others 1985).

Development and Field Verification of Map-based Plans

For each of the three restriction levels, a map-based harvesting plan was developed using the existing aerial photos and topographic maps. The steps involved in developing each plan were:

1. To select potential landings from the topographic map and aerial photos.

2. To project road lines to each landing on the topographic map.

3. To develop an overlay of the area over which a specified target turn volume can be extracted to each landing. In the case of yarder settings, ground profiles are constructed from the topographic map and the payload capability of the yarder over each profile is compared to the target turn volume.

4. To combine all the setting overlays. Where two or more settings overlap, divide the overlapping area between them so that yarding distance is minimized.

5. To calculate the area and average yarding distance of each setting.

6. To calculate the length of new road needed, by terrain type.

The map-based plans were then checked in the field. During the field review, the area was thoroughly examined and the feasibility of the roading and extraction systems in the map-based plans was assessed. Potential landing sites were checked for size, accessibility, and anchor stumps. Proposed road lines were field checked.

Development of Revised Plans

After the field check, the map-based plans were modified where necessary. The areas were reworked using CHPP. A revised plan was produced for each planning restriction level using the same procedure as was used to produce the map-based plan.

Initial Logging Plan With Level 1 Restrictions

The initial map-based plan under level 1 restrictions was developed using the following criteria:

- Ground based extraction equipment should be used wherever possible.

- Slopes above 30 percent should be logged by cable systems.

- Tree-length yarding should be practiced.

- Uphill skidding should be minimized for ground based systems.

- Average yarding distance should be kept to about 140 meters.

- Existing roads should be used wherever possible.

Because of the relatively small tree size, all extraction equipment (skidders, tractors, and yarders) were assumed to be in the medium size range.

A total of 10 settings were planned. Six of these settings would be logged using ground extraction based systems. A Madill 071 yarder[3] with the following specifications was used in the analysis of the remaining cable settings:

Skyline diameter	25 millimeters
Skyline drum capacity	589 meters
Mainline diameter	22 millimeters
Mainline drum capacity	488 meters
Haulback diameter	16 millimeters
Haulback drum capacity	1342 meters
Carriage weight	100 kilograms
Tower height	14 meters

This is a medium-sized yarder by New Zealand standards.

A jeep road on the northern ridge would be upgraded for logging truck traffic.

During the field inspection the following points were noted:

- The jeep road on the northern ridge would have to be rerouted to avoid excessive grades as well as be upgraded for logging truck traffic.

- An additional two landings would be required for the area--one cable setting and one ground extraction setting.

- Even though much of the area was reasonably flat, it was dissected by frequent small streamlets and appeared to be too wet to support conventional rubber-tired skidders.

Revised Logging Plan With Level 1 Restrictions

After the field review, the area was reanalyzed. For the area with wet ground conditions, it was assumed that a low ground pressure machine, such as a skidder equipped with wide tires or duals which was not flotation limited, would be used for extraction. Twelve settings were planned (fig. 5) with an average yarding distance of 137 meters. Table 1 contains a breakdown of the area by logging system. A total of 2285 meters of spur road would have to be built to log the area. Sixty-two percent of the spur roads (1420 meters) would be built across type 5 terrain. Thirty-eight percent (865 meters) of the spur roads would be built across type 6 terrain.

[3]Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

Table 1--Breakdown of the area by logging system with level 1 restrictions.

Extraction system	Area	Area
	Hectares	Percent
Tractor	10	11
High flotation skidder	58	62
Highlead	8	9
Skyline	14	15
Unstocked	3	3
Total	93	100

Initial Logging Plan With Level 2 Restrictions

The initial map-based plan under level 2 restrictions was developed assuming a Skagit BU-199 with the following specifications would be used for extraction:

Skyline diameter	35 millimeters
Skyline drum capacity	950 meters
Mainline diameter	28 millimeters
Mainline drum capacity	950 meters
Haulback diameter	22 millimeters
Haulback drum capacity	2000 meters
Carriage weight	500 kilograms
Tower height	32 meters

This is a large yarder by New Zealand standards.

Six yarder sites were selected from the maps and photos. All six sites are situated along the ridge on the southern part of the area. Each site was analyzed using CHPP. The analysis indicated that the entire area could be extracted to five sites (landings 1, 2, 3, 4, and 6) using this large yarder rigged as a slackline system over most of the area with a highlead system over some of the more stable areas (see fig. 6). This option eliminated the need for more than a kilometer of road down the ridge on the northern side of the area.

During the field inspection of the area, each of the proposed yarder sites was carefully examined. It was evident that several of the sites were not practical for the following reasons:

Landing 1 - The site was too small for the yarder. There were no suitable guyline stumps and no suitable locations for artificial anchors in a large area behind the site.

Landing 2 - The site could not be reached with a spur road suitable for the yarder.

Landing 3 - There were no suitable guyline stumps behind the yarder.

Landing 4 - There were no suitable guyline stumps behind the yarder.

Landing 6 was easily accessible with lots of stumps for guylines; however, it was felt that most of the available stumps would not be adequate for anchoring such a large yarder. The same problem was evident with regard to tailhold stumps. The stumps available for skyline anchors were not adequate to withstand the pull of a 32-millimeter skyline unless multiple stump anchors were rigged. Given this problem of lack of suitable stumps over the entire area, the option of using the large Skagit BU-199 yarder was rejected.

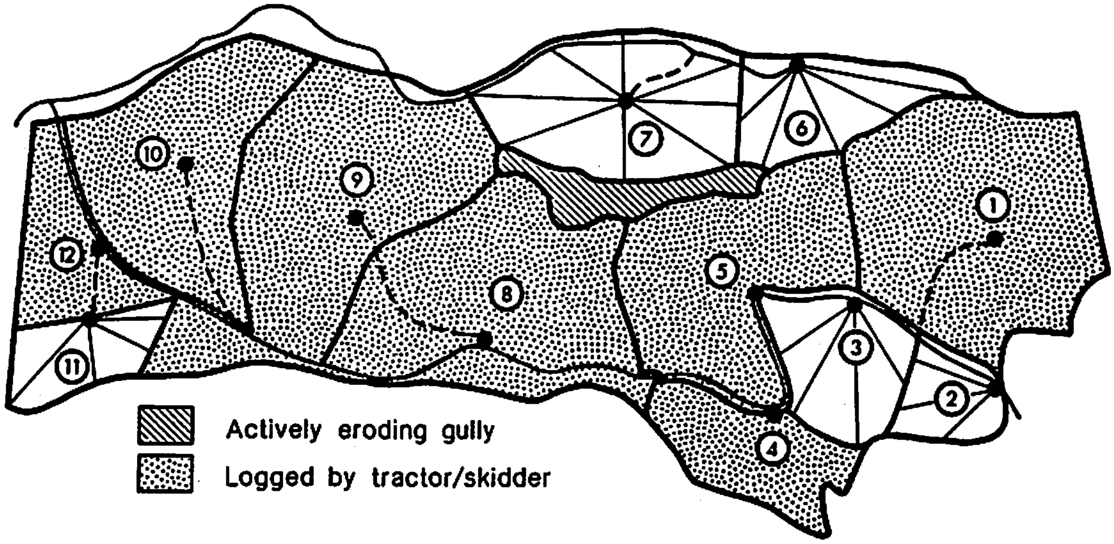

Figure 5--Revised logging plan for level 1 restrictions.

Revised Logging Plan With Level 2 Restrictions

After the field review, the entire area was reanalyzed using the CHPP. A Madill 071 yarder, with the same specifications as given previously, was used.

Twelve yarder sites were selected and analyzed. No yarder landings were located on type 6 terrain. It was found that 83 hectares of the area could be extracted using 11 of these sites (fig. 7). Table 2 gives a breakdown of the area by logging system. Because of the relative flatness of the area, resulting in very limited deflection or lift, most of the area was laid out to be highlead logged rather than skyline logged. Blind lead was avoided in all areas in an effort to avoid unnecessary soil disturbance in the highlead settings. An alternative to highlead logging that needs to be further investigated is the use of a multispan skyline system; however, this was not required under the level 2 restrictions.

Seven hectares in the northeast corner of the area cannot be reached unless 300 meters of additional road are constructed across areas of types 5 and 6 terrain and an additional landing is constructed on type 6 terrain. It was felt such additional construction would not be acceptable given the restriction to limit construction on types 5 and 6 terrain. The analysis showed that landing 12 is not needed; however, it could be used as a landing for a tractor setting if a tractor were available.

A total of 1865 meters of additional road is needed to get to the twelve landings. Table 3 gives a breakdown of spur roading by terrain type.

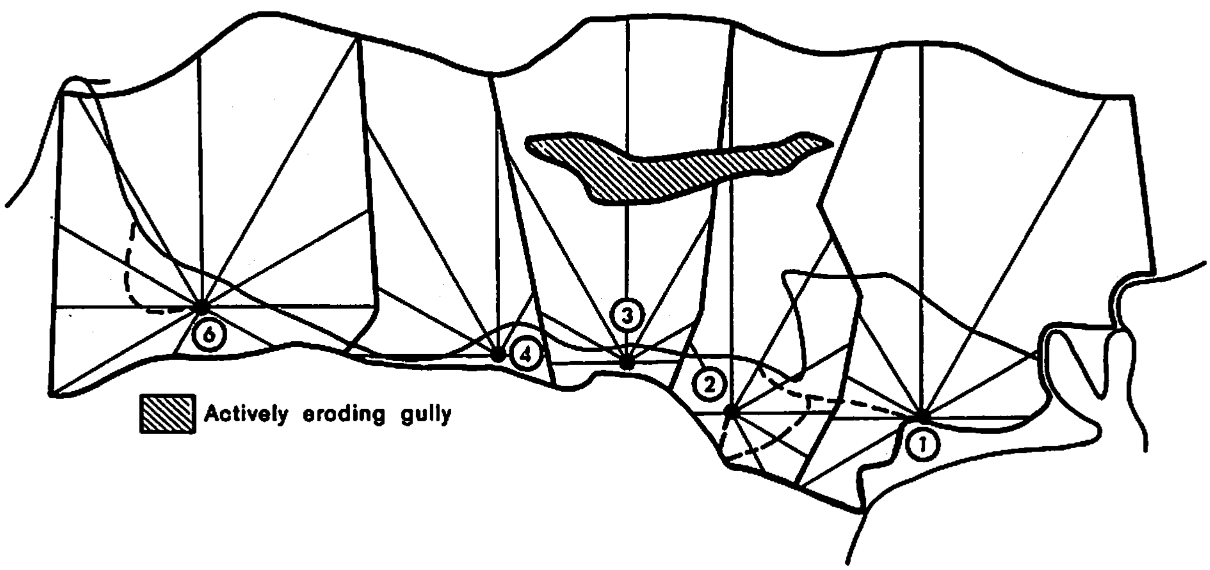

Figure 6--Initial logging plan for level 2 restrictions.

Table 2--Breakdown of the area by logging system with level 2 restrictions.

Extraction system	Area	Area
	Hectares	Percent
Tractor	4	4
Skyline	4	4
Highlead	75	81
Not accessible	7	8
Unstocked	3	3
Total	93	100

Initial Logging Plan With Level 3 Restrictions

Eight landings were selected from the topographic map and aerial photos. The same large Skagit yarder used in the level 2 map-based plan was used in the analysis of each landing. The analyses showed that only four of the landings provided enough lift to meet the restriction of full suspension over type 6 terrain. One third of the area (fig. 8) could not be logged under this restriction. A new exit road would need to be located over a saddle on the west end of the area. This was necessary because the existing road traverses type 6 terrain in several places.

The problems noted during the field check were the same as those mentioned for the level 2 map-based plan. In addition, the proposed exit road was not feasible.

Revised Logging Plan With Level 3 Restrictions

After the field inspection, it was determined that it would be impossible to get a road into the area without crossing type 6 terrain. The existing road crosses type 6 terrain in several locations, thereby violating the level 3 restriction on roading. Also, no alternative landings are available that provide sufficient lift to meet the restriction of full suspension over type 6 terrain. The area cannot be logged under the level 3 restrictions unless helicopter logging becomes economically viable at some time in the future.

Table 3--Breakdown of required spur roadbuilding, by terrain type, with level 2 restrictions.

Terrain type	Road Needed	Percent of total
	Meters	
6	155	8
5	1265	68
3	200	11
1	245	13
Total	1865	100

The use of a multispan skyline system was not considered in the analysis. The use of intermediate supports needs to be more fully explored; but because of the flatness of terrain within the case study area, use of such supports would generally provide only enough deflection for partial suspension of logs and not the full suspension over type 6 terrain stipulated in the level 3 restrictions.

COMPARISON OF THE LOGGING PLANS

Major differences in the road patterns and the logging methods are evident in the three logging plans. Table 4 illustrates the vast differences in loggable area that result from adhering to the three different levels of planning restrictions.

A much larger proportion of the area must be logged using cable systems under the level 2 restrictions. The length of new roading required under levels 1 and 2 are given in table 5.

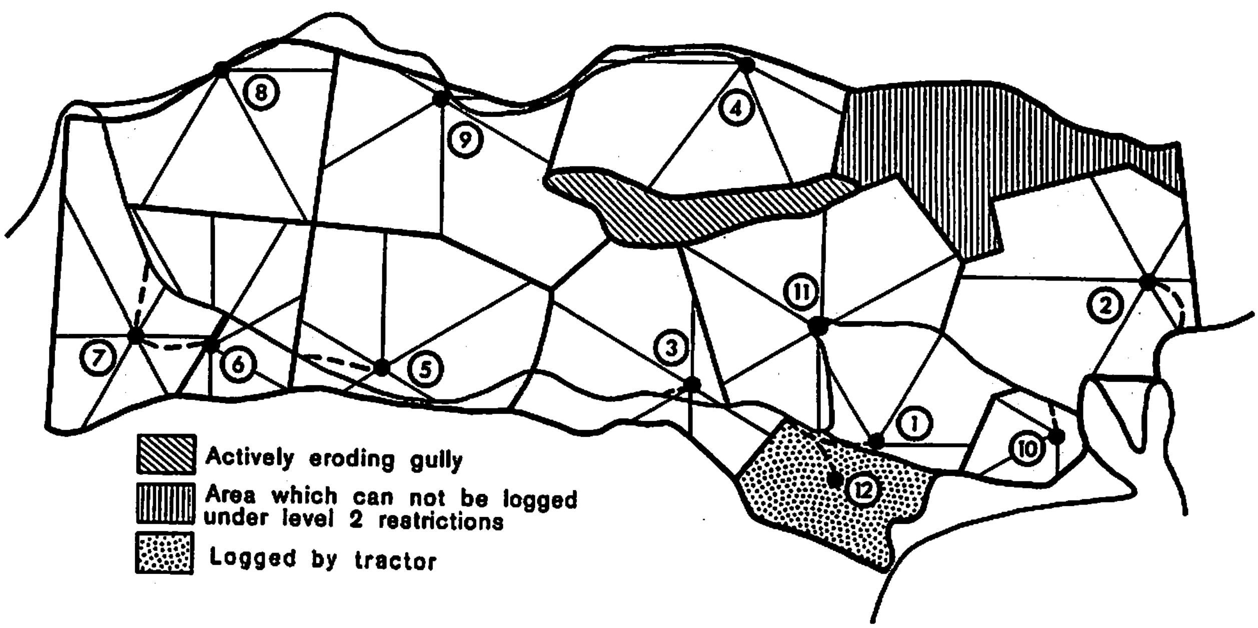

Figure 7--Revised logging plan for level 2 restrictions.

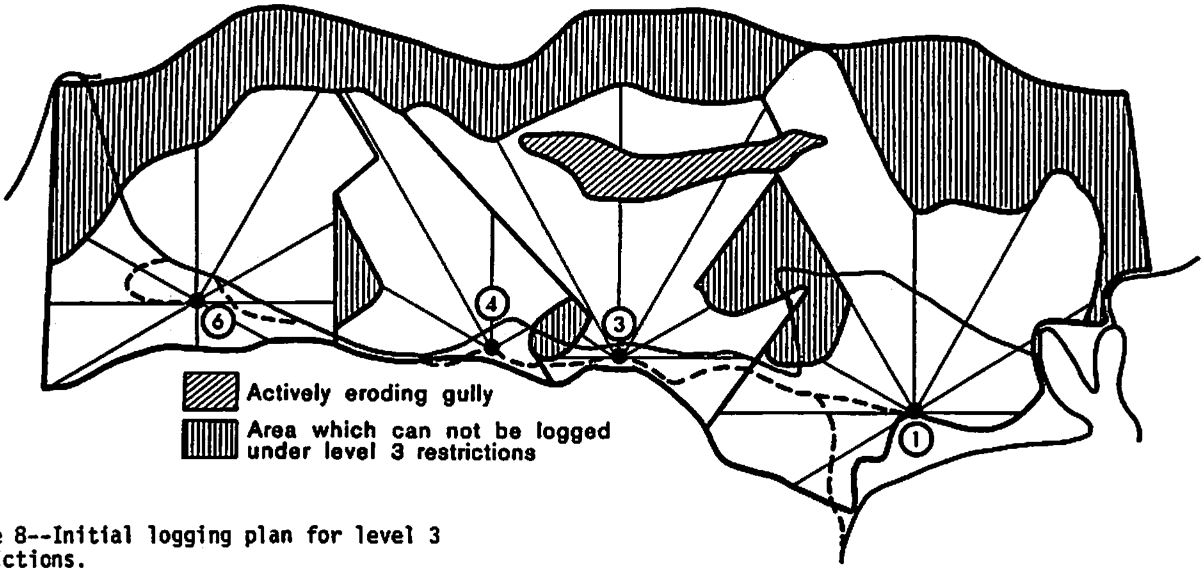

Figure 8--Initial logging plan for level 3 restrictions.

Although the overall difference in road length between levels 1 and 2 (420 meters) is not large, there is a large difference in the amounts of new road construction that must take place on the more unstable types 5 and 6 terrain. Under level 1 restrictions, the entire 2285 meters of new road would be on these sensitive sites; under level 2 restrictions, only 1420 meters (a reduction of 46 percent) would be on types 5 and 6 terrain.

ESTIMATED COSTS OF COMPUTER-AIDED HARVEST PLANNING

The time involved to produce plans for the three sets of guidelines using a computer-aided harvest planning package was approximately 20 staff-days. With a charge of $100 per day for the planner and $50 for the computing equipment, the cost of the planning exercise would be approximately $3,000 for the 90 hectares that are stocked in the area. With a merchantable volume of 500 cubic meters per hectare, this translates into a cost of $0.07 per cubic meter or $35 per hectare.

It is expected that a trained planner could analyze and field check about 10 hectares per day using a computer-aided planning package such as CHPP or PLANS in a production situation. Assuming a merchantable volume of 500 cubic meters per hectare, this translates into a cost of approximately $0.03 per cubic meter or $15 per hectare. Twito and McGaughey (1984) report costs of less than $1 per hectare to produce a preliminary harvest plan, excluding field verification, for a 1500-hectare forest using the PLANS computer-aided planning package.

Table 4--Proportion of area logged, by logging system.

Extraction system	Restrictions: Level 1	Level 2	Level 3
	Percent		
Ground-based systems	73	4	0
Cable systems	24	85	0
Not accessible	3	11	100
Total	100	100	100

BENEFITS OF COMPUTER-AIDED HARVEST PLANNING

Direct benefits resulting from using a computer-aided harvest planning package include:

1. Plans are developed in a systematic fashion guaranteeing that the entire area is carefully analyzed.

2. Specific features, such as landing locations and stream crossings, are pinpointed early in the planning cycle. This results in more efficient use of field time when checking the plan on the ground.

3. Modifications to preliminary plans can be quickly made when field work indicates such changes are needed.

Indirect and less obvious benefits include:

1. Well-designed, computer-aided planning packages help guide inexperienced planners through the multitude of complex choices that must be made during the development of a harvest plan.

2. In politically and environmentally sensitive areas, these packages allow the planner to effectively document the analysis planning decisions were based on, thereby boosting the confidence of the planner.

Table 5--Comparison of roadbuilding requirements under restriction levels 1 and 2.

Terrain type	Amount of road to be built: Level 1	Level 2
	Meters	
Type 6	865	155
Type 5	1420	1265
Type 3	0	200
Type 1	0	245
Total	2285	1865

3. Harvest plans are produced that generally result in lower logging and roading costs when compared with manually prepared harvest plans. Reimer (1979) reports savings of $0.15-0.70 per cubic meter attributed to better planning and layout resulting from the use of a computer-aided harvest planning package.

CONCLUSIONS

The computer-aided harvest planning package was incorporated into a methodology that enables planners to quickly evaluate the impact of planning restrictions on harvesting system requirements. In the case study presented, vast differences were evident in the roading patterns and logging methods needed to harvest the area when three different levels of proposed planning restrictions were applied.

Because of the lack of past operational harvesting experience in the area, it is impossible to predict at this time what the correct road patterns and logging methods will be for harvesting this area. Given the area's history of erosion and flooding, it is obvious that special guidelines will have to be developed as operational experience is accumulated. This will result in a situation where harvest plans will need to be reworked as new guidelines evolve. Computer-aided harvest planning packages, such as CHPP and PLANS, provide the planner with an efficient means of carrying out these plan revisions.

Because of the lack of harvesting production and cost estimators for the East Coast region, no attempt was made to estimate logging costs and production rates. For comparison purposes, past experience in New Zealand suggests that logging costs for cable systems are approximately double those of ground-based systems, and production rates for cable systems are often only half those obtained with ground-based logging systems (Murphy 1979, Terlesk 1980). Under level 1 planning restrictions 73 percent of the area would be logged using ground-based systems, and 24 percent of the area would be logged using cable systems. Under level 2 planning restrictions the situation would be reversed with only 4 percent logged with ground-based systems and 85 percent with cable systems. Given such differences in logging methods and the above-mentioned differences in costs and production rates, it is obvious that planning constraints can have a significant impact on the on-truck costs and the level of staffing needed to meet production targets. Use of CHPP enables planners to quickly evaluate the impact of evolving planning guidelines so that the impact on logging equipment and staffing levels can be estimated as early as possible. This is essential in remote locations where a long lead time is needed to bring specialized harvesting equipment into the region and to develop specialized logging skills in the local labor force. The cost of the computer-aided planning process, approximately $15 per hectare, is trivial when compared to the additional costs of several thousand dollars per hectare that can result from poor application of harvesting systems and from production delays caused by the lack of experienced labor.

Finally, in areas such as Mangatu State Forest, history has shown that improper land-use decisions can result in wide-ranging damage far beyond the boundary of the forest itself. In such cases it is important that land managers base harvesting decisions on thorough analysis of available data and are seen to be doing so by concerned public groups. The use of computer-aided harvest planning techniques assist the planners in this analysis and provide documentation indicating the thoroughness of the analysis.

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Logging Environmentally Sensitive Areas In Eastern Maine, USA[1]

Ernest L. Carle[2]

Abstract: This paper gives a brief description of how sensitive areas such as lake shores, streams, wetlands, and deer yards are protected by Maine State Land Use Standards and how logging operations conform to these standards.

Georgia-Pacific Corporation owns approximately 900,000 acres (364,000 hectares) of timber land in Eastern Maine and New Brunswick. As part of the wood supply for our Pulp and Paper Mill, Stud Mill, and softwood Waferboard Mill, our Princeton Operations Office controls the delivery of 200,000 cords (500,000 cubic meters) annually from company operations and contractors. As an integral part of harvest planning and control, our land management staff of 3 district foresters and one technician strives to keep all operations in compliance with state land use standards.

A description of our local logging methods is needed in order to understand harvest planning. Figure 1 shows how nearly all of our logging proceeds from stump to truck. Nearly 40 per cent of our softwood (conifer) harvest is delimbed mechanically at roadside. A more unique characteristic of our region is that practically all of the hardwood (deciduous) that is 20 inches (50 centimeters) in stump diameter or less is yarded whole tree (with limbs on) to a roadside chipping area, increasing the yield by as much as 60 percent over tree length hardwood.

Since the initial development of "Land Use Districts and Standards" by the Maine Land Use Regulation Commission (LURC) in 1977, timber land owners and logging operators have become increasingly dependent on foresters to interpret regulations. Nearly 60 per cent of the timberland owned by Georgia-Pacific Corp. in Maine is in unorganized townships and is under the jurisdiction of LURC. Because organized towns that lack protective zoning are required to match or exceed LURC standards, we apply these standards in all our townships in Maine. The notable difference is that when our planning involves an unorganized town, a "General notification" must be submitted prior to any road work or logging activity. This notification includes the following:

1. Locations of timber harvesting to take place in or near a) lake shores, b) streams, c) wetlands d) deer yards, and e) remote ponds.
2. Road construction in same zones listed in 1
3. Road water crossings of streams which drain less than 50 square miles. (130 square kilometers) Location of water crossings and culvert sizing method must be specified.
4. Option to operate under "subsection g" (see definition later)

[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985

[2]Ernest Carle, Western District Forester, Forest Resource Dept., Georgia-Pacific Corp., Woodland, Maine

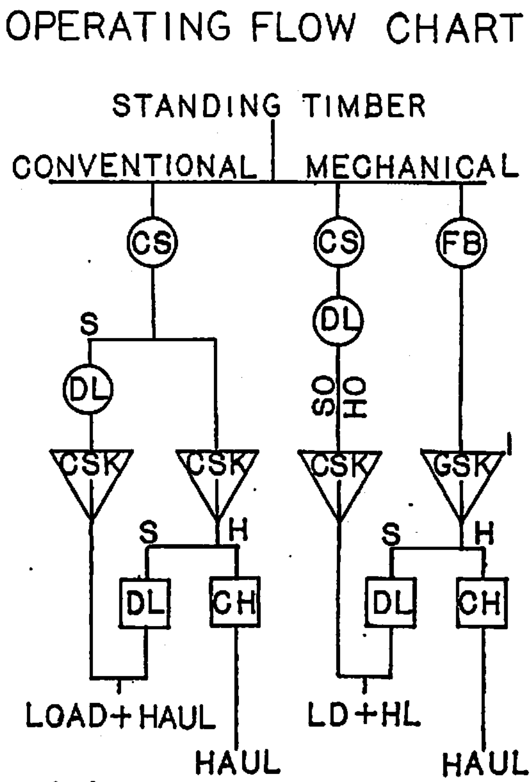

Figure 1--Operating flow chart shows how most timber is harvested on Georgia-Pacific Corp. land in Maine. CS=chain saw S=softwood H=hardwood SO=softwood oversize HO=hardwood oversize FB=feller buncher DL=delimb CH=chip CSK=cable skidder GSK=grapple skidder [1]Cable skidders have also been used effectively to yard mechanically felled wood.

Definitions of Terminology[1]

It is essential to understand the definition of some of the sensitive areas being regulated before a discussion of how logging operations comply can proceed.

"Great Pond Protection Subdistrict (P-GP)--Areas within 250 feet (76 meters) of the normal high water mark, measured as a horizontal distance landward of such high water mark", of those standing bodies of water 10 acres (4 hectares) or greater in size." We have timberland near more than 30 such lakes in our districts.

"Fish and Wildlife Protection Subdistrict (P-FW)--The shelter portion of deer wintering areas where documentation shows that in the last 10 years at least 20 deer per square mile (8 deer per square kilometer) have used the "yard" a minimum of two years."

"Land Management Road: A route or track consisting of a bed of exposed mineral soil, gravel or other surfacing material constructed for, or created by the repeated passage of motorized vehicles and used primarily for agricultural and forest management activities, in-

[1]Excerpts from Chapter 10 of the Land Use Districts and Standards are in quotes.

cluding associated log yards but not including skid trails, skid roads, and winter haul roads." The exclusion of winter haul roads from the definition is important since such roads can be built for much less and do not need to meet standards which provide for continued usage.

"Shoreland Protection Subdistricts (P-SL)--P-SL1: Areas within 250 feet (76 meters) of the normal high water mark...of flowing waters downstream from the point where such waters drain 50 square miles (130 square kilometers) or more. P-SL2: Areas within 75 feet (23 meters) of... stream channels upstream from the point where such channels drain 50 square miles... and, standing bodies of water less than 10 acres (4 hectares) in size." The P-SL2 zone is the most critical and controversial since many smaller streams are not detailed on the state zoning maps (fig. 2). Enforcement personnel at LURC maintain that "streams are where you find them." However some land managers have suggested that if a stream lacks the significance to be included on a zoning map, how can the state justify protection of it? New legislation is pending to map more streams.

"Stream Channel : A channel between defined banks created by the action of surface water and characterized by the lack of terrestrial vegetation or by the presence of a bed devoid of topsoil containing water borne deposits or exposed soil parent material or bed rock." Note that this could describe some skid trails.

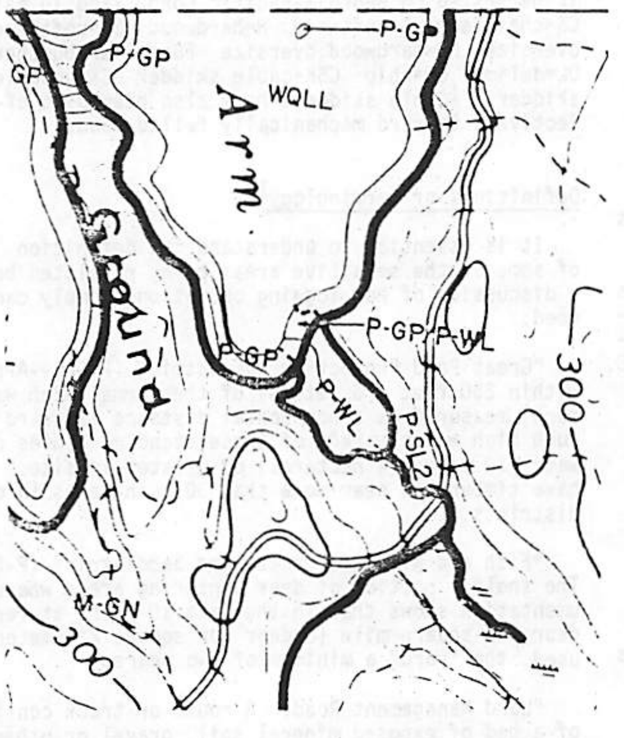

Figure 2--A copy of the state zoning map for part of T26ED.

"Wetland Protection Subdistrict (P-WL)--water logged or water covered swamps, marshes, or bogs encompassing 10 acres or more." These areas are useful in the winter time for a skid trail or winter haul road and are usually devoid of merchantable trees.

"Section 10.17,A,5,g. (Subsection g.)--Timber harvesting operations in P-SL2 protection subdistricts along stream channels upstream from a point where they drain 300 acres (121 hectares) or less...may be conducted in (any) manner...provided that such operations are conducted to avoid the occurrence of sedimentation of water in excess of 25 Jackson Turbidity units as measurable at a point where such stream channel drains 1 square mile or more." This provision for operating near small streams lets operators exceed operating standards applicable to larger streams such as minimum shading requirements and setbacks for exposing mineral soil (fig. 4). However good judgement must be used to avoid sedimentation as related to season, soil type, and size of equipment used along these small streams.

Logging in Protection Subdistricts

Lake Shores--Great Pond Protection (P-GP)

Even though LURC standards for operating along lake shores have caused a reduction of the overall harvest by less than 1 per cent compared to previous company standards, the administration of these standards has dramatically increased the field work needed to insure compliance with the law. During field layout a bright ribbon line is established by one person either by checking the 250 foot setback frequently or by using a compass, aerial photos, and sometimes a plotting board. The 40 per cent volume or basal area which can be harvested is usually marked using a spot on the tree trunk and one on the stump to aid in follow up inspections. Very few trees are marked within 50 feet (4.6 meters) of the water since slash is prohibited. One man can layout and mark approximately 1 mile of lake shore in one 40 hour week. A small portion of our operators are trained well enough in cutting P-GP areas that tree marking is not necessary. The importance of utilizing the experience of good men while operating near sensitive areas cannot be over emphasized. Our foresters spend roughly twice as much time on inspections and follow up involving lake shore cutting as they do on nonsensitive areas. The standard requiring the disposal of slash 3 inches (7.6 centimeters) in diameter and larger to within 4 feet (1.2 meters) of the ground gives loggers the most problems. See figure 3 for an example of a completed lake shore harvest.

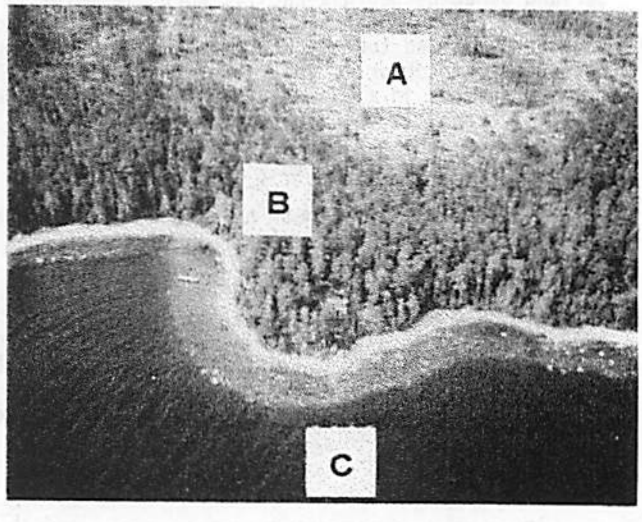

Figure 3--A. fully harvested area B. lake shore P-GP zone with 40 per cent removed C. West Grand Lake Notice the camp in the foreground.

We have used all combinations of equipment described in Figure 1 to harvest lake shore areas but the system that seems best suited to it in any season, slope, or ground condition is the conventional system. Even though we have accomplished superior partial cuts with the Kockums Tree King 880 and the Liebherr L925 feller bunchers, the risk of deep rutting is higher for grapple skidders, especially during the spring mud season. In some instances we have had to install water bars and/or put brush into the skidder ruts to divert or filter sediment.

Streams--Shoreland Portection (P-SL)

Large streams or rivers draining more than 50 square miles (P-SL1) are administered the same way the P-GP areas are handled, since the operating standards are the same.

P-SL2 streams are protected in a variety of ways depending on the following variables: size, quality of fishing, season of operation, stability of soil, and choice of logging equipment. Streams which drain more than 300 acres (121 hectares) are all subject to the same standards which basically require that shading of surface waters be maintained, slash be kept above the high water mark, and that mineral soil is not exposed within specified distances (fig. 4). We often put ribbon lines over or near brooks where visibility is poor or soils are unstable. Some of our better loggers can do a fine job along brooks without ribbon lines provided. Cutting standards are more lenient near brooks that drain less than 300 acres (121 hectares) (see subsection g.) but we still avoid crossing them to prevent sedimentation downstream. In addition to LURC standards, our company requires that slash be kept back 10 feet from fishing streams.

Average Slope of Land Between Exposed Mineral Soil and Normal High Water Mark (Percent)	Width of Strip Between Exposed Mineral Soil and Normal High Water Mark (Feet Along Surface of the Ground)
0	25
10	45
20	65
30	85
40	105
50	125
60	145
70	165

Figure 4--Slope setback distance table taken from LURC Standards 10.17,A,4 and 5

Wetlands (P-WL)

Wetlands can sometimes be used for skid trails during the winter to access islands of timber that could not economically be cut any other way. When the surface of a wetland is frozen into a skid trail the surface can become smooth enough to permit much higher skidder speeds. Under good conditions maximum yarding distances of 40 chains (1/2 mile) are common. Depending on the temperature and the water table under the wetland, at least 10 weeks of winter operating is possible. Last winter one of our contractors had a difficult time freezing down a section of wetland because of higher than normal temperatures and a low water table. The depth to hard pan was 6 feet and logging debris placed in trails would only support a loaded skidder for a few passes.

Deer Yards-Fish and Wildlife Protection (P-FW)

We are required to consult an Inland Fisheries and Wildlife regional biologist before we plan cutting in any zoned deer yards. Assuming a compromise can be reached on cutting guidelines, a notification to LURC must be submitted 10 days before cutting begins. P-FW areas make up a small fraction of our total ownership and we make every effort to cooperate in preserving deer habitat in this way.

Road Construction in Protection Subdistricts

Water Crossings-P-SL2 Streams

The standards governing how a road should cross a stream are detailed in LURC Standards 10.17,A,4. and in Handbook 6 (fig. 5). A definite increase in road construction costs has resulted from the application of these standards, but at the same time the risk of sedimentation and washout has been reduced. Bulldozer operators try to minimize the disturbance of stream banks and keep ditches from entering directly into the stream. This can be done by running the ditch out into the woods (ditch relief) and/or using settling basins. Most settling basins remain effective only if their overflow point is properly stabilized and the sediment buildup is periodically removed. The distance that a ditch relief culvert or settling basin is set back from the stream is determined by the slope (fig. 4). On roads that slope toward stream channels, cross drainage culverts must be placed at intervals specified in the standards. For instance if the road slope is 5 per cent, then cross drainage culverts should be installed at intervals of 140 feet. (43 meters)

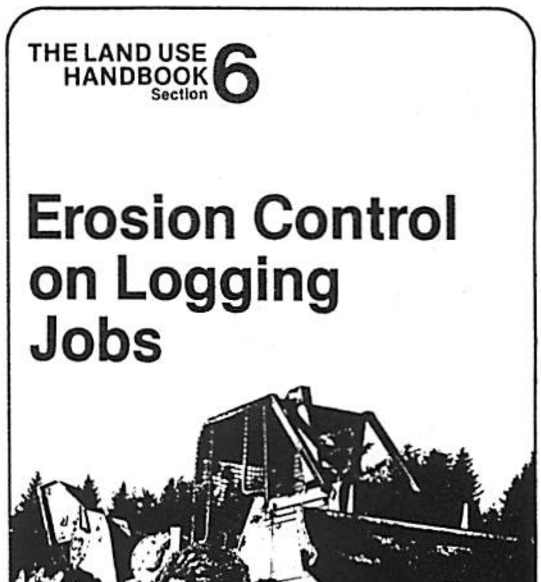

Figure 5--Front cover of Land Use Handbook 6.

Culvert size is determined during road layout and depends on the operating "chance". Of the five options available in the standards for sizing culverts we use 2 almost exclusively because of their ease of application. For example, when a haul road will access a cutting chance through the spring runoff period we size the culvert by multiplying the stream cross-sectional area by 2½ times. If the access is temporary and cutting will be completed before winter, then we will often use smaller culverts that will handle summer and fall runoffs. We remove these culverts before winter to prevent a spring washout.

Culvert placement is the most sensitive operation that a road crew can perform. The stream channel is disturbed only enough to give the culvert a firm foundation. (A landowner can expect to pay a large fine if stream bulldozing takes place. Fifty feet on each side of a stream is permitted.) Most road crews prefer to simply fill over the stumps within 25 feet of the crossing without removing any stumps. We stabilize culvert head walls by hand placement of rocks or by placing boulders with a log loader.

Roads Located in P-GP, P-SL, and P-WL Areas

We usually avoid locating haul roads within 250 feet of lakes or 75 feet of streams to avoid the additional standards required and to avoid the increased risk of sedimentation. Also the expense of crossing an unfrozen wetland forces us to use other options. Under normal winter conditions a winter haul road crossing a wetland can support a 5 axle tractor trailer with a gross weight of 80,000 pounds. Large loads can be subject to settling and operators avoid stopping for more than a few minutes.

Closing Remarks

Logging environmentally sensitive areas in Eastern Maine presents an ongoing challenge to loggers and foresters. The rewards of good performance are realized in the preservation of water quality, fish and game habitat, and areas suitable for outdoor recreation. However trends toward stricter regulation of timber harvesting threaten to undermine the spirit of cooperation now enjoyed between land managers and the Land Use Regulation Commission. The controversy between conservationists and those who would increase utilization is gaining in intensity each year in Maine and represents an opportunity for foresters to influence policy formation.

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Engineering a Development Plan for a Sensitive Area Dall Island, Alaska[1]

Dallas C. Hemphill, P.E.[2]

Abstract: Logging and transportation plans were developed for the USDA Forest Service for a 31044 acre (12568 ha) area of undeveloped timber on Dall Island, Alaska. Dall Island has rugged terrain, scoured by past glaciation; defective timber; extensive areas of shallow, saturated, unstable soils on steep slopes; widespread evidence of past mass erosion; and a valuable fisheries resource requiring protection. The plans were required to meet strict soil and water protection guidelines. This was achieved by route selection to avoid unstable zones as much as possible; by identifying suitable road construction measures; and by designing the setting layout, and by selecting logging systems, to avoid soil and water impacts. Intensive engineering was necessary to produce plans that were at the same time environmentally acceptable, operationally practicable, and economically sound.

Logging Engineering International, Inc. ("LEI") was a joint venturer with T.M. Thomson & Associates (International) Ltd. in a contract with the USDA Forest Service, Region 10 to develop and field verify logging and transportation plans for an undeveloped area on the Tongass National Forest, in the middle part of Dall Island, Alaska. Dall Island is located in the southern part of southeast Alaska (fig. 1). The project area, on the western side of the island, covers 31044 acres (12568 ha).

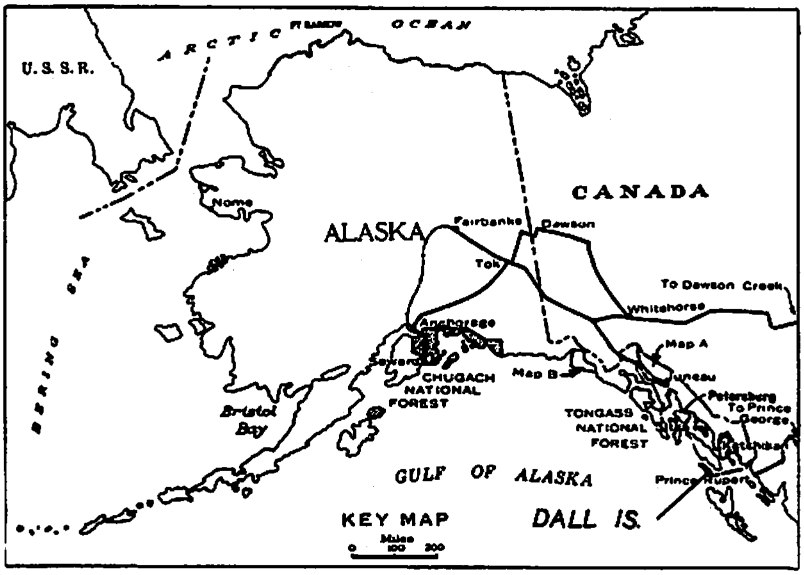


Figure 1--Location map.

[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

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

The purpose of the plans was to show feasible logging and transportation layouts for the development of the middle Dall Island timber resource, to provide the basis for subsequent economic and environmental analysis by the Forest Service, and to provide direction to the layout, planning, evaluation, and environmental assessment of timber sales. The plans show the complete layout of all roads, landings, setting boundaries, and logging systems necessary to log all of the commercial timber in the project area.

Two alternative plans were prepared. Alternative A, the "Short Span" plan, was based on the maximum use of conventional short span logging systems. Alternative B, the "Long Span" plan, was based on a greater use of long span systems with a wider road spacing to the extent feasible. Both plans met usual soil and water protection standards. Other environmental impacts - e.g. wildlife, visual, etc. were not taken into account; they were to be subsequently evaluated by the Forest Service using the plans as the basis.

Paper plans for the two alternatives were prepared in the winter of 1983-84. The most critical features of the plans were laid out in the field in the summer of 1984.

The Forest Service has, then, been provided with plans showing how to access and log all of the timber in the planning area. A basis therefore exists for future planning decisions, for example, which areas will not generate a positive stumpage, where the layout may require modification to protect wildlife habitat, which areas may logically be developed for first entry timber sales using a maximum mix of conventional logging equipment, and so on. Because the most critical portions have been verified in the field, the plans may be used with confidence although they were developed in a cost effective manner.

PHYSICAL DESCRIPTION

Dall Island has mountainous glaciated terrain, subject to a cool wet climate, with a heavy cover of timber broken by muskeg on the flatter terrain and by bare mountains above about 1500 feet (500 m) elevation. It is a difficult place for a logging company to realize a profit.

Most of the timber is of poor quality. Western and mountain hemlock and Sitka spruce are the primary species, with lesser volumes of red and yellow cedar. Defect and the prescence of non-timbered areas commonly limit cable system anchoring and spar tree opportunities.

The topography is generally steep, exhibiting the classical geomorphology of Pleistocene glaciation - U-shaped valleys, fjords, cirques, and medial moraines. Some slopes average 100 percent from the beach to the mountaintop. Moderate topography is confined to a few valley floors and to upland muskegs. Rock is widely exposed, much of it in the form of spectacular bluffs. Lakes and deep coastal indentations are common. Along the shoreline uplifted beaches exist, interspersed with rocky headlands.

Rainfall exceeds 150 inches (3800 mm) per year. Surface runoff and streams are abundant, and the salmon fishery is an important resource requiring protection. Subterranean drainage is common in limestone areas.

Because of the steepness, wetness, and rockiness of the terrain, practically none of it is suitable for tractor or skidder logging.

Two rock types predominate. Metamorphic rocks are common, and there are extensive areas of limestone complete with sinkholes and karst landscapes. The rock requires blasting and is competent for road construction and for rock bolt installation.

Soils are shallow and saturated in most areas. While present slide activity is localized, the potential for careless construction to accelerate erosion is considerable. Debris chutes are widespread and commonly constrain road location options. Slope stability considerations proved to exert major control on route selection throughout the project area.

PLANNING APPROACH

Logic

Plans were developed for conventional southeast Alaskan truck-raft-tow transportation, road construction practices, and logging equipment and rigging practices as far as possible. At the specific request of the Forest Service, economic comparisons between alternatives were not made, except to examine the feasibility of highly doubtful possibilities.

The layout approach was to fit the primary road system to major control points such as dump sites, passes, slides, water bodies, etc. The branch route and setting layouts were then developed concurrently on paper, with unstable slopes, stream crossings, major rock outcrops, and likely landing locations affording acceptable deflection, exerting the most control on road locations. Route selection stressed the avoidance of slope stability problems, in preference to using expensive mitigation measures to cross unstable areas.

For Alternative A, roads were projected into all areas without severe stability problems and affording acceptable deflection, aiming for an 800-foot (250 m) yarding distance where practicable. For Alternative B, as required by the Forest Service, the maximum practical use of longer spans was projected in order to minimize the extent of road construction.

The most critical portions of the plans were laid out in the field. Priorities for field verification included routes projected on potentially unstable terrain, such as steep slopes, debris chutes, and other features identified from photointerpretation as risky locations; stream crossings; switchbacks; and steep grades. Critical landing locations and skyline profiles were also checked in the field where they were important to the integrity of the overall plan and where environmental risks had been identified.

Procedures

Paper plans were prepared from 1:12000 topographic mapping and 1:15840 color aerial photography. A photogrammetric plotter was used to concurrently develop and plot the plans. Forest Service soils maps and reports for the project area were used to help assess slope stability. The soils reports also set out desired soils management practices such as full and partial log suspension.

Of a total construction requirement of 225 miles, 55.5 miles of centerline were laid out on the ground, representing the most critical portions of the transportation system. Field notes were collected to assist in cost projection, road design, and timber sale layout. Construction measures necessary for successful road building and to minimize soil and water impacts were recommended in the field notes. Techniques recommended included end haul, fabric installation, cut/fill slope support by a variety of means, and others as called for by site conditions observed in the field.

Roads were laid out to access the necessary landings to log all of the tributary timber, while avoiding unacceptable slope stability risks and impractical construction conditions. Grades in excess of 15 percent were laid out only where no practical alternatives could be found.

Engineering geology investigations were conducted to assess rock bolt anchor feasibility and slope stability problems impacting road location, and to determine the best construction methods. Successful interpretation of landforms, soils, and geology in the field is essential in determining the best location and construction techniques in difficult terrain of this type, for reasons of both operational economy and environmental impact.

An analysis of the transportation network was conducted, to determine the economics of access and transportation using alternative routes. The transportation network analysis procedure and results are more fully documented below.

Extensive cable systems payload analysis was performed, using LEI's Hewlett Packard 9816 computer. A sample of the skyline analysis output is shown in figure 2.

Where necessary to meet payload objectives, skyline extensions were typically specified in preference to tail trees or intermediate supports, as the former are simpler solutions for the average Alaskan logger.

While layout was generally based on the use of conventional 90-foot (27 m) towers or 50-foot (15 m) swing-boom yarders, scarcity of guyline anchors in some areas dictated the use of smaller 50-foot towers with a 1-1/8 inch (29 mm) skyline. Complex anchors (deadmen, rockbolts, multiple stump anchors, etc.) were found to be the only means available in some cases for yarder guylines and/or tailholds. Considerable evaluations were necessary to determine the practical feasibility of such installations, which were proposed only as a last resort, and then mainly for the smaller 50-foot towers.

Payload analysis was based on achieving sufficient carriage clearance above the ground for partial suspension in most cases. For those soils identified as having the greatest risk of accelerated erosion, attempts were made to provide for full suspension in the layout, but this could not be practically achieved on all areas where it was desired by the soil scientists. The layout was designed for full suspension above all streams where cross-stream yarding could not be avoided.

Sixty-one of the most difficult and critical landings were verified in the field. Field notes were developed to show earthwork requirements, guying requirements, anchoring possibilities, equipment layout, etc. Guyline analyses for the most critical guying situations were performed on LEI's computer.

Normal soil and water impact standards were met in both alternatives. This was done by avoiding road construction on sensitive sites where possible, avoiding yarding across streams and lakes, checking for full

-20-

LIVE SKYLINE LOAD ANALYSIS FOR PROFILE 739034-2

YARDER:

YARDER/CARRIAGE: MADILL 046
SPAR HEIGHT/TYPE: 90 ft /VERTICAL
YARDER WEIGHT: 0
COST/DATE 0 / 12.84
CARRIAGE WEIGHT: 1000 LB

	DIAM	LB/FT	S.W.L.	LENGTH
SKYLINE	1.375	3.50	64000	1900
MAINLINE	1.000	1.85	30000	2600
HAULBACK	.875	1.42	23100	5300
SLACKPULLING	.625	.72	12000	2415
GUYLINES(8)	1.375	3.50	55700	350
STRAWLINE	.4375			5500

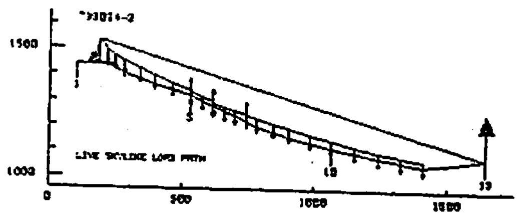
PARAMETERS:

HEADSPAR HT= 90 TAILSPAR HT= 0
HEADSPAR TERRAIN POINT = 1.8 TAILSPAR TERRAIN POINT = 13
LANDING CUT(-) OR FILL(+) = 0
INNER YARDING LIMIT= 2 OUTER YARDING LIMIT= 12
LOADED CARRIAGE CLEARANCE= 20
FULL SUSPENSION REQUIRES 55 FEET OF CLEARANCE

LIVE SKYLINE ANALYSIS FOR: 739034-2

TERR PT	FLYING PAYLOAD	DRAGGING PAYLOAD	MNLINE TENS	HLBACK TENS	CARRIAGE TO GROUND CLRC	SKYLINE LENGTH	MAX LOAD TO HDSPR	NO OF SKYLN LIFTS
2	0	257469	137102	N/REQ	20.0	1555	257469	0
3	0	87081	34567	N/REQ	20.0	1549	87081	0
4	0	40175	12503	N/REQ	20.0	1539	40175	0
5	0	24206	6703	N/REQ	20.0	1534	24206	0
6	0	24170	6455	N/REQ	20.0	1536	24170	1
7	0	25336	6500	N/REQ	20.0	1538	24170	2
8	0	27347	6683	N/REQ	20.0	1542	24170	3
9	0	26771	6077	N/REQ	20.0	1542	24170	4
10	0	25736	5268	N/REQ	20.0	1541	24170	3
11	0	27431	4705	N/REQ	20.0	1540	24170	3
12	0	32511	3998	N/REQ	20.0	1539	23416	3

RIGGING LENGTH REQUIRED FOR SKYLINE = 1706.2FT
MAINLINE LENGTH REQUIRED TO REACH T.P. 12.0 IS 1470.0 FT



HEMPHILL/THOMSON
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Figure 2--Sample skyline payload analysis output.

suspension over identified perennial streams, and checking for full or partial suspension over sensitive soils.

Critical to the success of a layout project such as this are the qualifications and experience of the field personnel. On this project, logging engineers with extensive experience in logging, construction, and layout performed the work, with technician help from graduate engineers. Specialist assistance was provided by an engineering geologist with extensive southeast Alaskan experience.

TRANSPORTATION LAYOUT

Three dump sites located on Sealaska Timber Corporation lands on the eastern side of the island were found to provide good egress for the middle Dall area. No feasible dump sites were found on the west coast, where a sufficient sheltered area was not available.

The transportation plan features a mainline running from north to south, linking the three dumps. Grades change along this route as it ascends and descends among the island ranges. Some grades are as steep as 18 percent, where no other means could be found to avoid unstable terrain. Therefore, haul costs will vary widely according to the direction of haul.

Main branches from this mainline were laid out to provide access to valley floor and lower slope locations. Midslope location options were found to be severely constrained by stability considerations and landing availability. Midslope benches often were not available in positions suitable for timber access. Ridgetop locations were used in a few cases where they were not above the timberline and where feasible grades could be found.

It proved possible to access most of the area in a manner consistent with cable logging. However, certain "hanging valleys" typical of glaciated terrain could not be economically accessed for cable logging and were planned instead for helicopter logging.

Transportation Analysis

An analysis of the transportation network was carried out, in order to determine the economic desirability of certain expensive road links within the mainline system connecting the three dump sites. Six links within the mainline route may be considered optional; that is, some of them could be eliminated without denying access to any of the timber. They are shown in figure 3. All other links in the road system are regarded as essential for access to landings, and they cannot be eliminated.

Within the route connecting Grace Harbor and Rose Inlet, two links are optional, as shown. Either of them, but not both, can be eliminated if desired.

To the north, within the route connecting Rose Inlet and Coco Harbor, four links are considered optional. Any one of them, but no more, may be eliminated.

The analysis was performed by summing the costs of mainline log hauling, mainline road maintenance, and construction costs for the optional links. Certain other costs, however, that would normally be considered in determining the optimal network could not be adequately predicted. These "unknown" costs were
- dumping and rafting costs,
- administration and scaling costs,
- road amortization and cost-sharing with other owners,
- the time or apportunity cost of capital.

These "unknowns" could not be predicted at this stage of planning because they would have been highly dependent on the cutting schedules ultimately adopted by the Forest Service and adjacent landowners, and on the outcome of negotiations between these parties. In view of this it was decided that a sensitivity analysis would be far more useful than a straight optimization. Had these costs been capable of reliable estimation, an optimization could have been performed, using one of the network optimization programs on LEI's computer.

Construction costs were projected by applying Forest Service cost experience figures to data collected during field layout of the links in question. Haul costs were projected by estimating round trip travel times from grade and alignment characteristics recorded in the field during route reconnaissance. Maintenance costs were estimated by applying current Forest Service experience figures.

The following conclusions were drawn from the sensitivity analysis:

1. Unless there are compelling reasons to do otherwise, timber from Node 9 north should egress via Coco Harbor; timber from south of Node 32 should egress via Grace Harbor; and timber sourced from Nodes 23 through 30 should egress via Rose Inlet. The remainder can be routed to either of the two closest dumps without a large economic forfeit.

2. Those links with the largest positive difference between construction and operating costs were the most likely to prove economic when all costs could finally be included. It was recommended that:
- in the south, link 31-32 should be built, but not link 30-31.
- in the north, all of the optional links are likely to prove profitable. Depending on the sale schedule adopted, link 9-12 may be of questionable value because of the opportunity cost not included.

It was recommended to the client that a transportation analysis be performed on the network after a timber sale schedule is adopted, to develop an optimal solution.

LOGGING SYSTEMS MIX

The percentage mix projected for the various logging systems was as follows.

System	Alternative: A	B
A-frame	1	1
Highlead (includes short-span skyline to 1000 feet)	24	22
Helicopter	7	9
Shotgun (gravity carriage return)	6	6
Longspan skyline (over 2000 feet yarding)	13	16
Multispan	4	5
Cold deck and swing	1	1
Slackline	44	40

The shotgun percentage planned is surprisingly low. This was because many settings that were partially suitable for a gravity-return carriage also included portions requiring a haulback and/or sideblocking capability. The terrain did not suit extensive layout for purely uphill logging.

There was a large percentage laid out for slackline. This was related to the difficulty of the terrain, which called for a mixture of uphill and downhill logging, spans that commonly exceeded the capabilities of highlead and related short span systems, and sideblocking to reach behind obstacles and into draws.

Most of the helicopter logging may be expected to be uneconomic, at domestic log prices. Not only is the climate inhibitory to this system, but helicopter logging was laid out only where cable systems could not reach. Such areas are commonly at higher elevations or in areas with tailhold problems - i.e., in the worst timber.

Similarly, much of the area laid out for longspan skylines will be found uneconomic. These systems, too, have a tendency to reach out to the more marginal timber types. Furthermore, their yarding costs are high because of the long skidding distances, and they are normally specified on the more difficult terrain, further inhibiting production.

The proportion of multispan laid out was also low. Multispan was not selected unless all feasible single span alternatives had first been exhausted, as multispan expertise is not widely available in Alaska. In the field, it was found that good trees for intermediate supports were often not available in the right locations.

There is a similar systems mix for both Alternatives. Because of the difficulty of the terrain, for many areas there was "only one way to get the wood". Greater differences in the systems mix are normally seen between alternatives of this nature on easier terrain, where more layout options exist.

CONCLUSIONS

On difficult terrain such as that on Dall Island, environmental protection to USDA Forest Service standards can be achieved through proper engineering and planning. Even on extensive areas, relatively intensive paper layout, with critical elements verified in the field, is necessary to ensure the integrity of a development plan without infringing on environmental standards.

Economic and operational success in such difficult conditions can be achieved only by having such a layout plan available as a basis for decisions such as determining which areas cannot be logged economically, an optimum schedule for area development, the selection of a logging equipment mix, and many others. Again, relatively intense paper planning and the field verification of the critical elements are essential, to ensure that the plan retains its integrity and practical usefulness to management as the area is developed.

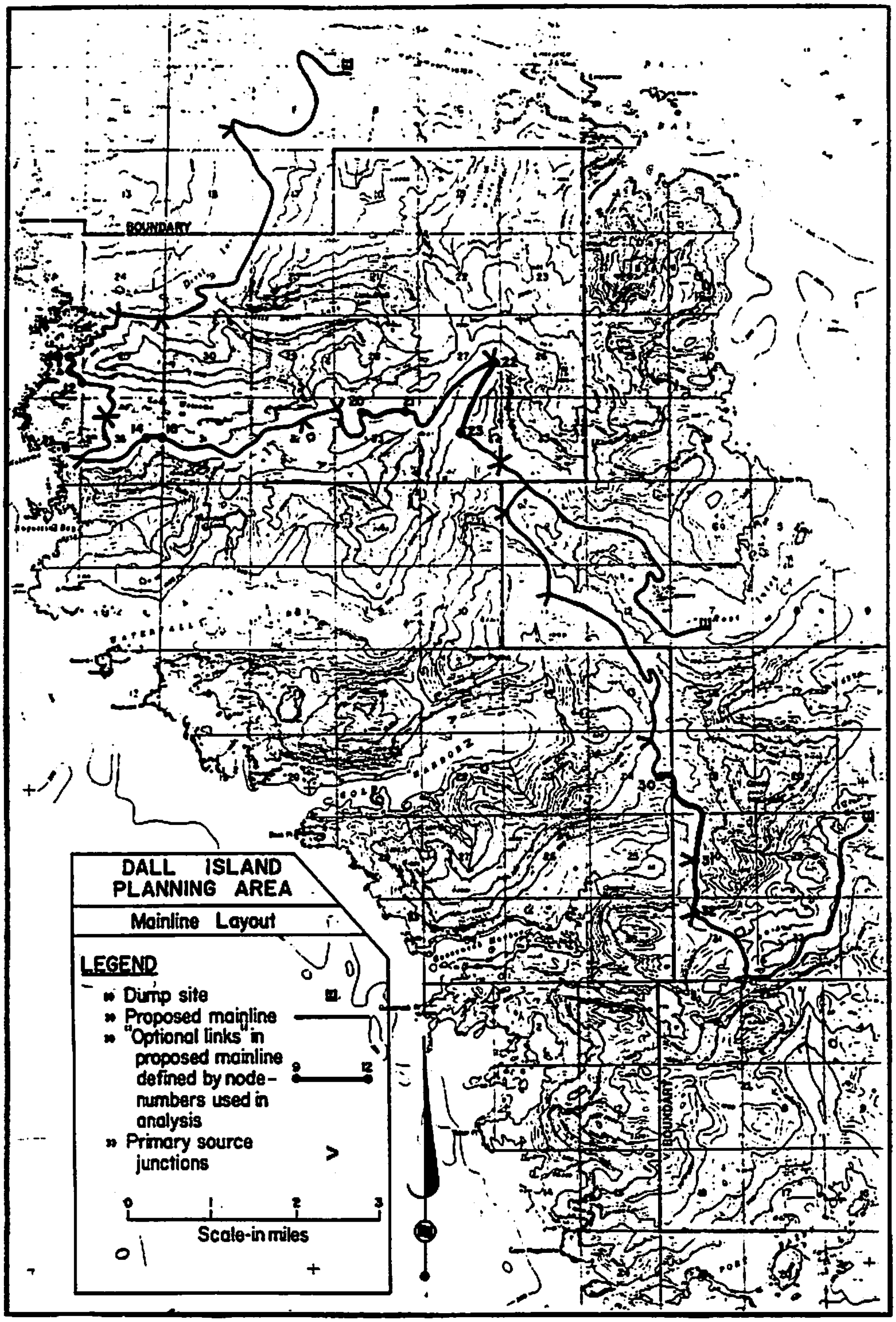

Figure 3--Project area, showing projected mainline.

Using Geographic Information Systems to Determine Operable Areas -- A Trafficability Approach[1]

Thomas W. Reisinger and Craig J. Davis[2]

Abstract: Detailed knowledge of terrain conditions is essential for operational planning of timber harvests if site disturbance resulting from the use of mechanized harvesting equipment is to be minimized. A terrain classification system utilizing a computerized geographic information system (GIS) with mapping capabilities is described. Ground strength, surface roughness, and slope criteria are combined to classify terrain in a forested area in Maine.

As harvesting systems become more mechanized, detailed knowledge of terrain conditions becomes essential for operational planning of timber harvests. Whenever larger and more powerful harvesting machines are employed, the risk of physical damage to the site increases correspondingly. To insure future site quality and stand productivity, today's harvest planners must not only evaluate the many diverse site-specific parameters such as topography, soils, climate, timber characteristics, and terrain features, but must also be able to relate them to machine performance before selecting the appropriate harvesting system. However, planning at this level of detail is often difficult and complex, particularly for large management areas.

Traditionally, forest engineers and other harvest planners have relied heavily upon their own personal experience to determine the most appropriate harvesting system to employ on any given site. This method may be satisfactory if the planner is well-acquainted with the harvest site. However, if the planner is not familiar with the site, this method may cause unnecessary site disturbance. Complicating the situation is the fact that even experienced planners may not be cognizant of all the limiting effects caused by interactions of site specific variables. Consequently, a more structured approach to terrain evaluation for harvest planning is needed.

The increased use of computer-based geographic information systems by forest industry offers a unique opportunity to improve harvest planning activities. With geographic information systems (GIS) and digital elevation models, the technology is available to develop a terrain classification scheme for determining trafficability ratings. A GIS system with mapping and database capabilities permits interactive retrieval of information for a variety of forest management activities. The advantage of such a system is the quick and efficient presentation of a wealth of data in a convenient manner -- graphically in map form. In addition, the database can be easily updated and selectively accessed to provide information on operational problems that exist in specific harvesting areas or to identify other areas which satisfy a given set of operating criteria.

This paper outlines the progress to date and the approach being used to develop a trafficability rating system utilizing a computer-based GIS with mapping and database capabilities. An example is presented that illustrates how the proposed terrain classification system can be used to produce descriptive and functional maps of a harvest area.

BACKGROUND

In 1984, the Department of Forestry and Natural Resources of Purdue University and Great Northern Paper Company (GNP) began a cooperative research project to investigate the feasibility of using a GIS for operational planning of harvest activities. The first phase of this study involves the development of a terrain classification scheme and its subsequent implementation on GNP's forest lands in Maine. GNP's primary interest is in developing planning procedures for identifying sites where mechanized harvesting systems can be operated productively and with minimal site disturbance.

Study Area

A 56,680 hectare (140,000 acre) study area in northern Maine was selected because of the diversity of topography and forest conditions and the existence of U.S.G.S. Digital Elevation Model (DEM) coverage. The area is in western Piscataquis county and includes all or portions of Seboomook, East Middelesex, T4R15, T4R14, T4R13, T3R15, T3R14, T3R13, and T2R13 townships. Over 95 percent of the study area is forested, with 55 percent of the total area classified as being balsam fir, red spruce, or spruce-fir stands; 21 percent being tolerant hardwood stands; and 9 percent being classified as water bodies, flowages, and bogs.

In general, the terrain ranges from level to steeply sloping areas. Elevations range from 989 meters (3244 ft.), in the southeastern portion of the area, to 293 meters (961 ft.), in the northeastern portion of the study area. The climate is typical of northern New England with long cold winters (mean min. January temperature 0-4^{o}F) and short summers with moderate temperatures (mean max. July temperature 74-78^{o}F). Annual rainfall averages 40 inches per year, with snowfall averaging 110-120 inches per year.

Geographical Information System

Great Northern Paper Company currently maintains a map-based information system for managing 2.1 million acres of company forest land. The database component of this system includes forest cover type, soil type, site class, inventory data, and information on past harvesting, silvicultural and protection activities. In addition, roads, major rivers and streams, lakes, wetlands, regulatory zones, and corporate and political boundaries are stored in graphical form. Each type of information is stored on separate thematic levels or layers within graphic design files.

The database and the graphic design files are maintained on a generalized interactive computer mapping system developed by Intergraph Corporation. GNP and Purdue have compatible Intergraph systems composed of a VAX minicomputer, a dual screen color graphics workstation, a digitizer, a color plotter, and Intergraph graphics (Interactive Graphics Design Software) and

[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

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database (Data Management and Retrieval System) software.

A feature of the Intergraph system is that graphical elements contained in the design files are linked to entries in the database. This linkage means that graphically defined areas may possess attributes that can be used for numerical calculations. This also permits the creation of reports based upon graphically specified areas. Previously stored graphical information can be displayed individually by level or combined to display multiple levels simultaneously. Another capability of the system is the ability to perform analytic overlay operations on the contents of two or more different layers to determine complex relationships.

TERRAIN CLASSIFICATION

Terrain classification systems, utilizing ground strength, surface roughness, and slope to determine trafficability ratings have been used in Europe (Haarlaa 1973; and Rowan 1977) and Canada (Mellgren 1980) to evaluate and classify harvest sites. The advantage of these systems is that the site is rated in terms of stable terrain parameters rather than classifying the site on a functional basis (i.e. the performance of a particular kind of harvesting machine). By concentrating on the site, rather than the machinery, the effects of technological advances in the equipment field are eliminated. Thus, a site has to be classified only once, not every time a new piece of harvesting equipment is developed.

Once a site has been classified, the harvest planner compares the terrain classification with the minimum or maximum capabilities of various machines. All equipment types that are unsuitable in terms of the trafficability rating are eliminated from further consideration.

While the trafficability approach has many advantages, two drawbacks to the method have been noted in previous applications. The first is that harvesting equipment must be rated in terms of trafficability parameters. Currently, there is no "standard" method for calculating rated footprint pressures for harvesting machines, and the ratings must be derived from manufacturer's specifications (Mellgren 1980). The second disadvantage of using trafficability ratings is the large amount of time spent in performing the classifications and then preparing maps based on the terrain ratings. A solution to this problem is the use of a computerized GIS that combines a database with a graphics display system to efficiently maintain and display data in map form.

Trafficability Criteria

Terrain classification has been used to determine trafficability indices in two primary areas: military mobility studies and timber harvesting operations (Mitchell 1973). Unfortunately for harvest planners, most of the literature and many of the more comprehensive classification schemes deal with planning military operations in terms of equipment mobility. These military applications usually consider 10 or more variables to determine a broad "go or no-go" trafficability rating. Since the objectives are usually very different, these military trafficability classification schemes are rarely applicable to harvest planning. Trafficability rating schemes proposed for harvest planning usually consider three variables: ground strength, surface roughness, and slope.

Ground Strength

Ground strength is a measure of the bearing capacity of the soil and is important when considering the type of harvesting equipment to be utilized, both from an environmental and a productivity perspective. Ideally, ground strength is determined from the engineering properties of the soil, as determined by a soil survey. However, due to the diversity of soils, variations in moisture content, and differences in vegetative root systems present, ground strength is difficult to measure accurately. The problem is further complicated by the fact that soil surveys may be unavailable in heavily forested areas and even if they are available, the sampling intensities used may not be adequate for detailed harvest planning purposes. When soils information is unavailable, ground strength may be assessed visually by the presence of indicator plants and forest cover in combination with soil texture and moisture.

Surface Roughness

Surface roughness is a measure of the height and spacing of obstacles that affect machine stability, and thus is an important factor in determining travel speed and productivity. Surface roughness is usually determined visually by making low intensity field surveys of the harvest site and recording the number and size of obstacles encountered. Based on the survey, a frequency distribution by obstacle size is constructed for determining the roughness class. Usually, only permanent obstacles such as rocks, boulders, depressions, rock outcrops, etc. are tallied in the survey. Isolated large boulders are not usually considered to be obstacles for logging equipment.

Slope

Slope is a major factor affecting travel speed and machine stability, and is usually strongly correlated to soil type. Slope is determined from either topographic maps or visually from field observations. In either case, the slope class is the dominate one in an area, and is usually measured between two points that are at least 25 meters apart (Mellgren 1980).

Proposed Trafficability System

The preliminary terrain classification scheme being developed for forest conditions in northern Maine is based on the Canadian system devised by Mellgren (1980). Consequently, similar site criteria and index-number notations are used.

Soil strength determinations for the study area are complicated by the lack of soil survey maps for much of northern Maine (Grisi and Butler 1984). For those areas that have been surveyed, ground strength will be based upon a composite of soil engineering properties and forest cover. For those areas not surveyed, ground strength will be estimated from existing information on vegetative patterns and landforms usually associated with particular soil types. Based on this information and the presence of indicator species, an area will be assigned a ground strength classification of 1 to 5, with 1 corresponding to very good and 5 being very poor. The criteria used to determine the classification is shown in figure 1. Blocks or area polygons representing ground strength classes will be developed and stored as a separate thematic layer in the graphic design file and descriptive soils information about each polygon will be entered into the database.

Ground Strength Rating Class

	1 V.Good	2 Good	3 Mod.	4 Poor		5 Very Poor	
Soil Moisture	Very Freely Drained	Freely Drained	Fresh	Moist	Wet	Very Wet	Very Wet
Soil Texture	Coarse Sands Gravel	Sandy Loams Mod. Coarse Sands	Fine Sands Sandy Silt and Clay Loam		Silt, Clay Silty & Sandy Clay Organic Soil < 2 ft.		Organic Soil >2 ft.
Forest Cover	Jack Pine W. Spruce Balsam Fir	Balsam Fir W. Spruce Aspen R. Spruce W. Birch W. Pine	Balsam Fir R. Spruce Aspen W. Spruce B. Spruce	Balsam Fir B. Spruce Poplar R. Spruce	B. Spruce Tamarack Eastern W. Cedar	B. Spruce Tamarack Willow	B. Spruce Tamarack
Indicator Species	Lichen Bearberry Grass Feather Moss	Herbs Feather Moss Grass	Herbs Feather Moss	Feather Moss Herbs	Alder Sphagnum Labrador Tea Kalmia	Sphagnum Labrador Tea Kalmia Alder	Leather Leaf Sphagnum Labrador Tea

Figure 1--Ground strength classes (modified from Mellgren 1980).

Surface roughness will be determined by field surveys that record the number and size of permanent obstacles in a 10 x 10 meter plot. Based upon the survey tallies, a surface roughness classification number from 1 to 5 will be assigned, with 1 representing very even ground and 5 indicating very rough ground. The criteria for this classification is shown in figure 2. Once all roughness classifications are completed for an area, this information will also be stored in the graphic design file as a thematic layer of polygons and corresponding surface roughness information will be included in the database.

Slope will be determined using U.S.G.S. 7.5-minute quadrangle Digital Elevation Model (DEM) data and Digital Terrain Modeling software supplied by Intergraph. The software will convert the gridded format of the DEM data into a triangulated network from which slope values can be computed. The slope calculation process results in a gridded data file of slope values, each of which is then classified according to the percent slope. As shown in figure 3, a slope classification is assigned in the range 1 to 5, with 1 representing level ground and 5 representing a very steep slope. The resultant slope class polygons are stored as another thematic layer in the design file/database.

Other features which limit machine operation should also be included in the classification scheme for future reference. Examples of these include: gullies, cliffs, rock ledges, power lines, surface pipelines, and reserved areas for wildlife and stream protection.

Surface Roughness Class

Obstacle Height/Depth	1 Very Even	2 Slightly Uneven	3 Uneven	4 Rough	5 Very Rough
10-30 cm	0-4*	>4	>4	>4	>4
30-50 cm	0	1-4	5-40	5-40	>40
50-70 cm	0	0	1-4	1-4	>4
70-90 cm	0	0	0	1-4	>4
>90 cm	0	0	0	0	>1

*Number of obstacles per 100 sq. m.

Figure 2--Surface roughness classes (after Mellgren 1980).

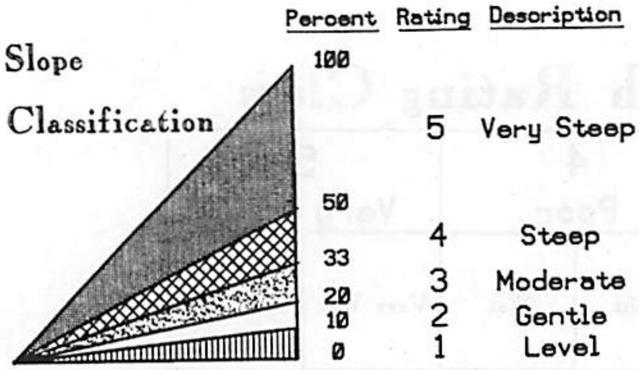

Figure 3--Slope classes (after Mellgren 1980).

Each of the above processes results in a new thematic map overlay in polygon or line form and new entries to the database. Following the data entry step, the polygon layers will be intersected using a scan-line cartographic modeling technique described by Boss (1985). The scan-line approach employs boolean AND, OR, and NOT operators to merge two (or more) layers of polygons to create a new thematic layer. In this case, ground strength, surface roughness, and slope layers will be merged and plotted together as a color fill map representing the terrain classifications for the tract being evaluated. Figure 4 illustrates the scan-line merge process which is used to produce the composite terrain classification layer in the GIS.

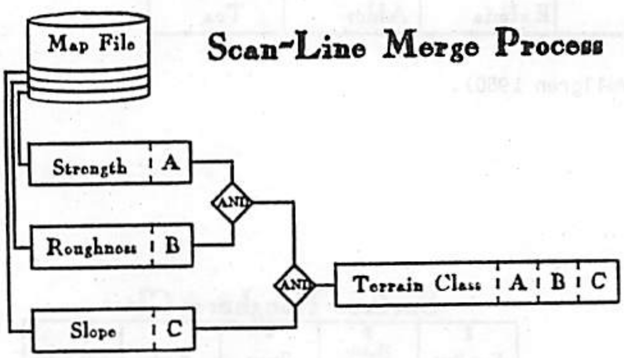

Figure 4--Scan-line merge process.

EXAMPLE TRAFFICABILITY EVALUATION

A 6,670 hectare (16,480 acre) tract located in the northwestern portion of the study area (Seboomook Township) was selected to demonstrate how the terrain classification system will be used for harvest planning and system selection.

Two types of planning maps can be generated rapidly with the GIS terrain classification system -- descriptive and functional maps. A descriptive map classifies the terrain in broad terms and provides information for planning system selection and road construction. The descriptive map is the basis for the functional map which depicts areas which are negotiable by particular machines types or areas to be harvested by specific harvesting systems. At the operations level, the planning process also could define working areas for individual machines, select landing and skid trail locations, and identify areas where terrain conditions warrant specialized harvesting techniques.

Although trafficability limits for operating specific types of harvesting equipment are being formulated in cooperation with Great Northern Paper, figure 5 represents the type of descriptive terrain map (for Seboomook Township) that can be produced with this system. The index-number notation is used to describe the terrain composite in terms of ground strength, surface roughness, and slope. The shaded areas (fig. 5) indicate wet areas where ground strength will limit the use of most harvesting machines. Figure 6 is an overlay of figure 5 and depicts a functional map for three different harvesting systems currently used by GNP. These systems include:

1. <u>Fell-Forward</u> with Koehring KFF and K2FF feller-forwarders to bring material to roadside.

2. <u>Fell-Bunch/Grapple Skid</u> with Drott 40 feller-bunchers and JD640 grapple skidder.

3. <u>Manual Fell/Cable Skid</u> with chainsaws and JD640 cable skidder.

Again the shading (fig. 6) indicates restricted areas having trafficability conditions unsuitable for use of these systems.

FUTURE APPLICATIONS

Terrain is an important factor affecting machine selection, but other factors may be equally important to harvest planners. Tree size/volume, type of cut, salvage operations, product specifications, equipment availability, seasonal restrictions limiting harvesting, and mill wood requirements may be overriding factors for a given company. To account for these other factors, the terrain classification scheme described above will become one part of a larger decision support system (DSS) for operational planning of timber harvests. It is envisioned that the heart of the DSS (fig. 7) will consist of a library of classical optimization techniques for scheduling harvesting operations, allocating equipment, and estimating harvest/transport costs. The DSS will use the graphic display capabilities of the GIS to act as an interface between the harvest planner, the GIS database, and the library of optimization techniques.

SUMMARY

Planning any new harvesting operation requires basic information about the terrain that will be encountered. Additionally, there is a need to classify and store information about the operating characteristics of the terrain to assist the forest engineer in planning future harvest activities. Computer-based GIS systems with mapping/database capabilities can substantially improve the development and evaluation of the harvest planning process. The speed and convenience of such systems should result in better timber harvest plans.

There is no reason to expect that the number of variables that must be considered in planning harvesting operations will decrease in the future. In all likelihood, the planning process will become more complicated as public concern over the environmental impact of harvesting practices intensifies and results in the passage of more restrictive legislation. Since the long term costs associated with poor planning are high and far exceed the immediate financial impacts of

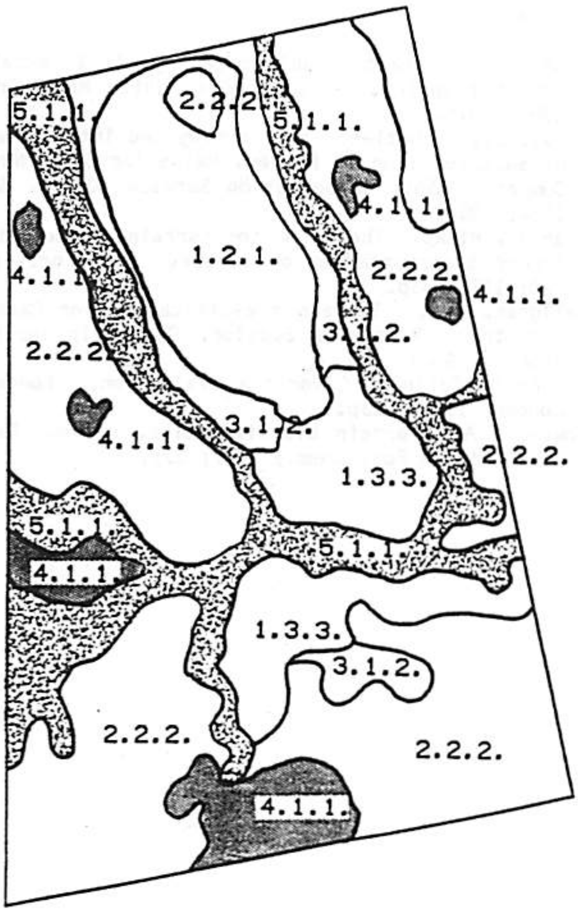

Figure 5--Descriptive map with index-number terrain classification codes.

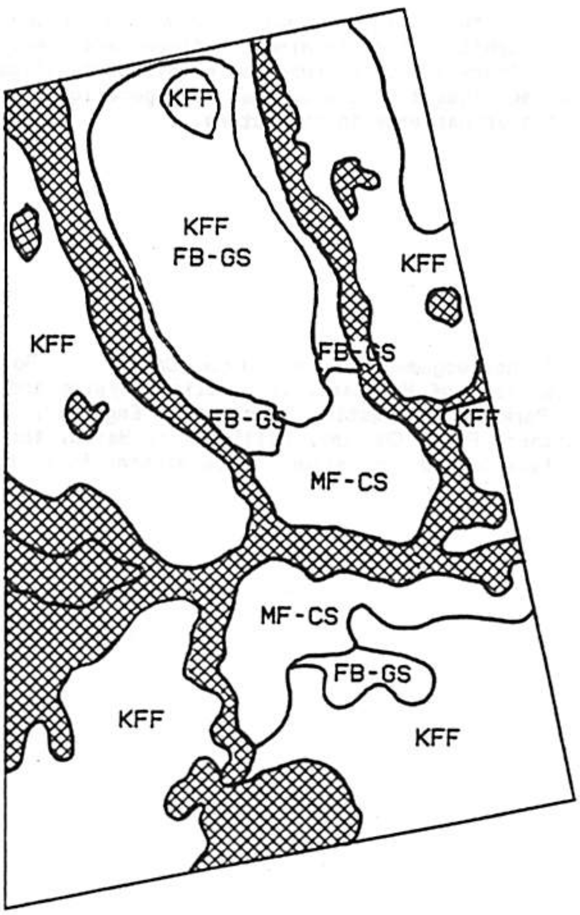

Figure 6--Functional map for operational planning for three harvesting systems: Koehring feller-forwarder (KFF), feller buncher/grapple skidder (FB-GS), and manual fell/cable skidder (MF-CS).

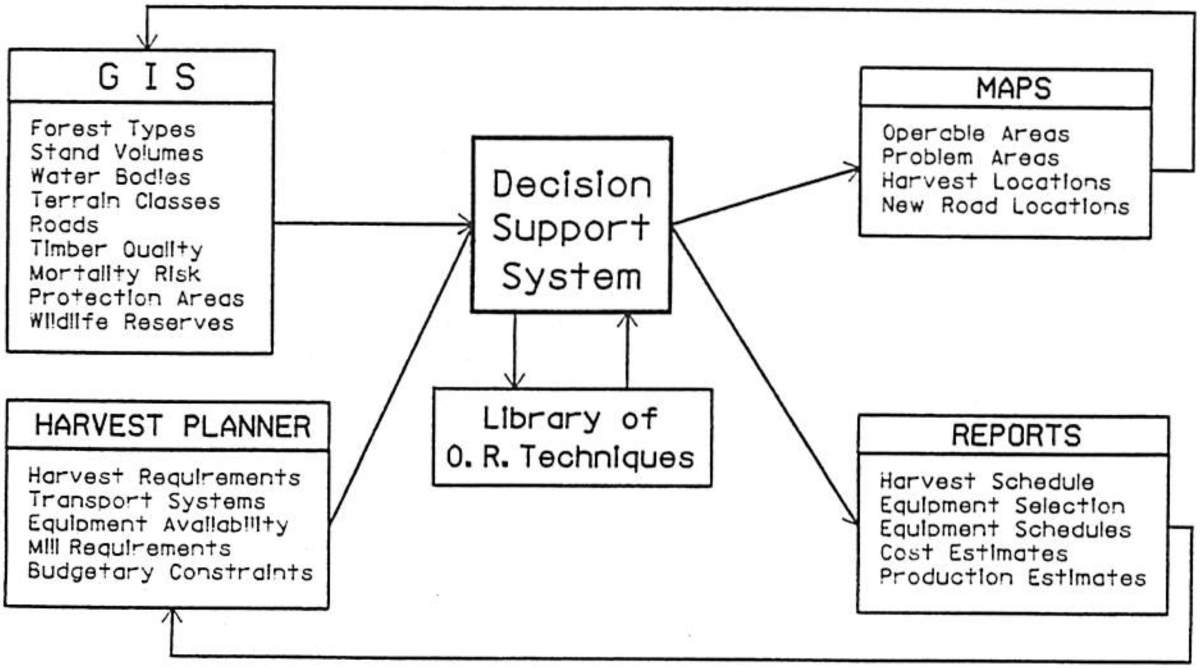

Figure 7--Decision support system for harvest planning.

choosing the wrong combination of harvesting machines, more sophisticated planning techniques are needed. The preliminary approach proposed in this study illustrates one technique that can be used for operational planning of timber harvests in the future.

Acknowledgements: We thank Daniel E. Boss, Supervisor of Map-Based Informations System and Glenn A. Perkins, Harvesting Development Engineer, Great Northern Paper Company, Millinocket, Maine, for their assistance and suggestions in developing this study.

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TIMBER VOLUME RELATIVE TO SLOPE[1]

Ross A. Phillips[2] and Douglass Powell[3]

Abstract: This work was to investigate a procedure for reporting effects of slope on available timber. Data were taken from Oxford and Franklin counties in Maine, the most rugged terrain on which data were available; and slope and stand data were compared on a SAS system. Results showed no change in timber size or volume with respect to slope for the limited area. Approximately 86 percent of this area was less than 25 percent slope. Further analysis needs to be done as data become available on other Appalachian areas. Steep forest land may be of little consequence if the total acreage is simlar to the Maine sample.

Timber and crop production on steep slopes has concerned landowners for many years. Most landowners prefer relatively level land where greater land use choices may be had, such as: raising grain, fruits, forage, or timber. Steeply sloped land does not lend itself to using labor-saving machinery, which has been the hallmark of American industrial development. As a result, sloping land is in less demand for food-crop production and more available for forest use.

In forest operations, the development of forest harvesting machinery has been directed toward more efficient and labor-saving applications as labor costs have increased and skilled woodsmen have become hard to find. The high-production machinery works best on reasonably level land (under 10-percent slope). As land slope increases, production and efficiency drops.

HARVESTING FOR PROFIT

The market value of the lumber produced governs the price that sawmills can pay for sawlogs. The purchaser therefore, faced with a set value for his logs, seeks to minimize his costs of both harvesting and payment for the standing timber (stumpage) in order to maximize his profits. The result is that, with higher costs for logging the steep slopes, he cannot pay the landowner as much for the stumpage on these slopes.

Eastern timber grows on land that generally will not support more profitable legitimate crops. Early timber harvesters cut the best timber in the easiest places first. As demand grew, timber on less favorable slopes became marketable and it was cut. In past years when an abundant supply of timber existed, limits of merchantability were set by factors of timber quality or difficulties in access. Recent development of total biomass production for energy has stimulated interest in harvesting all areas.

The functions of harvesting involve felling a tree, removing unwanted portions, cutting the bole into desired lengths, and transporting it to a road for hauling to a mill. Machinery has been developed to perform these tasks individually or in combinations for the wide variety of conditions and applications which have been encountered in the forest. Terrain, slope, stand density, and distribution of size classes within the stand influence the selection of suitable equipment and the method of operation. The interaction of these factors thus became of major importance when planning a timber harvesting operation. Big timber is heavy and may require large machines. Use of large machines to harvest small trees may not be efficient unless these trees are packaged in some form or handled in a bundle. Small timber may be harvested efficiently with relatively light equipment, particularly on small tracts, as the capital investment costs usually are lower. One set of equipment rarely performs efficiently on both large and small trees.

Current capital costs for equipment and high interest rates preclude loggers from maintaining a stable of equipment not in constant use. Thus harvesters will seek wood to cut which suits the equipment they own. Equipment development by manufacturers in recent years has featured higher production which usually means higher capital costs and greater dependency on dry, level land to achieve maximum production (Northern Logger 1981).

POTENTIAL EQUIPMENT

Gustafson (1983) indicates that with high equipment development costs, scarce risk capital, and keen competition, manufacturers are very reluctant to make equipment development investments. Mechanization of forestry is rapidly becoming a reality on moderate terrain, but not so on steep and difficult terrain. The equipment market for diffcult terrain is very difficult to quantify due to limited information on potential markets. The next big challenge is to mechanize operations on the semi-steep slopes (15-35 percent). Manufacturers had to know how much and what kind of forests occupy these slopes? Until the equipment manufacturers know the answers, it is not likely that they will move aggressively to provide the essential machines.

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Potential development would depend on the probable sales of equipment for timber in any given category over which the equipment would work. The manufacturer certainly would expect to sell enough equipment to make development profitable. Certain categories may contain such a small amount of timber that the most economical handling of the crop would be to follow the example of the first Appalachian loggers and retain it for posterity.

TERRAIN

Three broad land classifications in the Eastern United States (all States completely shown in Fig. 1) contain significant areas of steep terrain: mountainous regions, ridge and valley regions, and plateau regions. The plateau regions are not flat, as might be commonly assumed, but deeply dissected and eroded. The steep terrain area, described by Austin (1965), is shown by the hatched area in figure 1. Of the total area of 126 million acres in the Eastern United States, 74 million acres are mountainous. Agricultural uses generally are concentrated on the more level areas; forest land is usually on the steeper slopes.

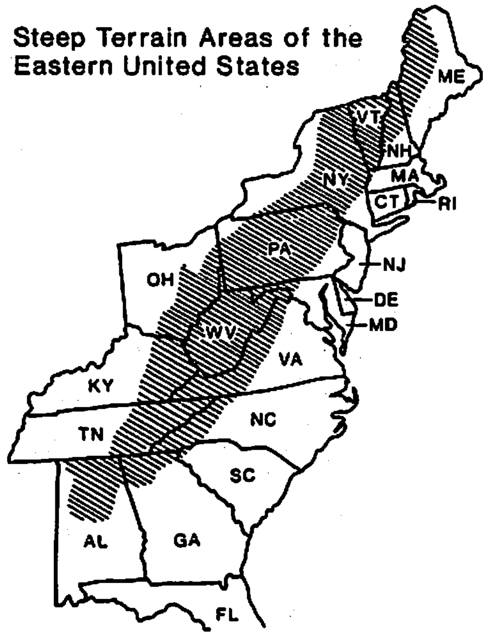

FIGURE 1

The percentage of the land use and timber volume by slope class is not available yet for all States. A study of the mountainous and escarpment counties of North Carolina, for example, indicated the relative ratios of growth to removal by slope classes as shown in table 1 (Deal 1980). The statewide average of growth-removal ratio is 2.64 to 1. As can be seen, a strong trend is indicated that timber on the level or lower slopes is overcut. Additionally, since a large portion of eastern commercial forest lands are owned by private non-industrial owners (i.e., 86 percent in New York State), a greater proportion of the future wood supply may come from steep terrain (Peters 1982) on the smaller, private woodland tracts.

DATA

The Forest Inventory and Analysis Work Unit of the Forest Service's Northeastern Forest Experiment Station conducted a resurvey of the forest resources of Maine in 1982 (Powell and Dickson 1984). Sample plots were selected to represent the entire area of the State. Bickford and others (1963) describe the sampling techniques used.

For this study, we used data from the western Maine geographical sampling unit. This unit is composed of Franklin and Oxford Counties and contains approximately 2.2 million acres of timberland. This area is a portion of the rugged terrain shown in figure 1, and contains the area in Maine with the greatest topographic relief.

The data were collected on 212 sample plots that were randomly located on timberland in these two counties. Each plot consisted of up to five points that were evenly distributed over an acre of land. At each point trees were selected for the sample, and a variety of measurements and observations, including diameter at breast height (dbh), were recorded for each tree. Gross weight was calculated for each tree. Slope percents, taken at each point, were measured in the same direction as the aspect for the point and were taken over a span of at least 100 feet.

Table 1.--North Carolina Mountain and Escarpment Counties 1968-1973 (Deal 1980)

Slope Percent	Volume MM ft^3	Volume Percent	Area M ac.	Area Percent	Growth: Removal
1-9	612	7.5	363	8.7	0.61
10-19	1,069	13.1	519	12.5	1.96
20-39	2,089	25.7	1,113	26.7	3.20
40-69	4,365	53.7	2,171	52.1	4.14
All classes	8,135	100.0	4,166	100.0	2.64

ANALYSIS AND DISCUSSION

Slope is the most obvious factor relating to engineering and timber harvesting. The next feature to consider is quantity, which greatly influences any material handling project. The first analysis was made using gross weight per acre broken down into 5-percent intervals for slope. Trees less than 5 inches dbh were removed from the samples to give more realistic averages of harvestable material. Each point on the sample plots was considered an observation. When average weights per acre are compared over these slope classes, there was a lot of variation (Fig. 2). The highest averages occurred in the steepest slope classes, but there were few observations in those classes (Table 2). No significant differences occurred between any of the slope classes.

Biomass per acre shows no trend over slope class in Franklin and Oxford Counties.

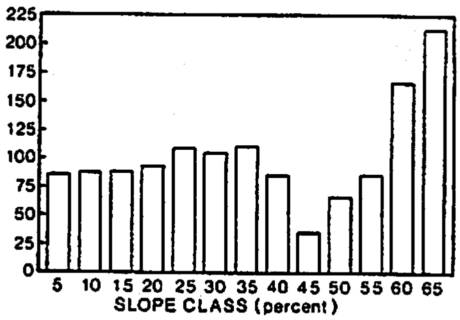

FIGURE 2

Table 2.--Gross weight in tons per acre of trees 5 inches dbh and larger by expanded slope class, Franklin and Oxford Counties, Maine, 1982

Slope Class Percent	Average Gross Weight	Standard Deviation	Number of points	Percent of points
0-5	86.58	58.83	313	34.0
6-10	87.95	51.65	155	16.8
11-15	88.69	52.95	140	15.2
16-20	93.00	51.76	131	14.2
21-25	109.57	51.10	56	6.1
26-30	105.49	59.20	48	5.2
31-35	110.96	56.38	33	3.6
36-40	85.30	56.89	27	2.9
41-45	34.76	--	1	0.1
46-50	66.69	33.30	11	1.2
51-55	86.07	44.75	3	0.4
56-60	166.47	63.05	2	0.2
61+	214.30	--	1	0.1

Garner (1980) suggests that a system with more than five classes becomes too complicated for practical use. We developed abbreviated slope classes of 0 to 15 percent, 16 to 25 percent, 26 to 35 percent, 36 to 50 percent and 51 percent and over. The first breaking point of 15 percent is selected because most existing ground harvesting equipment such as wheeled skidders, crawlers, and forwarders operate on slopes up to 15 percent with little or no need of road construction due to slope. The slope classes of 16 to 35 percent can be harvested with this same type of ground equipment with reasonable road-building costs. Ten percent increments within this range are used since this range is anticipated to be critical for analysis of harvesting costs and equipment development. Above 35 percent slopes, the cost of roadbuilding increases rapidly, and most operators consider off-road operation on these slopes as unduly hazardous. This is often considered to be most economical for cable operations. Table 3 shows weight-slope relationships using these slope classes. While there does appear to be a trend toward more weight (and thus timber volume) per acre with increasing steepness, no statistically significant relationship can be demonstrated from this sample.

Table 3.--Gross weight in tons per acre of trees 5 inches dbh and larger by abbreviated slope class, Franklin and Oxford Counties, Maine, 1982

Slope Class Percent	Average Gross Weight	Standard Deviation	Number of points	Percent of points
0-15	87.42	55.66	608	66.0
16-25	97.96	51.98	187	20.3
26-35	107.72	57.77	81	8.8
36-50	78.75	51.28	39	4.2
51+	134.24	68.45	6	0.7

We also analyzed the average diameter of trees 5 inches dbh and larger by these abbreviated slope classes. Each tree (rather than each point) was considered an observation for this purpose. The results, shown in table 4, again show no significant differences across slope classes for these two counties. One might expect in more mountainous terrain that older trees would tend to be concentrated on the more inaccessible sites with steeper slopes. Thus the average diameters might be greater in the higher slope classes. On the other hand, growing conditions are probably more favorable on gentler terrain and larger trees may be more prevalent in flatter slope classes. More research is required to resolve this question, which has obvious implications for economical timber harvesting.

If one assumes that the sample points are uniformly distributed across all slope classes, then the proportion of points in a given slope class provides an estimate of the proportion of area in that slope class. The last column of tables 2 and 3 provide the percentage of points in the expanded and abbreviated slope classes, respectively. A majority of the points are on slopes of 10 percent or less, and over 90 percent of the points are on slopes of 30 percent or less.

Such data indicate a very mild "rugged" terrain. The slope class distribution of the analysed area in Maine differs considerably from that of the Monongahela National Forest in West Virginia (Fig. 3) and the Mountain and Escarpment Counties of North Carolina (Table 1.)

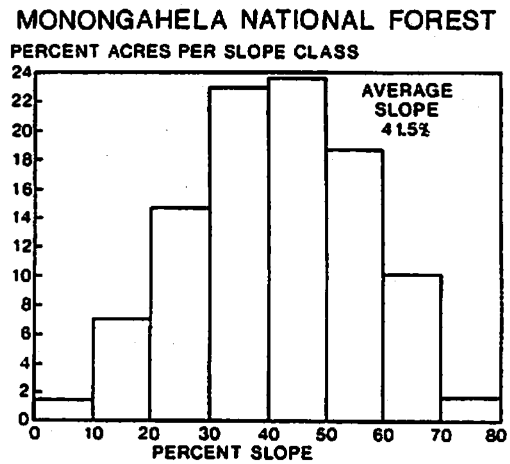

FIGURE 3

Table 4.--Average diameter in inches of trees 5.0-inches dbh and larger by abbreviated slope class, Franklin and Oxford Counties, Maine, 1982

Slope Class Percent	Average Diameter	Standard Deviation	Number of trees	Percent of trees
0-15	8.95	3.66	4,610	65.1
16-25	9.41	3.89	1,426	20.1
26-35	9.21	3.81	666	9.4
36-50	8.22	2.95	290	4.1
51+	8.46	3.55	89	1.3

The results of our analyses can be reported best using simple tables and charts. Elaborate charts such as Hedin (1978) used for reporting timber stands in British Columbia are of little value in these relatively uniform stands as indicated in figure 4.

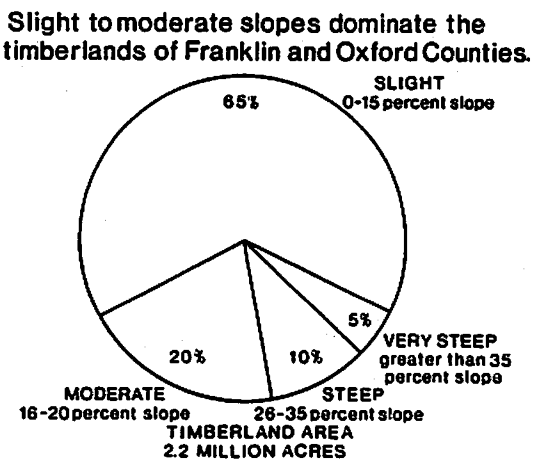

FIGURE 4

CONCLUSIONS

Data for Franklin and Oxford Counties in Maine showed there were no differences in above ground whole-tree biomass with respect to slope for the range of slopes encountered. Similar analysis of another area could give different results. Simple tables and charts appear to be the best means to report stand characteristics with respect to slope for engineering purposes.

Data show that slope presents little, if any, problem for harvesting timber in western Maine. Ground equipment, such as skidders, may need some skid-road construction on steep or very steep terrain (Fig. 4). This would be steep land where less than 15 percent of the points sampled were located. These slopes would present the most difficulties and challenges for mechanical timber harvesting.

Additional data have been collected in the Northeastern area. Further information on timber volume-slope relations will be available as soon as these additional data are analyzed. Other areas may indicate considerably different results.

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Modeling Wood Flow Under Salvage Conditions[1]

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ABSTRACT

The boreal forest of eastern North America periodically experiences severe outbreaks of the spruce budworm. The damage caused by this insect potentially necessitates the salvage of large quantities of the spruce-fir timber resources. The objectives of the salvage may be two-fold: (1) to provide a viable wood supply before wood deterioration destroys the fiber content and/or quality and (2) to alleviate dead or dying timber that will eventually constitute a serious on-site fire danger.

As an adjunct to an inventory system, designed to monitor spruce budworm infestation severity, a computerized mapping and information storage/retrieval system was developed. Originally, the system tabulated sample data and produced lineprinter maps displaying calculated spruce budworm hazard ratings capable of being correlated on a priority basis to potential harvest sites.

During the development of this earlier program, it was realized that incorporating information about transportation networks, wood markets, and wood volumes could be very useful in planning salvage strategies. Expansion of the program led to the development of an automated technique for the selection of timber harvesting sites and determination of schedules for cost-minimized wood flow to associated market locations. Expanding further, an interactive graphics routine, that assists in the optimization of the harvest area spatial layout of all-weather logging roads and associated decentralized processing locations (landings), was integrated as an extension to the overall system.

A road network classification module - incorporating road design specifications and land form features - has been recently added to the system. This module provides additional report request capabilities including basic road mapping, road identification, road and materials specifications, maximum loads for specified travel routes, maintenance planning, route restrictions, and travel time and distance estimates. These features are complimentary to the data-base and thereby enhance the planning of road networks and allow accurate forecasting of harvest/transportation costs.

INTRODUCTION

The spruces (Picea spp.) and balsam fir (Abies balsamea L.) are important components of northern New England's forest ecosystem. In Maine, spruce-fir forests cover some 3.2 million hectares or 47 percent of the State's forestland (Figure 1). The economic importance of Maine's spruce-fir resource is indicated by it's annual harvest of more than 2.2 million cords (solid wood content of approximately 4.8 million cubic meters) of pulpwood and 600 million board feet (2.7 million cubic meters) of sawtimber (Field 1980). Current data indicates that between 1975 and 1980, spruce and fir mortality amounted to nearly twice the harvest of these species (Schiltz et al. 1983). Thus, the current spruce budworm (Choristoneura fumiferana Clem.) epidemic potentially necessitates the salvage of large quantities of the spruce-fir timber resource.

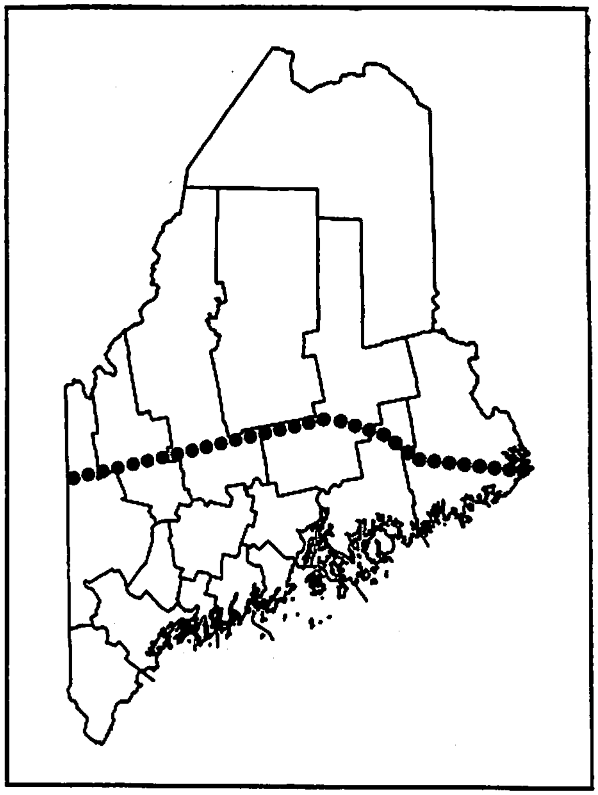

Figure 1--Map of the State of Maine showing spruce-fir protection district in upper portion.

PROGRAM INITIATION

An inventory system has been established to monitor spruce budworm infestation severity. To facilitate handling of the inventory data, a computer program was developed to tabulate and display information on budworm levels and stand conditions. The program produces lineprinter maps showing the distribution of budworm hazard ratings throughout the State or any portion of it. The lineprinter maps are based on grid coordinates which divide the State into rectangular units of approximately 240 hectares. These rectangular units are one minute by one minute subdivisions of U.S. Geological Survey 15-minute quadrangle maps and are referenced by State fire control division designations. Although survey information is lacking for smaller subdivisions, the mapping routine will produce maps down to ten acres. Each map character - a dot, letter, number, or other symbol - represents the center of one rectangular unit or cell (Figure 2). In addition to indicating high population levels, budworm hazard ratings are

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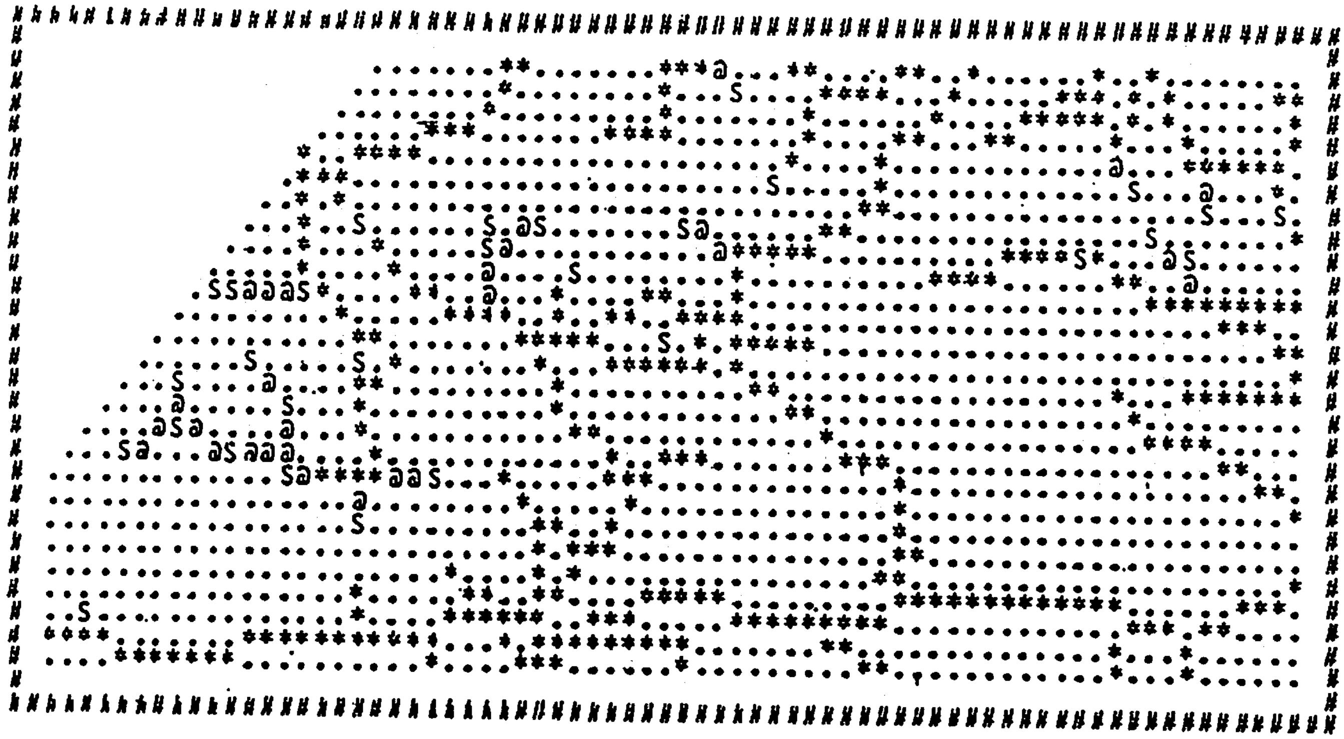


Figure 2--Lineprinter map showing grid layout, with existing roads (*), new road locations (@), and salvage sites (S).

used to determine areas potentially in need of timber salvage operations.

SYSTEM EXPANSION

During the development of the tabulation and mapping program, routines were included that allowed the construction of an automated technique for selection of timber salvage sites, transportation network routing, identification of markets, and the optimum cost allocation of wood volumes to specified destinations. The system's construction allows numerous overlays of data to be associated with each identifiable data-point, based on the grid layout. A data-point can contain overlays of information on existing roads, infestation severity, wood volumes, and market locations. Information storage/retrieval flexibility allowed the development of intricate data manipulation routines. These routines include the simulated creation of new roads to access timber salvage sites, a transportation routing technique, and the "classical" linear programming transportation model.

SYSTEM METHODOLOGY AND EXECUTION

Specification of boundary cells and transportation network segments comprising the selected base area is required for initiating progam execution. Additionally, the potential salvage sites, as identified by pre-selected criteria (eg. infestation severity ratings), require associated timber volume input.

In the second execution phase, routines manipulate the selected data-base connecting all potential source locations (salvage sites) to the existing transportation network. From each selected source location not adjacent to an existing road, a new road location must be computed and connected to the network. In order to allow newly constructed roads to be shared by multiple timber source locations while attempting to minimize new road construction, two passes are made over the source location data. The first pass calculates the shortest distance to an existing road for each source, and the source locations are sorted by these distances (shortest to longest).

During the second pass the roads are hypothetically constructed by the following procedure. Beginning at the top of the sorted list resulting from the first pass, each source location (k) is processed in a similar manner: for a given source location k_i (where locations k to k_{i-1} have already been processed), the shortest distance to an existing road network (existing roads and roads hypothetically constructed up to and including k_{i-1}) is determined and the road is "built". When K_{i+1} is processed, it has available to it all existing roads as well as all roads built up to and including the road built during the processing to source location k_i.

Once all source locations are connected to the road network, a shortest path network analysis technique calculates the minimum transportation cost per unit volume from each source to each destination. This process begins at a destination or market location and proceeds outward along the transportation network. The product of the cost per unit distance for each road class and the linear distance between grid cell centers is sequentially summed to provide transportation costs for each source/destination pair (Figure 3). The process continues until all source locations are "costed" or all elements of the transportation network connected to the destination have been processed (Phillips, Corcoran and Brann 1985).

Lastly, the calculated costs, salvage site volumes, and mill (destination) requirements are utilized in the linear programming transportation model. The result is a list of salvage sites allocating their associated timber volumes to specified market locations (Table 1). The total transportation cost is

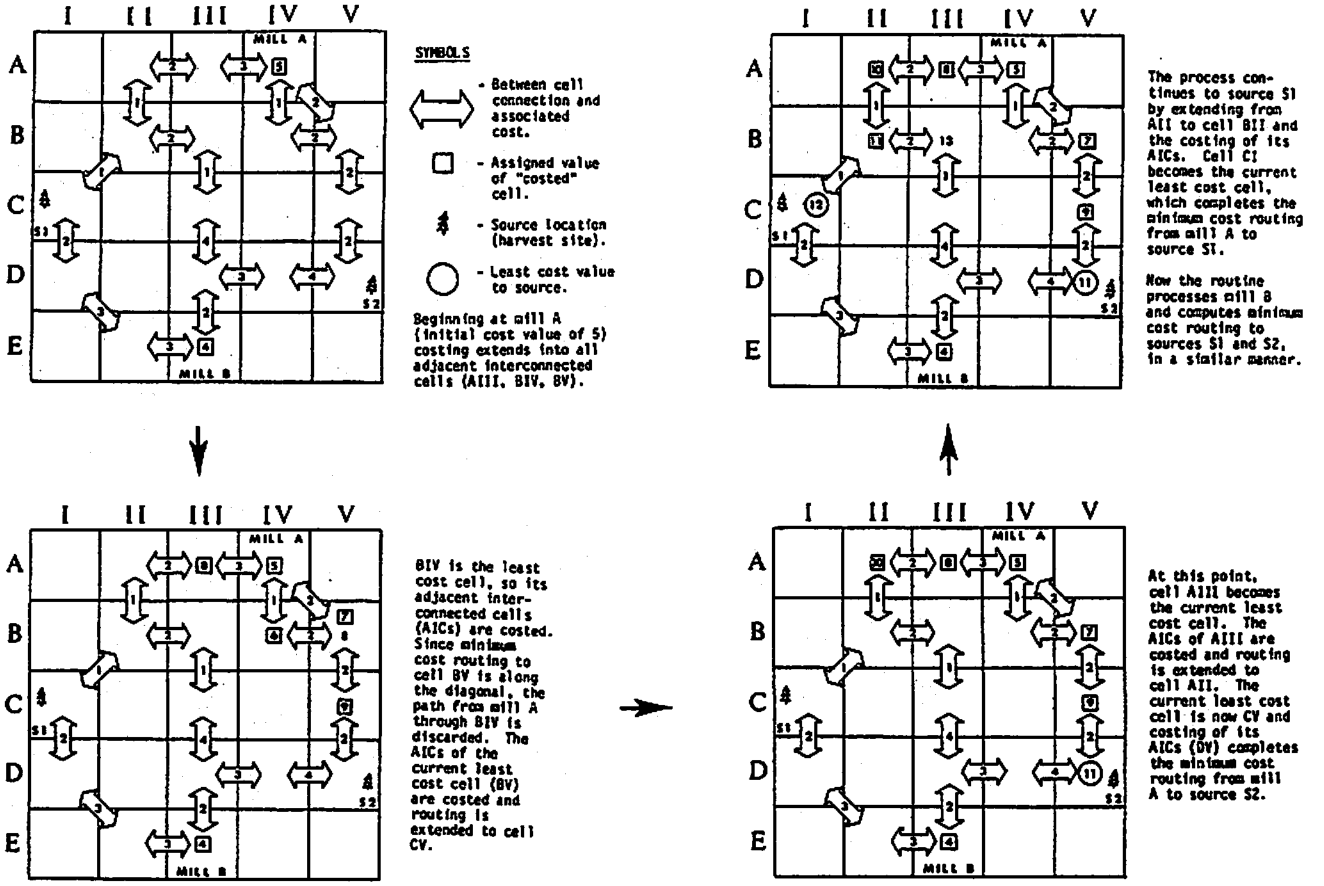


Figure 3--A simplified view of the shortest path network analyses technique.

the minimum cost obtainable, while still satisfying the constraints of supply and demand.

Table 1--Optimal allocation of salvaged timber presented as partial listing.

DESTINATION	SOURCE	QUANTITY		UNIT COST	TOTAL COST	
1: 021610						
	29: U19E21	510		56.67	28900.93	
	35: C20415	970		46.09	44707.87	
	34: C204C8	630		50.77	31985.46	
	8: C19614	1390		47.19	65593.13	
	TOTAL		3500			171187.31
2: E19F23						
	5: C18806	840		60.96	54258.50	
	40: D16204	920		90.05	[illegible]	
	41: C16913	130		[illegible]	[illegible]	
	10: C14325	510		[illegible]	[illegible]	
	18: C12507	500		[illegible]	[illegible]	
	49: B19405	970		[illegible]	[illegible]	
	47: B19719	560		[illegible]	69640.38	
	TOTAL		[illegible]			416704.81
3: C21015						
	25: B154[illegible]	[illegible]		30.31	20608.92	
	[illegible]	[illegible]		32.19	13280.11	
	[illegible]	750		39.11	30894.69	
	[illegible]	1020		37.35	38094.16	
	[illegible]	960		41.94	40266.20	
	B17213	970		41.99	40728.35	
	2: D17124	320		41.56	13315.43	
	TOTAL		3200			199247.68
TOTAL UTILIZED			35040			1964855.00
SURPLUS						
	10: B18609	740		0.00	0.00	
	3: B18118	990		0.00	0.00	
	20: A19415	1050		0.00	0.00	
	23: A19802	910		0.00	0.00	
	21: A19503	960		0.00	0.00	
	46: D16204	220		0.00	0.00	
	43: C16819	320		0.00	0.00	
	44: D14206	840		0.00	0.00	
	40: A19521	920		0.00	0.00	
	16: A19922	1230		0.00	0.00	
	TOTAL		8430			0.00
GRAND TOTAL			43470			1964855.00

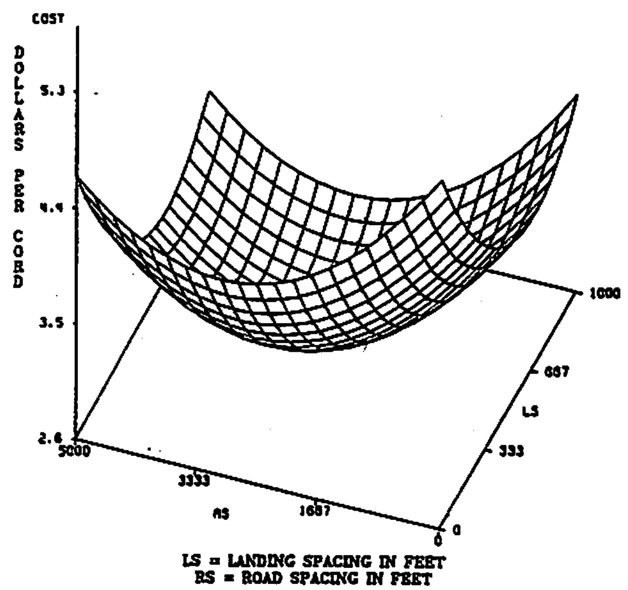


Figure 4--Relationship of cost on a per unit basis to road and landing spacing.

HARVEST SITE PLANNING

A modular component of the system deals with the layout of roads and landings at the salvage site. When salvaged timber is skidded to a roadside landing and roads are laid out - roughly parallel and equally spaced - optimum road spacing is a function of road construction cost, variable skidding cost and landing development cost, if applicable (Figure 4). Standard computational factors include such notation averages as machine speed and load size, operating area designation, timber volume, travel patterns and distances plus costs of road construction, of landing construction, and of relevant machine usage. When manipulated mathematically, they produce as a defined cost-optimum, the spacing between parallel roads and between the systematically located landings. Solution of the model involving multiple unknowns required a heuristically iterative procedure. A program was developed to determine the ideal spacing arrangements and their effect upon costs (Ashley et al. 1973).

Once salvage sites have been selected, an interactive computer graphics routine provides assistance in optimizing the spatial layout of logging roads and landing locations over the harvest area (Corcoran and Bryer 1982). The routine allows the operator to input data values, within pre-determined limits, and the program calculates and displays the optimum road and landing spacing and associated costs. In addition to tabular output, the routine allows the production of grids that can be used as overlays on aerial photographs or maps (developed by computer displays) in the initial stages of harvest site planning. Furthermore, unusual ramifications of road/landing layout patterns have been described by Bryer (1983).

DESCRIPTION DATA-BASE INTEGRATION

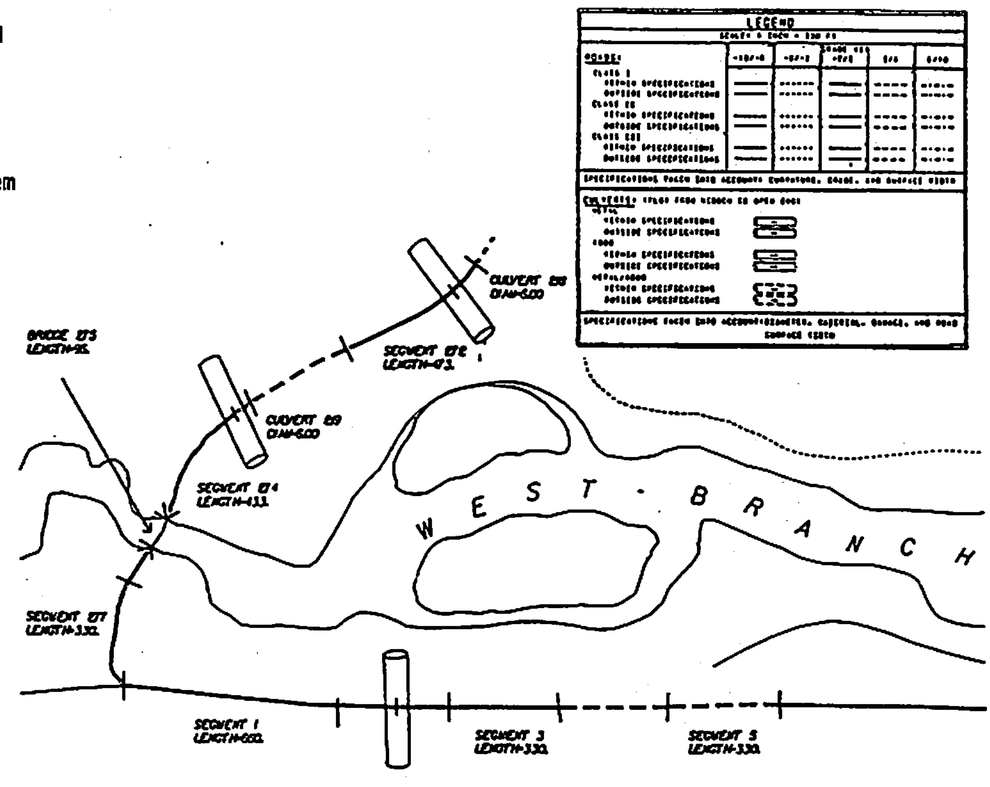
As an outgrowth of the "road building" and harvest area spatial layout routines, a map-based information module combining layers of map data with related non-graphic data has been organized as a data-base. The structure of the new module includes a road description data-base with parallel linkage to the existing location data-base. The description data-base contains all alpha-numeric data associated with the road network. This data includes road names, road numbers, lengths, widths, curve-radii, pavement types, grades, functional class (primary haul, secondary haul, spur, light vehicle) and maintenance information. Descriptive data for special structures (bridges, culverts, intersections) is also stored in the description data-base, while the location data-base has been expanded to accommodate location data for these structures.

The linkage between location data and descriptive data allows a wide range of maps and reports to be requested, entering from either data-base. The graphics sub-system can be used to identify an area of interest and provides indirect access to the data-base. All data or some subset of the descriptive data pertaining to that area can be displayed. Furthermore a map can be plotted displaying the location and extent of the features or areas selected during the data-base search, using the graphics routines (Figure 5).

Other report request capabilities include basic road mapping, road identification, road and materials specifications, maximum loads for specified travel routes, maintenance planning, (minimum) travel time and distance estimates between two points, and exception reports providing the location and description of all road segments and structures where structural and functional specifications do not coincide. Also, the impact of environmental and other land-use regulations on road networks will be readily available (e.g. protected buffer zones associated with roads or water ways).

Expansion of the map-based information module to include landform features and terrain considerations in the new road location algorithm, will require a three-dimensional representation of the area to be stored in the location data-base, which currently holds two-dimensional data. This feature will enhance the planning of road networks and allow more accurate determination of transport equipment limitations, harvest/transportation costs and wood flow schedules.

Figure 5--Road system map showing segment lengths and structure locations. The map was photo-reduced from a multi-color computer-generated larger scale map plotted on a CALCOMP 960 plotter. The mapping system was programmed with INTERGRAPH software.



DISCUSSION

Successful application of the entire system requires diverse information about potential harvest sites, timber volumes, existing road networks, market locations, market requirements, and landform features. Although detailed information for all parameters is not yet completed on a state-wide basis, each segment of the system is independently useable where the appropriate data is available. In the recent past, the system operatively utilized estimated salvage volumes, estimated road costs, and budworm survey data to provide total timber volume allocation and associated costs. Into the year 1984, a U.S. Forest Service grant (CANUSA) financially supported the system's utilization as a research tool in developing harvest scheduling procedures.

While development was motivated by a forest insect problem, the system's inherent flexibility provides high potential for more generalized use. Whenever the short-term timber supply in need of harvesting is in excess of market requirements (supply > demand), the association of timber sources with market locations - based on a cost minimization - can be utilized to determine where harvesting should be concentrated. Conversely, specific markets that are allowed to participate in a limited short-term supply (demand > supply) can be defined and quantified.

The techniques applied in this system should be readily adaptable to other regions or nations, particularly where the forest resource is quite extensive, roads are limited, and the timber sources and delivery locations are usefully differentiable in terms of macro-policy, whether the policy goals be publicly or privately motivated.

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DOCUMENTATION

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Computer Program for Modeling Multiple-Entry Economics[1]

Eldon D. Olsen[2]

Abstract: Traditional road and landing spacing models are substantially enhanced by considering the net present value of all entries, not just the next entry. Therefore, a computer program using microcomputer spreadsheet software was developed for evaluating multiple entries. The model can be applied to aerial, skyline, and ground-based systems and provides features unavailable in previous models, including road maintenance costs, real appreciation of expenses and incomes, landing change time, and yarding path options. Model input includes fundamental cost and production information; output consists of cashflow summaries of each entry as well as a net present value summary of all entries. User-designed output for sensitivity analysis of any variable is also easily produced. The program has already been used as a classroom aid, in designing field trials of experimental logging methods, and in predicting the long-term impact of soil compaction related to harvesting operations and should be a valuable computational tool for formulating cost-effective timber management plans.

In many logging planning and cost analyses, the sole focus is the next entry, which usually involves some road construction and setting up for a specific type of timber harvesting. But this approach ignores two important issues. First, decisions made at any one entry affect operations later on. Second, forest managers need a long-range economic analysis to get the perspective of at least one complete rotation of the timber crop. An approach that can calculate the net present value of multiple entries will remedy these present shortcomings.

Several excellent microcomputer programs have been developed recently for foresters (Cooney 1985). Although useful for general-purpose investment analysis, these programs do not model forest-engineering-related options in sufficient detail to help foresters and managers evaluate road-building and harvesting decisions. Traditional road-spacing models have dealt with simplified situations because of computational limitations. Model features of the simplest case include single entry, no discounting, skidding and road-construction costs, straight line travel, and volume harvested per acre. However, with the wide availability of spreadsheet software on microcomputers, more complex and realistic conditions can now be modeled with a documentable, repeatable process. This paper describes a computer program[3] that takes advantage of spreadsheet applications to model multiple yarding entries, to help formulate the comprehensive economic picture so necessary for developing the most cost-effective timber management plans possible.

GENERAL MODEL DESCRIPTION

The model is centered on yarding activity and can be used for aerial (balloon, helicopter), skyline, or ground-based systems. Desirable features unavailable in earlier models include multiple entries, road-maintenance and silvicultural activities, revenues (timber pond values), appreciation of revenues and costs, landing construction costs, landing change times, sensitivity analysis, and user-defined output. Previous pioneering work by Matthews (1972), Peters (1981), and Gonsior (1981) has been enhanced with various travel patterns. Yarding path options include perpendicular/lateral yarding of rectangular settings (the default), continuous landings, uphill/downhill yarding, straight line yarding to the landing, and circular settings; however, irregular boundary cases cannot be handled. The program can determine the optimal road and landing spacing; give the harvesting, road, and silviculture cashflow for each significant activity in a rotation; calculate the net present worth of each entry and report the summary of all entries; and give detailed reports of each entry on a per-acre and per-unit-volume basis.

The model's main strength is its ability to show the overall financial analysis for an extended time period. Decisions made during one entry may significantly affect subsequent entries, and the program will make those effects apparent. The program also can show what happens in a multiphase operation during a single entry.

MODEL INPUT AND OUTPUT

The model's input, similar to that used by Gonsior (1981), consists of fundamental cost and production information as well as stand and terrain data; table 1 shows the input requested for each harvesting entry. The units and accuracy desired are displayed for each value. If a particular activity does not occur, then no value is entered. A default table provides typical input values, should the user wish to select them; such a table exemplifies the additional level of forest-engineering detail unavailable in previous models. The program also asks for information on the timing and cost of road maintenance and on costs and revenues associated with nonharvesting activities. Real appreciation rates on timber pond values and on each type of cost may be entered, if desired. Sensitivity analysis of any condition or input variable is easily performed with the spreadsheet. The capabilities of several typical ground-based and skyline systems are stored in the program and may be accessed with a "macro," a feature similar to a subroutine with stored equipment data sets. Although the program has numerous preprogrammed calculations, the user can override any program output by merely typing in another value.

[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

[2]Associate Professor of Forest Engineering, Department of Forest Engineering, Oregon State University, Corvallis, Oregon. Paper 2048, Forest Research Laboratory, Oregon State University. The mention of trade names or commercial products does not constitute endorsement or recommendation for use.

[3]A copy of the Symphony[R]-formatted disk and documentation will be available at cost from the author beginning January 1986.

Table 1--Input for each timber harvesting entry.

Variable	Description
S	Average maximum yarding distance of span (not the road spacing!)
KS	Coefficient reflecting one (1) way, two (2) way, or circular (0.637) yarding
KA	Fraction of acreage accessed by road system to be harvested
V	Average volume per yarding cycle (net)
VB	Per-acre volume of merchandise timber to be extracted (net)
VR	Per-acre volume of residues to be extracted
VW	Average walking speed in woods
CR	Per-mile cost for design and construction of access roads
CF	Daily cost for yarding system
PF	Hourly production rate for falling system
TF	Available hours in work day for falling
CY	Daily cost for yarding system
TY	Scheduled hours in work day for falling
CH	Cost per unit volume for hauling system
RO	Fixed time for rigging setup and landing construction
R1	Rigging time variable (function of S)
YO	Yarding fixed time and minor delays
Y1	Outhaul and inhaul average rate (function of S)
Y2	Lateral outhaul and inhaul average rate
Y3	Hook and unhook average rate (function of N)
N	Average number of stems per yarding cycle
I	Real rate of return desired assuming no inflation
PB	Pond value of merchantable material
PR	Value of residue at landing
Y	Year of entry after year zero
L	Landing cost in dollars
D	Percent of yarding time lost to major delays
O&D	Overhead and depreciation as percent of harvest cost
P	Yarding configuration factor (automatically calculates average yarding distance)

The final output presents the combined discounted cashflow for all harvesting entries as well as other relevant cashflows. An example (table 2), for yarding from both sides of the landing, shows the significant size of certain costs which often are overlooked. Standard levels of summary within the program can unveil other "hidden" information. For instance, a three-entry example with a 40-year planning horizon (table 3) reveals both impact of discounting money at 4 percent and the deficit cashflow on first entry. In a user-defined sensitivity analysis using a "what if" option (table 4), the high cost of an unroaded low-volume harvest is shown for several road spacings. Actual road spacing and location are subject to field variables, but these results provide planning guidelines for managers; in this case, lowest total cost ($246.43) results from selecting a road spacing of 1600 feet. Once again, the output illustrates the available level of detail.

Issues concerning landings can be investigated. Table 5 illustrates an unmanaged stand for which two possible thinning entries are considered. For one, the landing would be built on first entry, for the other, on final harvest. If landings, at $500 each, were built before the first thinning (in year 10), optimal landing spacing would be 182 feet. But if landing construction were delayed until final harvest (in year 40), optimal spacing would be 137 feet instead. The construction delay also produces a smaller net present cost--which is desirable. Further, the table shows how optimal yarder spacing for each entry differs from the single spacing representing the best compromise for all entries.

APPLICATIONS

The program was originally designed as a classroom aid so that students could see the effect of various equipment and logging options. But it also has been used to predict the production and cost of experimental logging trials and could be used to assess the economics of soil compaction, to evaluate residue management options, and to predict the feasibility of futuristic systems. For instance, in the case of long-term impacts of systems that compact the soil, the reduction in tree growth and the area taken out of production in skid trails could be modeled, and the cost limits for methods designed to ameliorate these negative impacts then established. In this way, the relative advantages of designated skid trails, skyline logging on gentle slopes, and soil tillage could be predicted. An Oregon State University Master of Forestry study applying the program in this way, as a computational tool, is in progress.

The relative ease of handling both input and output features makes this program "user friendly." Moreover, the user can manipulate the model to represent the specific yarding conditions anticipated. Operational options can then be economically evaluated and the combined effect of all entries viewed in total and over time.

Table 2--Net present value summary of all activities for yarding from both sides of the landing.

Item	Value
	feet
Road spacing	2000
Span	1000
Corridor (landing) spacing	182
	dollars/acre
Harvests, net revenue	3,550.44
Road maintenance costs	26.97
Labor intensive costs	176.31
Miscellaneous costs	98.44
Overhead and depreciation	687.30
Total net revenue	2,561.40

Table 3--Harvesting cashflow, discounted at 4 percent, for three entries over a 40-year planning horizon.

Entry year	Cashflow	Net present value
	dollars/acre	
10	-647	-437
20	747	431
40	17,505	3,646
Total	--	3,550

Table 4--Sensitivity analysis ("what if" option) for determining the cost of an unroaded low-volume harvest at various road spacings.

Road spacing in feet	Turn time	Output	Cost		
			Road	Yard	Total
	min.	mbf/day	dollars/mbf		
400	4.4	6.2	247	79	386
600	4.9	5.8	165	85	309
800	5.4	5.4	123	92	275
1000	5.9	5.0	99	99	258
1200	6.4	4.6	82	107	250
1400	6.9	4.3	70	114	246
1600	7.5	4.0	61	122	246
1800	8.0	3.8	55	130	247
2000	8.5	3.6	49	138	250
2200	9.0	3.4	45	146	255

Table 5--Effect of delaying land construction for an unmanaged stand for which two thinning entries are possible.

Optional yarder spacing, by entry	Landing built first entry	Landing built final entry
	feet	
First entry	267	115
Second entry	94	94
Final entry	125	198
Single best spacing for all entries	182	137

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COMMERCIAL COMPUTER SOFTWARE FOR FOREST ENGINEERING

Dale E. Danell - Marketing, Terrasoft, Inc.[1]

Abstract: Forest Engineers are faced with management problems which do not conform to the applications scope of most general engineering computer software available today. Terrasoft, Inc. specializes in developing computer software solutions to the unique requirements of forest and land-use management. Software systems that are available as individual packages are discussed individually. Commercial software gives the purchaser flexibility, long term return on investment, user support and turn-key systems for personnel untrained with computers.

In the pioneer days of North America, forest operations simply meant logging. Forestry or land management interests on a whole were non-existent. Suitable timber was selected, cut, felled and utilized in the most convenient manner and location for the need at hand. As intensive forest management and environmental awareness expanded, micro-computers became the inevitable tool for record keeping, design and planning.

The computer software marketplace offers a huge selection of programs for micro-computers, however very few are remotely applicable to the requirements of the forest industry. The priorities, constraints and objectives in land management problems extend beyond simple formulae calculations. Analyses and presentations for public agencies has become a real part of land management as well as experienced field work alone.

AVAILABLE SOFTWARE

Software that can be utilized for forest engineering purposes can generally be described in four categories. Most users will accumulate a collection of programs from these groups as they expand their library of programs and computer utilization over time.

General Purpose Systems

The spreadsheet and database packages available from computer dealers can be used for a large number of applications encountered in the forest industry. Any experience the user has with computer programing will be a definite advantage. For simple tasks the spreadsheet systems are generally easier to use for those who are new to the use of computers.

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The initial cost of the general purpose systems is very low, and is a worthwhile investment. However, if the user is intending to install a large application using one of these systems, they must be prepared to allocate time to the development of the system. Most users encounter a learning curve requirement for the system before any speed develops in their programming ability.

Depending on the sophistication of the application developed using these systems, the error handling for incorrect data entries can be anything from annoying to a disaster. The user often has the opportunity of overtyping a formula or inadvertently wiping out some of the database. As the complexity of the application increases, the speed of system performance will decrease severely, depending on hardware configuration. These systems however, can be used effectively within the scope of their limits.

Routines and Freebee Programs

A countless number of programs has been developed as quick routines and are available as freebees. The availability of any useful program to the user is generally by word of mouth. Programs or sub-programs as these are valuable only in that someone else has taken the time to think out a problem and develop an algorithm to perform the task. When using a program of this standard, the user is usually faced with considerable hand tabulation and organization in addition to calculations being performed. There is rarely any error checking made and the user may have to start the task over several times in the event of a mistake. More often than not, only the person who developed the program can run it, as no one else can understand what was intended by the messages which appear on the screen.

Custom Programing

To have a program developed to perform a specific function will ensure that the task is completed as desired. The defined task is generally the conceptual design of the program at the beginning of the project, but rarely at the end. Most likely, someone will realize that an oversight has been made on the next day, and a change will have to be made. This can be a subtle scenario for driving the programing cost to astronomical levels.

Although custom programing eventually achieves the exact intended result, the long term implications may not be desirable. Unless the preliminary planning of the custom package is impeccable, oversights will surely be encountered. If the long range planning has not been carefully thought out, the system may become inadequate for future expansion and utilization. Custom programing may be the best solution in some applications, but thorough planning is the only method to keep a control on development costs and ensure the product has a long useful life.

Application Software

Application software has the advantage of having a scope narrow enough for specialized functions as encountered in the forest industry, yet is flexible for individual tailoring and adapting to similar tasks. Although the objectives are consistent in the forest industry, individual requirements dictate that special considerations be accommodated. This ensures that the software purchased is not only useful for one operation today, but can accommodate changes to the management scheme in the future. The same system must also meet the needs of companies operating independently of each other to qualify as satisfactory application software.

APPLICATION SOFTWARE PACKAGES

Terrasoft, Inc. is a company of Forest Engineers and Computer Scientists that specializes in application software systems which serve the needs of the forest industry. Several systems are offered as packages which operate independently on most micro-computers.

Survey Package

Road engineering is a major aspect of forest management, especially in mountainous terrain. The cost implications of a poor design are compounded not only at the construction stage, but also by logging difficulties and maintenance. This package is a tool which enables engineers to design road alignment, separation, grade and earthwork to minimize the costs attributed to harvesting.

Some companies require a high level of detail in the surveys they conduct. This may be for reasons such as horizontal control difficulty or contract commitments. The Survey Package provides the capability of detailed designs to users working with high accuracy levels. The system also is applicable for use in circumstances which do not require complete detail. When using the package for this purpose, the user does not have to be burdened by answering numerous prompts for data required for detailed surveys. The system incorporates form development utilities for creating and storing input and output formats for entering only the data entry recorded from the field survey. The user does not have to step through input prompts for an accurate survey of a P-Line traverse when only a rough projection was made with a hand compass.

Reports for soil and rock volumes for multiple soil types as well as overburden sidecasting can be produced along with slope-staking reports. Mass-haul and cross section plots can be made for design and presentation purposes. The system provides the user complete capability to produce road designs with optimal grade and alignment while minimizing the earthwork involved.

Computer Assisted Drafting

The Terrasoft CAD package is a high powered tool for maintaining maps and graphic design on a micro-computer system. The CAD system is the preferred method of record keeping for applications where the drawing is of primary importance.

The user is able to create high quality maps and drawings to depict plans, proposals as well as record historical activities. A tabular report on all objects can be written to a DOS file for access with a database or spreadsheet package. The report file identfies each object individually by object number, type, level of storage, area, length and starting point location. By using database functions, the user can expand the data associated with each object, perform sorts and selections, and produce resultant plots with the CAD package based on selections made.

The Terrasoft CAD package offers extensive editing capabilities for all objects and information that is used for developing maps and drawings. Size, location, rotation, plotting characteristics and individual point or groups of points can be changed at any time. Line type, thickness and color of lines, shading patterns, object location, size and rotation as well as drawing functions for lengths, spacing, areas and multiple copies are also available to the user.

A form feature is included for quickly producing legends and title blocks for drawings. Once the form has been developed, it can be easily merged into other drawings to provide standardization to all drawings that are developed. A special feature of this form utility enables the user to define prompts for keyboard input of text that will appear in the standard form or title block. The user simply has to key in the responses to the prompts and these will be plotted in the appropriate positions in the title block along with the form and any logo graphics that may be included. Other related drawings as well as the legends can be merged together to produce a final graphics file.

Geographical Information System

The GIS package is a universal map related database system used for polygon overlay analysis. An example application of this system is for silvicultural record keeping and reporting. This system is particularly useful where tabular reporting and record keeping is the preferred method of storage and analysis.

The basis of data input into the system are areas as delineated from a mapsheet. Attributes which describe the area are entered from the keyboard and stored with the geographic shape. These attributes are completely user definable and are used to record activities, costs and statistical information which are associated with the unit either as a whole or in part. Where partial areas in a given unit are designated with specific attributes, these areas are entered as layers into the database. The layers describe the activities on the unit in a manner similar to using transparent overlays on a map.

The reporting module of this system enables the user to make enquires as to multiple activities which may have occured on individual units or all units stored with the system. The area which is common to all qualifying activity layers is calculated for each unit and summarized for all units. Additionally, the areas of the units can be selected based on ranges or limits of the numerical data stored with the layer attributes. Selections can also be made on units for areas which do not qualify for specified criteria.

Harvest Planning

The Harvest Planning system employs all of the features included with the GIS package. In addition to those capabilities, this package incorporates two special layers that are used for harvest planning purposes. These layers are used for forest cover stand and logging system area designation. The user is able to define several stands or logging systems within an individual logging unit, and include the attributes of production rates and cost, volume, species and grade with each designation. On the stand inventory layer, the areas of each stand occur on the same level and will add and subtract from each other to maintain the total unit acreage. The logging system layer functions in the same manner. These two layers can also be overlaid with other layers of attribute information as in the GIS package for selective reporting capabilites.

The reporting module in the Harvest Planning system provides the user the opportunity to use the package for logging cost projection and planning as well as for recording actual costs from logging activity. The system can be used for selecting qualifying unit areas for logging systems, species mix or grade, and other attributes stored with the system. Management questions as to availability of species or selected contractor areas can easily be made in a short time, complete with acreages, volumes and associated costs.

Digital Terrain Modeling

Computer modeling of topography is a valuable tool for companies involved with environmental impact and landscape architecture. 3-D projections of a model can be viewed from variable positions, angles and with different magnifications. Area boundaries and roads or lines can be overlaid onto the surface of the model along with projected tree heights around the perimeter. These features can be viewed and plotted along with the projection to simulate the viewable image from the specified vantage point.

The package also provides planimetric plots of the areas which are viewable from the vantage point. The user can define cross sections across the model and plot the ground profile. Skyline deflection analysis can be made along the selected profiles.

The value of the DTM package is quickly realized with projects involving environmental impact of logging or mine operations. The user is able to prepare and make presentations of operational plans to agencies that will portray the actual impact of a project.

Skyline Analysis

Long line yarding systems are being evaluated more than ever with the high costs of road construction and logging. The Skyline Analysis system enables the user to enter deflection lines either from field traverses or by digitizing contours from a map to define a ground profile. This profile is displayed graphically on the computer for the skyline analysis.

Several logging systems can be defined in the system for selection in the analysis. For each logging system, the user must enter criteria for tower height, line weight, maximum line length, yarding configuration and tension limits which are to be used as defaults in the calculations. Payload, clearance, load zone and deflection parameters can be varied in the analysis. The results of all interactive changes to these parameters can be quickly viewed on the computer screen, as well as being drawn on a plotter. The load zones and tensions can be printed in a tabular report.

Log Production Accounting

This system simplifies the accounting procedures for log production where trip tickets are utilized for each load delivered to a final destination. The package features user-definable data entry fields which can be set up to record all information the user is recording on their current trip ticket system. For each of the items on the ticket, the valid names of the mill or contractors are identified along with the payment rates for either or all of the respective operating areas.

The trip tickets can be entered and stored in the system on a daily basis. Reports can be produced for user selected intervals to quickly provide summaries for financial or operating periods. The reports will show the costs and volume produced for the selected interval, and can be based on sorts or partial selections of the data that is recorded on each ticket entered.

Engineering Utilities

The daily functions of a forest engineer include considerable time spent working from maps and drawings. Area measurements, length measurements, scale changes between different mapsheets and quick plotting of check traverses are fundamental to the planning and decision making tasks.

The Engineering Utilities package has been developed to perform these routine tasks to free engineering time of counting dots and pantographing. With a fast means of obtaining measurements at a greater precision over manual methods, the engineer can devote more time to planning rather than tedious labor. The traverse reduction utility enables the user to enter and plot simple traverses at any scale.

Inventory & Equipment Cost Tracking

The warehouse inventory package enables the user to implement an inventory card record keeping system on a micro-computer. The system includes part number cross referencing, vendor address, current part cost, minimum and maximum stock levels, and to/from cost code charging. Purchase order record keeping is included to simplify reordering and control of inventory costs. Inventory is maintained by material or service issue entries which correspond to slips used by the warehouse. Part slips can be eliminated by direct key in of part numbers and quantity at time of issue or they can be retained for batch entry later. The issue slips are stored and posted to update the inventory database.

The reporting capabilities include all referencing for individual parts as to stocking status, pricing, bin location, vendor, etc. Cost reports can be made for inventory values and job and labor expenditures. Reorder reports for maintaining inventory levels can be produced as well as purchase orders printed out to the applicable vendors. When new parts are stocked into the system, the current prices can be compared to those of the previous inventory to identify discrepancies. Job or project accounts can be summarized as to the parts and labor charged to the respective code number.

The package utilizes the Rbase 4000 database system (Microrim, Inc.). This gives the user the flexibility of being able to make special modifications that are unique to a particular operation. As the user becomes comfortable with the database system, special inquiries on the inventory records or expansions for future accounting purposes can be accommplished without making the original inventory package obsolete.

RECOMMENDATIONS

Application software as the packages offered by Terrasoft, Inc. provide the user the flexibility required for a long term investment. These packages will not be outgrown a few months after they are purchased. The flexibility that the packages offer also ensures the user that they will not have to ultimately become computer programers to maintain the systems in the future. The application software which is offered by Terrasoft is supported both by telephone and on-site training. The majority of the programs are being enhanced and expanded to utilize large memory capabilities of the new generation computers and peripheral components. Clients who have purchased these packages previously are provided with updates as they become available.

Application software ensures the users that they will remain with the current state of art in computers in the forest industry. The purchasers are also assured that they will be making the most of their investment in computer hardware by utilizing it fully. A purchase of software packages for a microcomputer should be considered as buying a tool for a trade rather than just something fascinating. Application software as described quickly becomes indispensable to any organization engaged in forest engineering.

A Practical, Integrated Planning System for Harvesting Timber on Sensitive Areas[1]

H. L. Hammond[2]

Abstract: A practical planning system effectively integrates a wide variety of forest land uses in environmentally and politically sensitive areas. Data collected for broad planning levels can be efficiently upgraded to more detailed planning levels. Control lines located approximately perpendicular to the contours of the microterrain are the basic field technique for data collection. The data base contains sufficient resolution and reliability to accurately design and carry out timber harvesting while protecting other forest values. Use of this planning system produces a practical understanding of forest ecosystems, the key to both operational efficiency and environmental protection.

A planning system was developed which can be applied to the planning of all forested areas and to a broad range of forest management objectives such as harvesting, engineering, and silviculture. The technique is particularly effective in politically and environmentally sensitive areas such as consumptive use watersheds, areas of high visual impact, or areas with unstable soils because data required for a specific planning purpose is collected to effectively and efficiently integrate variables.

Flexibility permits application of the planning technique to collect specific data or a broad comprehensive data base. Regardless of the data details or planning resolution desired, the system employs the same approach to data collection. This feature results in practical data collection to meet present objectives and provides for cost effective data upgrading to meet future needs. Since data upgrading is cost effective, the planning system is an efficient means to obtain data confidence levels necessary to plan and operate effectively on politically and environmentally sensitive sites.

When used to obtain a comprehensive data base, the system stratifies an area into forest ecosystem types. "Go/no-go" decisions and management prescriptions can be confidently developed from this data base. For planning which requires only specific data, the system stratifies an area by primary variables dictated by the objectives of the plan. For example, in forest harvesting applications, the planning system is employed to assess feasibility, to design, to lay out, and to evaluate all components of harvesting operations by dividing the area into terrain units. These components include haul roads, landings, skid roads or yarding routes, and block boundaries. A clear definition of the shape and stability of the terrain promotes efficiency and cost effectiveness in all phases of a logging operation and results in reduced soil disturbance levels.

To provide a framework to discuss the planning system, environmentally and politically sensitive sites will be briefly defined. These definitions, while not intended to be comprehensive, will serve to show some characteristics that are important in a planning system used on politically and environmentally sensitive sites.

Environmentally sensitive is applied to forested areas that have ecosystem characteristics which may be easily degraded by development activities (e.g. timber extraction, mining, and large scale recreation facilities). Schwarz and others (1976) define fragile lands as, "Those land or water areas containing ecosystems, possibly but not necessarily rare, that are sensitive to external stimuli which may disturb their balance, especially in an irreversible direction."

Soil erosion causing forest productivity losses and resulting in siltation of water supplies is a common result of poorly planned forest management on environmentally sensitive areas. In analyzing environmentally sensitive areas, we must recognize the interconnected nature of ecosystems. Degrading one part of an ecosystem may damage adjacent or "downstream" ecosystems. Hence, environmentally sensitive sites should be considered to be fragile areas and adjacent areas which may be degraded if damage occurs to the fragile area.

An area becomes politically sensitive where governments and/or groups of people have different land use objectives for a particular forest site. Groups compete with each other to gain management control over a politically sensitive area because different land uses are often incompatible or are perceived to be incompatible. The professional forest manager is charged with the responsibility of distinguishing between perceived and actual incompatibility. Since people's views are a large part of politically sensitive situations, foresters need to actively listen in order to clearly understand all peoples' values and wishes (Magill, 1983).

Environmentally and politically sensitive sites are often one and the same. People are more likely to intervene with proposed forest management activities on an environmentally sensitive area because any activity carried out there assumes a high natural risk. When high natural risk is combined with the management-induced risk inherent in any type of forest management, there is a high chance for environmental damage. On both politically and environmentally sensitive sites, forest planners must ask and objectively answer the question: Due to risk of environmental damage, should proposed development activities occur in this area? The answer to this question involves technical, social, economic, and moral issues.

A PLANNING SYSTEM FOR POLITICALLY AND ENVIRONMENTALLY SENSITIVE SITES

Important characteristics of a planning system to be used on politically and environmentally sensitive sites include:

1. A data base which includes all variables necessary to make go/no go decisions and to plan and carry out approved operations in an environmentally safe manner.

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[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

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2. Adequate data resolution to ensure that environmentally sensitive areas are identified and accurately defined.

3. A clear, dependable means of presenting and interpreting data so that all people involved in the planning process may understand and develop trust in the plan.

Development of Planning System

The planning system described in this paper was developed following a study of soil disturbance levels on ground skidded clearcut areas in southeastern British Columbia (Hammond 1984, 1985). One objective of the study was to develop a practical means of reducing soil disturbance. The study showed that total soil disturbance ranged from 10 to 20 percent of the harvested area on simple terrain with less than 20 percent slope gradient, and reached 47 percent of the harvested area on simple terrain with greater than 40 percent slope gradient.

Soil disturbance, in the form of soil compaction and the burying or removal of productive soil horizons, can have severe degrading effects on site productivity for forest tree growth (Carr 1983, Schwab 1982, Emmingham 1983, Sidle 1980). Wert (1981) found that the timber volume produced on skid roads was 74 percent less than that produced on adjacent undisturbed areas, while Froehlich (1981) determined that the height growth of several coniferous species was reduced 10 to 50 percent by soil compaction. Erosion of exposed soils can lead to stream sedimentation (Smith 1976), degraded water quality (Garland 1983), and damage to fish habitat (Adams 1981).

Our soil disturbance study (Hammond 1984) observed that operational inefficiencies and high levels of soil disturbance were often related. Parallel main roads were recorded in valley transportation networks, where one main road would have sufficed. Harvest unit boundaries that did not conform to logical terrain configuration resulted in unnecessary haul road construction, excessively long skidding distances, and high skid road densities.

High levels of construction associated with a harvest system result in high levels of soil disturbance. Unnecessary costs and inefficiencies in an operation occur when construction is not required, or where construction could be reduced through improved design and location. Design of an efficient operation will result in low levels of site degrading soil disturbance.

Terrain is the primary variable affecting the degree of construction, operational efficiency, and levels of soil disturbance. Terrain shapes, slope gradients, and the relative location of various types of terrain need to be thoroughly understood. Practical terrain information enables design and layout of construction activities necessary for efficient timber harvest and is vital in minimizing soil disturbance. Practical terrain analysis is the core of the planning approach.

Elements of Planning System

This planning system (Hammond 1985) is applicable to a wide range of planning purposes, from reconnaissance level investigations to detailed operational planning and implementation. Field terrain mapping procedures and ecosystem sample point selection are identical for each planning level. However, the variables measured at each sample point will differ with the purpose of the planning exercise.

Preliminary stratification of areas of interest into terrain types is performed from air photo interpretation and study of available topographic and planimetric maps. This step helps to define the amount of field work required, depending on the intended purpose or level of the plan. If available, ortho photographs with contour overlays are particularly valuable for this step.

The basic field procedure consists of control lines along which terrain is mapped and ecosystem variables are sampled. Control lines, or transects, are located approximately perpendicular to the elevational contours of the microterrain. All data is collected along the control lines which cross the spectrum of ecosystems and terrain changes occurring in a forest area. Ecosystems vary with changes in elevation and are accurately and efficiently sampled by control lines situated perpendicular to the lay of the land.

The separation of control lines varies with:

- the level of planning desired. The objectives of the plan indicate the necessary resolution or intensity of the data to be collected. More detailed, more specific plans require more frequent control lines.

- the complexity of the ecosystem and terrain. Simple terrain can be readily sampled with fewer control lines.

- visibility within the forest. Increased visibility reduces the number of control lines necessary.

Sample points, located along control lines, are used to measure ecosystem characteristics. Sample points are located where ecosystem characteristics change significantly, or at minimum intervals specified by the purpose of the plan. Ecosystem characteristics measured at a sample point may be comprehensive or specific, depending on the objectives of the data being collected. Soil, understory vegetation, microterrain, and tree data are commonly collected.

Site sensitivity, forest engineering, harvesting, and silvicultural prescriptions may be developed from data collected at sample points and from terrain maps produced along control lines. Terrain maps are stratified into ecosystem types. The prime variables used for stratification are determined by the purpose of the plan. For example, soil and slope characteristics may be the prime variables employed to describe ecosystem types in an area where soil mass movement into water courses is the major concern.

Data may be efficiently upgraded to higher levels of resolution by increasing the control line intensity. Resampling of previously sampled areas is not required, provided data collected at sample points does not vary between sampling sessions. These factors result in cost efficiencies in multiple stage planning processes, since data collection is performed in fewer steps. Even at the reconnaissance level, this planning system collects a complete range of reliable site specific data because control lines accurately cross the full range of ecosystems present in an area. Common broad level or reconnaissance data collection methods employing spot or random sampling do not provide a data base as reliable as this control line procedure.

Stations are marked along control lines and sample points are indicated in control line field notes to provide future references for effective, efficient design and layout of harvest or silvicultural systems. Where this planning system is used at a broad planning level, stations along control lines may be permanently marked. The initial control line data can then be used to design and lay out future operations that have been determined to be feasible.

Identifying terrain changes is critical to timber harvesting considerations in environmentally and politically sensitive areas. By locating operations within stable terrain units, a wide spectrum of problems associated with soil disturbance may be avoided. Control lines accurately locate and map terrain. Slope breaks may be pinpointed and mapped to reveal whether or not they are contiguous across a steep slope. A slope break is defined as a change in slope gradient of 10 percent or more which extends for a width of 3 metres or more. Reasonably continuous terrain features may become important locations for haul roads, landings, tailhold roads, or skid roads. Location of these harvest system components on slope breaks will result in lower construction costs, less soil disturbance, and good operational efficiency.

Ecosystem stability may also be determined from data collected at sample points. This part of the planning procedure, termed terrain unit stability, identifies sensitive areas which require special treatment or which should be excluded from harvest operations. Determination of terrain unit stability is described in detail later in this paper.

A wide variety of data may be collected using this planning system including ecological, silvicultural, pedological, engineering, terrain, and timber volume inventory. This system is equally successful in a wide range of applications, from a complete forest resource inventory to a specific purpose such as road location. The data collected and control line intensity are tailored to suit the purpose of the planning being undertaken.

This planning approach is also adaptable to the requirements of forest administration.

MAJOR INTERPRETATIONS OF PLANNING SYSTEM

Major interpretations developed from this planning system include (Hammond 1985):

- -classification of terrain stability
- -terrain maps with ecosystem characteristics
- -soil disturbance predictions

These interpretations may be made at any level of application of the system. However, confidence in these outputs increases with increased control line frequency.

Classification of Terrain Stability

Stability of terrain is expressed by a terrain unit stability rating which is determined from control line and sample point data. The rating is used to predict potential site degradation from soil disturbance associated with timber harvesting activities. Terrain unit stability ratings are also useful in assessing risk to water courses from soil erosion and to landscapes from mass movement of soil. Unnecessary soil disturbance may be avoided by application and interpretation of the stability rating. In areas of extreme sensitivity the terrain unit stability rating may be used to determine the overall advisability of harvest operations. Certain specific areas or larger general areas may be classified as too unstable to harvest or to construct roads due to slope instability. The rating is used at all planning intensities for areas stable enough for timber harvest to prescribe:

- -harvest method and machine
- -harvest moisture conditions
- -design and layout requirements
- -guidelines for operations

Six variables contribute to the determination of terrain unit stability. Where significant variation in these variables occurs within an area, stratificaiton into terrain units of similar characteristics is necessary for effective planning, design, and operations. The variables are:

- -the gradient of the slope
- -the uniformity of the terrain
- -the frequency of slope breaks (defined above)
- -the site moisture regime
- -the depth of the soil to an impermeable layer
- -the gradation of the soil

The characteristics of each variable determine its point value, as shown in Table 1. The sum of all points is the terrain unit stability rating.

The terrain unit stability forms the primary means of stratifying an area into management units or areas with enough similarity to be managed with similar systems and methodologies. Within each management unit, the following major decisions may be made:

- -appropriate land uses and land use priorities
- -inclusion or exclusion of timber harvesting as an appropriate land use
- -in management units where timber harvesting is deemed acceptable:
    - -silvicultural systems
    - -logging systems
    - -timing of operations

Table 1: Terrain Unit Stability

Terrain						Site Moisture Regime		Soil			
Uniformity		Slope		Slope Breaks				Depth to Impermeable		Grading	
Simple <40%	1	0-20%	1	Not applicable <20% slopes		Dry	1	>1.5 m	1	Well Graded	1
Simple >40%	3	20-40%	2	Closely Spaced	1	Moist	2	1.0-1.5 m	2	Poorly Graded Coarse: >60% coarse grain	2
Slightly Complex	2	40-50%	5	Moderately Spaced	3	Wet	5	.5-1.0 m	3	Poorly Graded Fine: >40% fine grain	4
Strongly Complex	3	50-60%	7	Widely Spaced	5			<.5 m	5		
		60%(+)	10								

Point Rating for Total Area	Stability Rating
6-9	Stable
10-14	Moderately Stable
>14	Unstable

Maps

Clear, practical terrain maps are an integral part of the planning system. These maps are prepared from control line field notes recorded at a scale of 1:1000. For each terrain unit delineated on the map, ecosystem variables sampled are summarized. The major variable for stratifying maps is microterrain characteristics because changes in microterrain accurately define ecosystem boundaries. However, different variables may be used for stratification to develop maps focusing on understory vegetation, trees, soil nutrient status, water courses, or other variables sampled.

Recording of terrain shape and slope gradient not only occurs along the control line, but also is recorded for the area to either side of the control line. Hence, the terrain map provides a detailed yet practical planimetric view of an area. Survey data recorded along control lines permits development of contour maps.

Terrain maps and other interpretive maps which may be produced serve as the primary communications tools for all people involved in the planning process. Administrators, managers, supervisors, engineers, loggers, and public interest groups use the maps throughout all planning and operations phases.

The maps vary in scale according to the frequency of the control lines, the resolution of the data on which they are based, and their intended purpose. Map scales from 1:10,000 to 1:20,000, based on control lines from 250 to 350 metres apart, are used for broad valley planning purposes. Operations design and layout require close control line spacing of 100 to 150 metres with maps at scales of 1:2,000 to 1:3,000.

Maps may be prepared in a variety of formats such as working maps for use by field engineers and loggers, or multiple overlay maps for land use analysis and public presentation purposes. The clarity, practicality, and reliability of the maps makes them useful for all parties involved in a planning process, including people without a technical background.

Operations Map

Harvest systems are designed on an operations scale terrain map. Haul roads, landings, skid roads, yarding routes, and other harvest system components are located on the terrain map. Following this design step, the harvest system components are located in the field. This "on site" step results in certain changes to the harvest system designed on the terrain map. Once these changes are incorporated on the terrain map, an accurate, practical operations map is complete.

The completed operations map forms the basis for predicting soil disturbance levels associated with the harvesting operation. If this soil disturbance level exceeds stated standards, harvest system design modifications to reduce soil disturbance levels can be made prior to operations. A target for the operation is provided and the importance of minimizing site degrading soil disturbance is emphasized. Many planning systems do not estimate soil disturbance levels prior to operations and thus do not know if a regulated or desired maximum soil disturbance level is achievable. Soil disturbance predictions may also be used to eliminate a portion or all of an area from timber harvesting on politically and environmentally sensitive sites.

Following operations, a field evaluation is performed to determine the actual level of disturbance created. A comparison of actual and target levels is essential to rate the success of the operation in terms of meeting acceptable soil disturbance levels and to determine the efficiency of operations. From the evaluation, personnel can be trained and adjustments can be made to future design and layout which will improve the quality and efficiency of operations.

The evaluation step also provides a means of determining necessary site rehabilitation work, such as cross ditching, reduc- tion of compaction, and revegetation.

THE PLANNING SYSTEM ON POLITICALLY AND ENVIRONMENTALLY SENSITIVE SITES

Earlier in this paper three important characteristics of planning systems were listed for politically and environmentally sensitive sites. This planning system, when used by competent people, meets those characteristics:

1. The data base may be expanded or contracted to collect all information necessary to make accurate planning decisions for a particular area. Stratifying data collection by microterrain units ensures that all significant ecosystems will be sampled. Hence, the chances are low of making a poor decision or a critical error in describing the environment of an area.

2. By varying control line frequency, adequate data resolution is efficiently and effectively accomplished by the system. Data is upgraded to improve reliability by increasing control line frequency. This is routinely done in changing from a broad planning level to a more detailed planning level. However, within any planning level, additional control lines may be efficiently added to better define areas in question.

3. The maps produced by the system furnish a clear, dependable means of presenting and interpreting data. All people involved in a planning process find the maps useful. Trust in the maps is obtained by understanding the accurate nature of the control line sampling technique.

A logical area or unit must be planned at one time in order to have an accurate data base and adequate planning resolution. The most logical unit is a watershed. "Downstream" effects of development are accurately analyzed by using a watershed approach. The planning system achieves best results when used to plan watershed units.

This planning system works well for planning environmentally and politically sensitive sites. However, forest planners must always recognize that the final test of a planning system is whether operations are designed and carried out according to the plan!

TIME REQUIREMENTS (COSTS) OF PLANNING SYSTEM

The time requirements (costs) of using this planning system vary primarily with the data resolution desired. The intensity of the data collection is directly related to the purpose of the plan. Greater data resolution, necessary for operational planning levels, requires greater control line intensity and higher sample point frequency than broad valley planning. However, if valley plans are performed with this system, subsequent operations plans will require less time and will be less expensive because the same approach is used and the same data is collected at both the valley and operations level. Partial data required for operations is collected at the valley planning stage.

Two other variables that have significant impact on the time requirements (costs) of using this planning approach are:
- the complexity of terrain and ecosystems
- the available access

The greater the variation in terrain ecosystems, the greater the sampling intensity required to attain the desired level of data reliability. Poor access to an area results in increased travel time and use of expensive transportation such as helicopters.

Planning costs are usually stated per unit of timber volume harvested rather than per unit of area planned. Planning costs for areas with higher volumes of timber per unit area will therefore be proportionately less than equal areas with lower timber volumes. However, writing off planning costs against timber volumes does not accurately reflect planning benefits to forest land planned but not harvested. Such land may be harvested in the future or reserved from timber harvest due to other land use considerations.

From 1.5 to 3.0 hectares (3.7 to 7.4 acres) per person day may be planned using this system in a comprehensive mode, including valley or watershed planning, design and layout of timber harvest operations, and evaluation of operations. When used in a comprehensive mode, areas are planned which are scheduled for timber harvest in the future. Planning time for these areas when harvested will only involve the addition of necessary control lines to attain operations reliability. Planning time for these future harvests will range from 2.7 to 5.4 hectares (6.7 to 13.3 acres) per person day.

CONCLUSION

The planning system described is useful to a wide range of applications from extensive reconnaissance to intensive inventories. A particular benefit of this planning method is efficient, cost effective upgrading of extensive plans to intensive plans. The system is especially valuable to assess the feasibility, to design, to lay out, and to evaluate forest management operations on politically and environmentally sensitive sites. Clear, practical planning system interpretations, particularly in the form of terrain maps, ensure effective communications between all parties involved in planning and operations processes.

Computer based data management and mapping are currently under development for the system. With the assistance of computer technology, time (costs) required for using the planning system is expected to be reduced.

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Meeting the Eastern Challenge: Planning and Producing[1]

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Abstract: This presentation addresses the political, environmental and economic climates surrounding the planning and preparation of timber sales on National Forest lands in the Eastern United States. Two possible solutions to maintaining quantity and quality of timber sale offerings within these arenas are discussed.

The National Forests in the Eastern United States are coming under increasing pressures that are often difficult, if not impossible to resolve. Politically, intensive even-age management is being challenged; environmentally, harvesting operations on the sensitive terrain of the mountains and coastal plains is being questioned; and economically, the pressure to reduce or eliminate below-cost timber sales is very real. Attempts to mitigate all three concerns in timber sale planning frustrate transportation planners and timber sale planners. Intensive training in new techniques of timber sale planning and the development of new harvesting systems hold two of the keys to addressing these political, environmental and economic concerns facing the National Forests in the Eastern United States.

CHALLENGES TO TIMBER MANAGEMENT IN THE EAST

Political Climate

National Interests

Many national organizations focus on the sensitive management areas of the east. The past three presidents of the Sierra Club are from North Carolina and South Carolina, and the immediate past chairman of the National Wildlife Federation is from Clemson, South Carolina. State, as well as national wildlife organizations are very strong in the east. The heads of these state agencies are political appointees which tends to intertwine policy and resource management. Wildlife considerations affect timber sale planning and sale economics because of limitations on unit size and the distribution of cutting units. Unit size in hardwood regeneration areas is generally limited to 40 acres by the National Forest Management Act of 1976. The management perception of acceptable practices has further restricted the average clearcut sizes to less than 15 acres on some forests. Through the Forest Land Management Plans (FLMP), the Southern Region is incorporating expensive group-selection alternatives that will be applied in special management areas. Two regional directors of the Wilderness Society writing about the Southern Appalachian Highlands exhibited the national interests in the even-age management alternatives of the FLMP. "But the U.S. Forest Service has proposed that we take a chainsaw to this superb resource" (Tipton and McGrady, 1985).

Local Interests

The ownership pattern of federal lands in the east complicates timber management in terms of access and management alternatives. Small blocks of interspersed federal and private lands bring concerns from adjacent landowners. Right-of-way acquisition is difficult, often resulting in condemnation where subdivisions and small landowners crowd the forest boundaries. There is landowner resistance to allowing public access through their homesteads.

The strength of the tourism dollar finds its way through the political systme to challenge even-age management in areas where tourism is dependent upon the visual quality of the landscape.

Forest Land Management Plans (FLMP)

Land management plans are in various stages of draft and review nationally. Once a resource management process, but now a political and legal process, the vehicle has been created and designed for public participation in the management strategies on NF lands. With the high population densities of the east, tremendous interest and participation in the forest plan is being shown. The National Forests in North Carolina received 3,500 comments, the Chattahoochee National Forest in Georgia received 2,000. The legal status of the FLMP will present difficult management opportunities (Behan, 1985).

Forest Managers

Forest Supervisors in the eastern regions are in the politically sensitive and often powerful position of carrying out the management of the National Forests within the context of the laws and amid local concerns. Unlike most of the western regions where there are numerous national forests within a state, in Regions 8 and 9, there are 29 Forest Supervisors in 25 states and 1 territory. They must be responsive to 2 U.S. Senators and the House of Representatives in the districts that the forest covers. Daily Congressional inquiries are commonplace on the forests in the east.

Environmental Climate

Visual Quality

Much of the federal ownership in the mountains is at higher elevations. With scenic drives like the Blue Ridge Parkway that runs from North Carolina to Virginia and major hiking trails such as the Appalachian Trail that runs from Maine to Georgia being heavily travelled, the scenic quality of the landscape is a very important part of the recreation experience. The Smokey Mountain National Park is the most visited park in the U.S. with 9-10 million visits per year. Access to the park from major population centers such as Atlanta, Louisville, and Washington comes through the national forests in Georgia, North Carolina, Virginia and Tennessee. The urban public is hard pressed to distinguish between the National Park System and the National Forest System and the perceptions of one carry over to the other. Road locations, unit shapes and skidding patterns must be analyzed to meet visual quality objectives.

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Water Quality

A Soil Conservation Service study in 1967 estimated a total of 18 million acres of commercial forest timberlands in slope classes over 35% in the 13 states that comprise the Southern Region (IFF, 1981). As road systems are being developed for the previously unroaded mountain forests, more and more of the timber harvesting which until recently had been on the lower elevations and flatter slopes, will be conducted on the steeper lands. With increased roading and harvesting in the steeper lands comes more concerns about soil movement and water quality. Many municiple watersheds as well as private water systems lie on NF lands in the east.

Wetlands

Wetlands in the southern states of South Carolina and Florida and the northern states of Michigan and Minnesota offer complicated balances of multiple use and protection. Wetlands necessitate changes in management practices and limited logging equipment and seasons not only on National Forest lands but also on private lands. Scott Paper Company is currently operating a small skyline yarder in the bottomlands of south Alabama.

Economic Climate

Stand Quality

Timber stands because of past logging practices, fire, farming, blights, etc. are in very poor condition on many eastern forests. Eighty-nine commercial species grow on some of the Southern Appalachian forests, making marketing difficult. The resulting stumpage rates may cause stand values to be as low as $50 per acre to as high as $5000 per acre in some northern Pennsylvania cherry stands. Diameters are rarely uniform in the mountain hardwoods and may see a full commercial range from 6" to 55" dbh on an acre.

Access Costs

Access costs are extremely high relative to timber values in most of the eastern hardwood forests. The mountain forests in Region 8 average $53 per mbf for road costs while stumpage values average $40 per mbf. The coastal plains forests average $22 per mbf for road costs with stumpage easily covering the access costs. Past logging methods used access patterns that are not currently acceptable for todays equipment or environmental concerns and in most cases must be completely abandoned and relocated. The mountains were skidded down the drains and wetlands saw wire ropes operate through a canal system. With harvesting equipment changing from ground lead to skyline and bobtail trucks to tractor-trailers, the gap between stumpage and access costs has widened.

Management Costs

Using the planning and input system defined by the Forest Service, the public is able to direct the management and ultimately the management costs on NF lands. Public lands that were considered back country where pure silvicultural decisions could be made are almost gone. "Vacuum Forestry" is a foregone profession on NF lands in the east. Now the forester is simply another specialty that is involved in shaping NF management.

The return on the investments (timber sale revenues) that have been made in presale activities and planning are constantly being delayed through appeals during the environmental analysis process. Timber sales are delayed, re-analyzed, and environmental assessments re-written costing valuable dollars and limited man-years.

Higher Value Uses for Forest Land

As the public helps to shape NF management in the east, it is becoming increasingly evident that Federal lands are more valuable for other than timber production.

Tourism--Since the early 1800's, many mountain cities have been developed around and with the tourism dollar and it is a primary source of income for local economies. Tourists come to the mountains to enjoy the scenic beauty. Roads and cutting units are not an acceptable part of the landscape. Tourism is reaching farther back into the mountains of the east which makes virtually all management activities visible.

A large part of the tourism dollar is spent recreating by driving, hiking, camping or fishing. The NF in the east are the principle providers of those experiences. Recreationists don't care to drive open roads concerned about running into log trucks, to hike through clearcuts, or to camp on log landings.

Land Development--To visionary developers the mountain lands adjacent to the national forests offer the potential for subdivisions and small acreage development. A place in the cool mountains is highly desirable, with time share developments and golf clubs (which have a special place in my heart) driving land prices for undeveloped mountain land to $4000-$5000 per acre. Being adjacent to the NF is like having a game reserve or park in your back yard. Developers and land investors write their congressmen if they sense upcoming NF activities. Part of the consideration of group selection on special management areas is a result of the development of "subdivision silviculture." Timber harvesting activities must enhance the price of the land, because you can't afford to clearcut $5000 per acre land for $400 per acre timber. Developers don't want the NF activities to reduce the value of their land either, these people also write their congressmen and carry a big stick.

Conference centers, religious retreats, and retirement villages all have a vested interest in the activities on NF lands surrounding them.

PLANNING AND PRODUCING

Let's review some of the challenges briefly:

- low timber values
- high access and management costs
- difficult and expensive harvesting
- land that has higher values for other than timber production
- lots of people
- broken land ownership
- special local and national interests
- politically sensitive management direction

So what is a forester to do? The simple solution is to bag the sensitive and highly controversial eastern forests for other than low intensity timber production. And this may yet be the public's future direction for long-term managment.

However, right now this is not an alternative for the next 10-year planning horizon. The southern region of the National Forest System produces 1.4 bbf and the eastern region produces 700 mmbf annually. Despite the pressures for other uses of NF lands there is a tremendous wood based economy in the east that depends on much of the high quality timber coming from NF lands. #1 red oak logs still bring $800 per mbf at the mill and we all like solid oak furniture! Because of the low costs of natural hardwood regeneration, the high quality lumber produced and the central location to high population consumer centers, the sensitive lands in the east are potentially a valuable and cost effective land base.

So, forester, logging engineer give me some solutions!

Planning

Timber sale planning is not new to the Forest Service, but the changing arena has caused some necessary modifications in the way we must analyze the management alternatives. The objective remains the same: an offering that satisfies the FLMP objectives with the least amount of environmental disturbance at the lowest possible cost.

Forest Planning

These challenges to timber management along with others create a particularly challenging framework in which to plan for the production of forest products from the NF's in the east. The planning process itself is rapidly changing and now centers on the forest land management plans (FLMP). These forest plans are an attempt to resolve issues and objectives that affect the individual forests. The plans contain a proposed 10 year harvest schedule with compartments to be entered, acreages to be cut, and miles of road to be built. As one can see, predicting 10 years worth of activities is subject to low confidence. Assuming one day, many of the plans will be approved, further analysis must be conducted on the proposed projects because of the broad management direction contained in the plans.

Area Planning

The planning process can not stop with the forest plans but must further evolve to more and more site specific plans. This next step in planning we call area transportation planning. The objective of this phase of planning is to begin to establish roading patterns and logging systems which can be applied to a particular timbershed. Patterns which will implement the objectives and goals within the standards and guidelines of the FLMP. The emphasis is on long-term economics of area development by minimizing development costs and harvest costs. The area plan is tiered to the FLMP.

Project Planning

The area plan having been established and the position taken that some activity within the planning area will result in attaining some goals, the next phase of planning evolves: Project level planning. It is at this step of planning that we have considered actual units to be cut and actual roads to be built. This is the focusing and refinement of our earlier position. It is the basis for which we make a decision to allocate funds and begin implementation. The emphasis is now on short-term project economics of roading and logging systems and on logging feasibility. Paper planning with field recon is done during the silvicultural examination. A financial analysis of the proposed project helps to assess the necessary funding for the activities and the developments needed. As the project gets closer to the ground, the intensity picks up. As information becomes better, plans are refined, and the credibility of the analysis increases.

Unit layout

Unit layout is the final step in the planning process. Although paper design is done and skidding or yarding paterns projected, the final road locations must now be put in, landing locations flagged and unit boundaries flagged. The emphasis is on short-term economics of road construction and logging costs and on environmental protection. Streamside protection, wildlife inclusions and final unit shaping must all be done in the field just prior to marking. Unit layout is tiered to the environmental assessment document, the final quality control.

Training

One of the keys to implementing a successful planning framework is the training of those involved at every level of sale planning. The southern and eastern regions conduct an intensive 6-week training session for our foresters and engineers in the principles of harvesting systems and timber sale planning. In conjunction with Clemson University, SALHI (Sale Area Layout and Harvesting Institute) has addressed all the levels of planning with emphasis on the economic analysis of area plans, project logging plans and timber sale alternatives, and with emphasis on timber sale planning within FLMP standards and guidelines.

Producing

The national forests can do their part to plan and offer well-packaged, economically attractive timber sales which minimize the combination of development costs and the logger's harvesting costs. However, once the timber sale contract is signed, much of the NF's flexibility to adjust for success is gone. In order to carry out our management strategies, we need the road builder and the logger. They are the final link in the solution to the challenges we addressed earlier. They must be able to produce, to have a profitable business operating within the contract stipulations. If not, there is <u>no</u> success.

Current Situation

Ok logger, it's your turn. Let's discuss this situation. You're not in the flats, you're in steep, rugged terrain and you can't build contour skid roads because it doesn't look good, and you can't skid down the creeks like your dad did because of erosion problems. You're not on high ground either, you're in the swamps and you can't go in up to the top of your forestry specials because you damage the tree roots and cause ponding and the trees won't grow. It looks like some of the equipment you've got won't work in these places and you won't be able to work it all year either. We want you to try this overhead highline system called skyline yarding. That's right, overhead skidding, rehaul, buggies, the works. Well, no there hasn't been any equipment developed for the east, but the west coast has lots and so do the Europeans. It it breaks down? Well, no there isn't any place to buy parts or get service, but you can do that yourself, you're a professional logger. Setting the machine up, splicing the cable? No there isn't anyone back here to teach you except these Forest Service logging engineers. But the good news about overhead skidding is that we are going to offer lots of it. No, not so much in cottonmouth country, mostly in the mountains. People are trying some different things where the water runs both ways through the culverts, like fat tires, lots of tires, and some wire rope here and there. Somebody needs to get down there and see what we can do though.

Making It Work

So, logger, tell me what do you think you might need to make this highline system work? We're in it together.

Affordability--You have to be able to afford it. That makes sense. Somewhere around $100,000. Why so cheap? Oh, in case the pulp mill puts you on quota, you can still make your payments. I guess some big companies could afford more but then they can haul their own timber even if they shut you guys down, right?

Service and Parts--You have to be able to get it serviced and repaired. Guess I have to agree with that too. Makes sense to buy something from somebody that will stand behind it, just like a skidder or loader I suppose.

Training--You need somebody to help you get set up and teach you about rigging and splicing and deflection, HEY where did you learn that last word? You mean you can't just start something new and make money right off? I guess we need some training, teach some new skills. We could get some of your relatives from Washington or Oregon, that would help. Is that all? Just a couple other minor things. OK.

Commitment--Make sure the Forest Service lays out units you can log. OK, short and sweet. Make sure the Forest Service holds up their side of the bargain to provide a sales program for your highline. OK. We'll keep the loggable sales coming, and you get in the business, I think we'll make a good team. Nice talking to you.

SUMMARY

The complex management situation, sensitive terrain conditions and the economic climate present some major challenges to accomplishing timber management on the National Forests of the east. Without planning, we don't know how we are going to accomplish what we promised in the FLMP, and without the producer we can't deliver what we promised, either in terms of quality or quantity.

Our objectives remain the same, provide a timber sale offering that satisfies the FLMP objectives with the least amount of environmental disturbance at the lowest possible cost. Unsold timber sales accomplish very few of our management objectives and virtually no timber management.

Not only is there a necessity for improvement in the technical aspects of planning and producing but also a need for integrated resource management specialists, let's call them "Social Engineers", and place them in a shortage category!

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Simulation as a Tool for Harvest Production Planning[1]

Leonard R. Johnson[2]

Abstract: A general simulation model called SAPLOS (Simulation APplied to LOgging Systems) was designed to assist in the production planning steps of timber harvesting. It can be used to determine cost and production changes in a harvesting system when layout of timber sale, travel distances, silvicultural prescriptions, or equipment combinations change. Some of these changes may be caused by environmental constraints and by restrictions placed on system layout or equipment that will be allowed to operate. The model consists of three general components. The production process is modeled following traditional procedures of discrete event simulation. The environment of the timber harvesting operation is modeled to emphasize the raw material characteristics that have the greatest effect on system production. The third segment of the model represents the interface between the raw material and the production process. SAPLOS is written in FORTRAN IV, the language called for in the GASP IV simulation language. Examples of its use in production planning subject to harvest restrictions are presented.

Design tools used for production planning in most manufacturing settings do not work well in planning operations where the work environment or the "plant site" and "plant layout" are constantly changing. Production of a timber harvesting system will vary with changes in the physical environment of the workplace. Form and steepness of the terrain will dictate the type of material handling system used to move material to the landing. Slope and uniformity of terrain can change significantly within a single logging site. The dimensions of the raw material can also change dramatically from one standing tree to the next.

The large number of variables that affect production of timber harvesting and their wide range of values make it difficult to plan for production improvements using traditional production planning techniques. Design tools are needed, however, to allow the manager to anticipate production costs and experiment with system layout. The tools must provide continual guidance for the decision maker in areas where traditional production planning involves infrequent, but major decisions. Layout of the processing facility, the subject of detailed design in most manufacturing processes, will be subject to new constraints imposed on the harvesting system by environmental conditions at each new harvesting site. Distances between work stations, the capacity of the system for in-process inventories, and even the sequence of processing steps can vary with each site. Transportation of material between work stations, a constant for most manufacturing processes, has the highest cost and greatest amount of variability of any of the components of timber harvesting.

Planners in timber harvesting need a flexible tool that can provide input to these and other tasks involved in production planning. Simulation modeling can meet these needs. A simulation model that accurately duplicates harvesting activities can be used to plan the layout of existing logging systems, to develop data necessary for appraisal of timber prices, to investigate the feasibility of new equipment, to determine the cost impact of additional constraints, and to teach students and practitioners about the management of logging operations. The model must be capable of simulating normal harvesting configurations as well as specialties such as whole tree chipping and cable yarding. It must be adaptable to conditions in a variety of sites and for a variety of raw material sizes. The simulation model, SAPLOS (Simulation APplied to LOgging Systems), is a flexible tool that can be adapted to many production options. The general harvesting cases it was designed to handle are outlined in Table 1.

SIMULATION LOGIC APPLIED TO TIMBER HARVESTING

Development of a discrete event simulation model requires identification of the unique activities of the system being simulated. Activities represent the actual operations of the system: cutting of a tree, travel of a skidding machine from the landing to the woods. They are controlled in a simulation model through the occurrence of events. Events signal the beginning and end of system activities. For example, the arrival of a skidder in the woods is an event that signals the end of a travel activity and the beginning of a hooking activity. One of the keys to a realistic discrete event simulation model lies in the ability of the model developer to organize system events so that their order and logic in the computer duplicates that of the real world. This will often require duplication of a human response to a set of conditions usually affected by the physical environment. It will also include recognition of system delays and of both expected and unexpected interruptions in the production cycle.

Table 1: General cases that can be simulated with the SAPLOS model.

FELLING:
- Manual felling with chainsaw
- Mechanical feller/buncher operations

BUCKING:
- Bucking in the woods by faller
- Bucking at the landing
- Mechanical bucking and limbing at the landing

SKIDDING:
- Ground skidding from stump to landing with single or multiple landings
- Cable yarding uphill and downhill with single or multiple landings
- Prebunching loads to a main skid trail

LOADING/CHIPPING:
- Loading with separate loading units
- Loading with self-contained loaders mounted on hauling units
- Whole tree chipping of material

HAULING:
- Hauling with trucks from landing to mill
- Hauling with trucks from landing to intermediate dock

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The structure of events and activities will be similar in all discrete event simulation models. Arrival and end of service events at specific points or service stations in the system are commonly modeled. In SAPLOS system events are tied to critical inventory locations in the physical environment. This procedure allows development of an interface between the production steps and the physical environment. Since inventory locations are usually transition points from one subsystem activity to another, system events also occur at these locations. Five critical locations have been identified for the logging systems simulated with SAPLOS:

1. the tree stump or tree location in the woods;
2. the edge of a main skidding trail for systems using prebunchers;
3. the log landing;
4. the prehaul dock for systems using shuttle trucks and prehaul trailers; and
5. the processing point such as a mill yard.

Development of event subroutine logic also requires knowledge of the specific activities of each of the subsystems. The general flow of activities for each harvesting subsystem are shown in Table 2. Note the location of the beginning and ending points of activities. They generally coincide with the inventory points just mentioned.

The physical environment includes factors over which the manager has little control but which will limit the number of feasible management options. The physical environment includes such things as tree size and location, ground roughness and slope, and the layout of skid trails and roads. The description of a system's physical environment must also be coupled with assumptions about human response to that environment and to constraints imposed on harvesting because of the physical environment. If a simulation model is to be generally used, however, data required about the environment must parallel the available data of potential users.

The physical environments of timber harvesting systems impose additional constraints on model development. Because the physical environments are highly variable, models must be designed to ignore some of the variation or they will grow to an unmanageable size. Variables in the physical environment important to system production must be described in some detail, but the others must be ignored. SAPLOS treats three aspects of the physical environment: a description of the timber stand, layout of the harvest area, and the influence of stand and terrain on production. Treatment of these areas allows the harvest planner to impose simulated constraints on the operation and to determine the cost impact of those constraints.

SIMULATION OF WINCHING AND HOOKING

The interference in hooking caused by leave trees and the effect of an increased winching distance on production could be products of constraints imposed on a harvest operation. Their impacts on production are often hard to determine, but could be estimated through simulation. Winching and hooking production equations developed by Gebhardt (1977) for a crawler tractor working in the intermountain region were used to simulate production in the winching and hooking portion of a skidding cycle. The impacts on production of changes in stand density, tree size, and the percent of trees harvested were determined. Specific findings are related to the specific timber stand generator and winching function used, but the simulation procedure could be used in other instances to determine the cost impact of changes in the harvesting prescription for the stand.

Table 2: Cycle of activities for equipment and men in each of the subsystems of timber harvesting.

FELLING:
- Move to tree
- Cut tree
- Top and limb tree
- Buck tree (in some systems)

PREBUNCHING:
- Move to felled or bucked tree
- Hook tree to machine
- Move to skid road
- Unhook and deck trees

SKIDDING:
- Move to felled tree at stump or bunched trees at skidroad
- Hook trees to machine
- Move machine and trees to landing
- Unhook and deck trees

BUCKING:
(when done as separate operation at landing):
- Move to trees at new landing
- Cut trees into sections

LOADING:
- Move to trees at new landing
- Load trees onto truck

PREHAULING:
- Travel to landing
- Hook full trailer
- Travel to prehaul dock
- Unhook full trailer
- Hook empty trailer

HAULING:
- Travel to landing or prehaul dock
- Wait while being loaded
- Hook full trailer
  OR Unhook empty trailer
- Travel to mill
- Unload logs or trailer

The production function used for winching and hooking was as follows:

Winch and hook time =

$$-.0556 + .78505\,(\text{No. of Pieces}) + .00594\,(\text{Winch Distance}) + .01381\,(\text{Cu. Ft. Volume per Turn}) + .04609\,(\text{Cu. Ft. Volume per Piece})$$

The function accounts for most variables that might be considered important to winching and hooking production including number of logs or trees, winching distance, and load volume or weight. The limitation in this function is its failure to account for multiple drags of the winch cable per skidding turn. Since the entire function was applied to each winch drag, any preparation time included in the function was added to the time of each drag. Normally this preparation time would occur once per skidding turn. Preparation time includes the time for such functions as dismounting from the machine, untangling chokers, and looking for logs. The function was still used to test simulated results because it represented a case where winching and hooking times would be very sensitive to the number of winch drags and therefore, the number of leave trees in the stand.

The number of trees harvested per acre will affect the distance that must be walked with the winch cable to secure a turn of logs. Stands with greater density should have shorter winching distances and lower turn times. The effect of leave trees, however, should be to increase the number of winch drags per turn. Simulation of winching and hooking reproduced these effects as illustrated in Figure 1. Numbers listed beside each observation point in Figure 1 are the number of winch drags per turn. Drags per turn decrease as trees per acre increase because trees are located closer together. Drags per turn increase with an increase in the number of leave trees because of the interference they cause with hooking. Results show a large impact of various levels of thinning at 200 trees per acre and lesser impact at 400 and 800 trees per acre. Figure 1 also shows a relatively large increase in drags per turn as percent of trees cut decrease from 75 percent to 50 percent. Selection cutting influences production with both increased winching distances and normal interference. The logic developed for SAPLOS could be used by managers in specific instances to demonstrate the cost impact of selection cutting.

Volume per tree is generally acknowledged as having the greatest effect on harvesting production rates and costs per unit of volume. Individual piece size does not have a large effect on production time but does influence the volume of material moved. The time required to move a single large tree will be about the same as the time required for a single small one. The volume moved in this amount of time varies significantly, however. A logging simulator must duplicate the sensitivity to volume changes that result from changes in tree size. The production examples just presented used a constant piece size of 60 cu. ft. per tree. Production differences in cubic feet per minute when the tree size is allowed to vary about average sizes of 30, 45, and 60 cu. ft. per tree are shown in Figure 2. Decreasing the average piece size caused significant decreases in the production rate. Production differences are consistent for 200, 400, and 800 trees per acre.

When average tree size is combined with stand density, however, a different result will often occur. As stand density increases, average volume per tree is likely to decrease. A unit of land area can generally support a given amount of biomass and that volume can be contained in many or few trees. The dotted line on Figure 2 illustrates a conceivable production line when stand density is coupled with average tree size. In spite of the decreases in average turn time that result from increased density, the loss in volume caused by decreased piece size results in a net decrease in the production rate.

INFLUENCE OF SKID TRAIL LAYOUT ON SKIDDING PRODUCTION

An infinite number of skidding patterns could be used to deliver wood from the stump to the landing, but that degree of variation is unacceptable in a simulation model. Skidding patterns are restricted in SAPLOS by allowing the user to choose from five general skid trail types as illustrated in Figure 3. Parameters of the five general skid trails can be varied to allow a skidding layout that closely resembles most patterns found in the woods. By specifying the number of trails, length of trail, and distance between trails, the user is specifying the area that is to be harvested. Machines can be restricted to the main skid trail or allowed to travel into the stand.

Figure 1: Hooking and winching production as a function of cut and leave trees per acre.

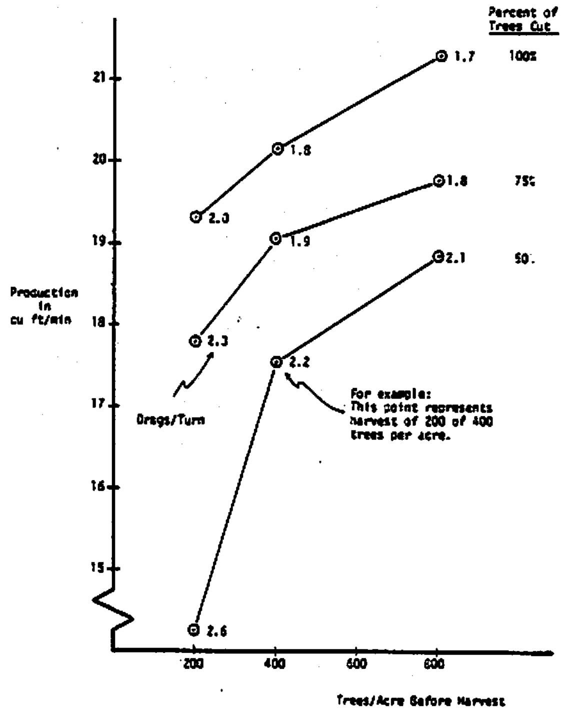
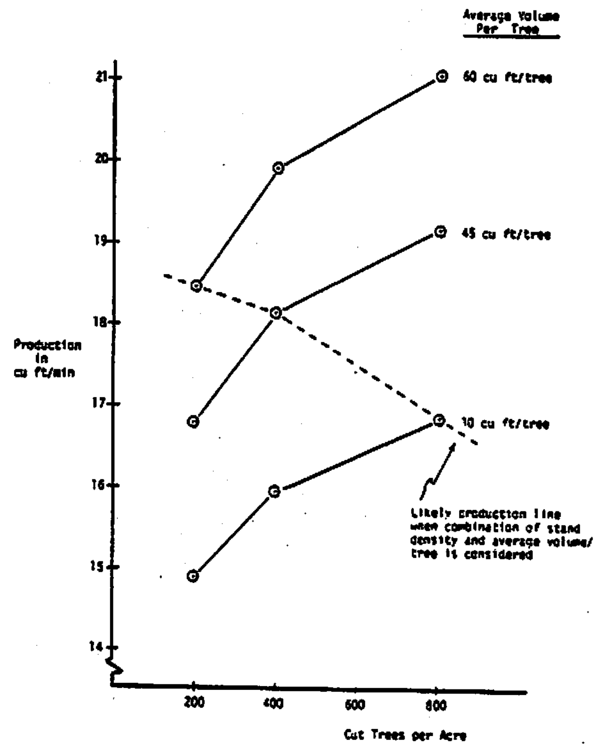


Figure 2: Hooking and winching production comparisons when average piece size and cut trees per acre vary.

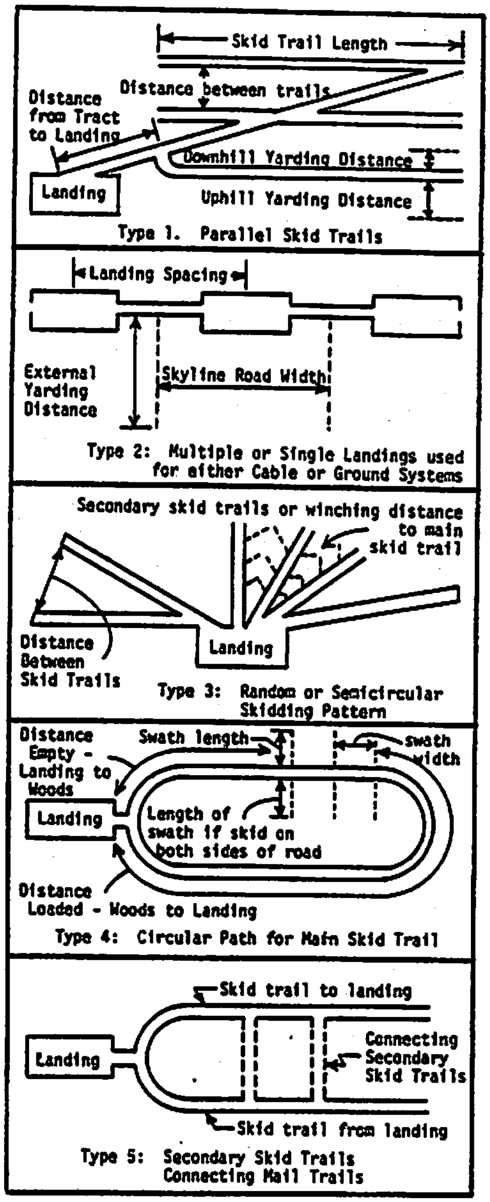


A timber stand of about 10 acres was laid out for skidding with the five trail types to investigate production differences by trail type. The layout alternatives could represent restrictions on a harvest operation so that production differences represent the costs of the constraints. Distance between secondary skid trails was set at 50 feet for all options. Skidding was simulated for a Caterpiller Model S518 rubber-tired skidder. Seifert (1982) investigated the production of several ground skidding machines and developed production equations for each element of the skidding cycle. The S518 skidder was one of the machines tested.

Skidding production on the five trail types is shown in Figure 4. The "on-trail" cases represent a skidder restricted to designated skid trails. Winching distances are longer in these cases. Off trail production rates exceed on trail production for all trail types. The number of main skid trails in "on" and "off" trail operations did not change in this example, but simulation would allow the user to experiment with the tradeoff between the number of main skid trails and winching distance.

Extensive off trail operations can cause large amounts of site disturbance and can result in unacceptable levels of soil compaction. SAPLOS could be used in planning to determine the incremental cost of on trail skidding operations. Comparison between skid trails gives the production advantage to skid trail type 3. Trail type 3 is the pattern generally selected by logging managers that have developed SAPLOS data as typical of their operations.

Figure 3: Schematic illustrating skidding pattern of five skid trail types and respective parameters.



INFLUENCE OF MACHINE PARAMETERS ON PRODUCTION

Another factor of concern to production planners will be the impact of changes in machine characteristics. The cost effectiveness of improvements in various facets of machine design can be evaluated through simulation. A user contemplating the purchase of a new machine with stated advantages over an existing machine could simulate operations with both and compare cost and production results. The effect of travel speed on production is an example. Previous comparisons of the production differences between on and off trail operations assumed that travel speed on secondary skid trails would be the same as travel speed on the main trails. This may not always be true. SAPLOS provides the user with an opportunity to vary travel speed with the trail classification. Skidding was simulated on two types of sale layout and with travel speeds on secondary skid trails of 25, 50, 75, and 100% of main trail speeds. Results in Figure 5 show the impact of slower secondary skid trail speed at both levels of secondary trail distance.

Increases in machine capacity can increase the production of a machine, but other factors can prevent that capacity from being fully utilized. This effect is shown in Figure 6 where capacity of a rubber-tired skidder was varied from 300 to 640 cubic feet. Capacity of 300 cubic feet was 75% of normal; 640 cubic feet was 150% of normal. Results show a significant gain in production when capacity is changed from 300 to 425 cubic feet. Gains are small between 425 and 640 cubic feet. Reasons for this can be explained from the detailed simulation results. Turn times increase substantially with changes in capacity indicating the increased time required to hook additional pieces. Pieces hooked per turn, however, do not keep pace with the increases in turn times. At large capacities the maximum winch distance of the machine becomes a limiting factor. Additional time is required to hook all the pieces a machine can carry because drag size is limited by winch distance. A large number of winch drags are required per turn and this increases turn time. Results in Figure 6 show the need to match component capabilities in a skidding machine.

CASE STUDY: EQUIPMENT CHOICES IN CABLE YARDING

The case studies presented to this point have dealt with one subsystem of harvesting. The model can also be used to investigate production and cost changes when the entire system is considered. This is illustrated through a cable yarding example. Much of the area that will be harvested can be characterized by the cross section of terrain shown in Figure 7. Slope distances from ridge top to the bottom average 1800 feet.

Figure 4: Skidding production for a rubber-tired skidder compared for five skid trail types and skidding on and off the main trail.

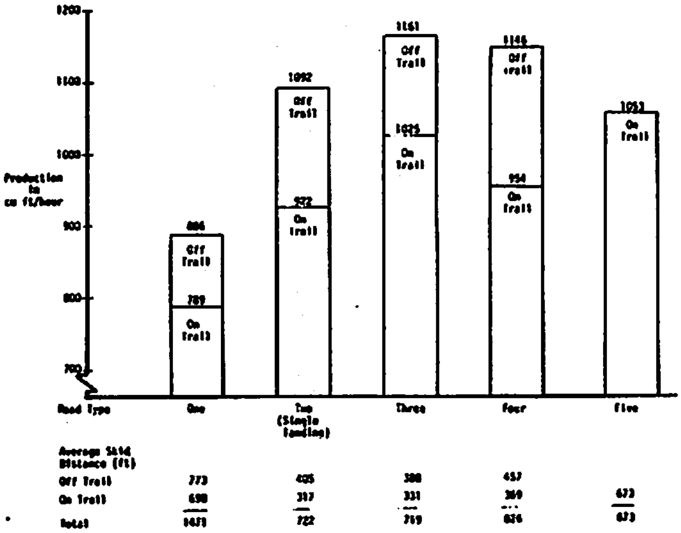


Figure 6: Production of a rubber-tired skidder as a function of changes in machine capacity and skidding distance.

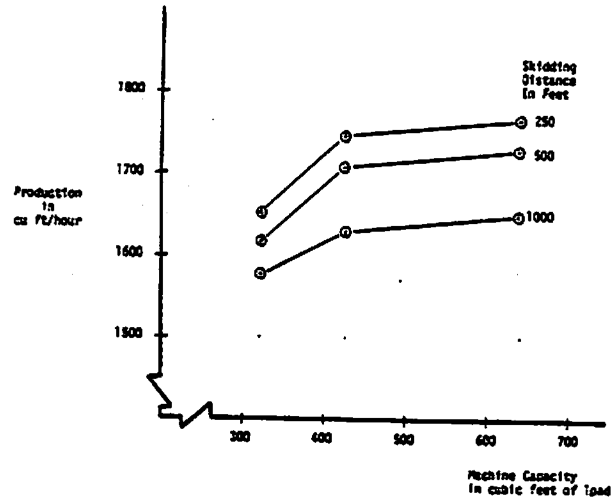


Figure 5: Skidding production of rubber tired skidder as a function of on and off trail skid distances and travel speeds. Basic speed is 7.9 MPH empty and 6.6 MPH loaded on the main trail.

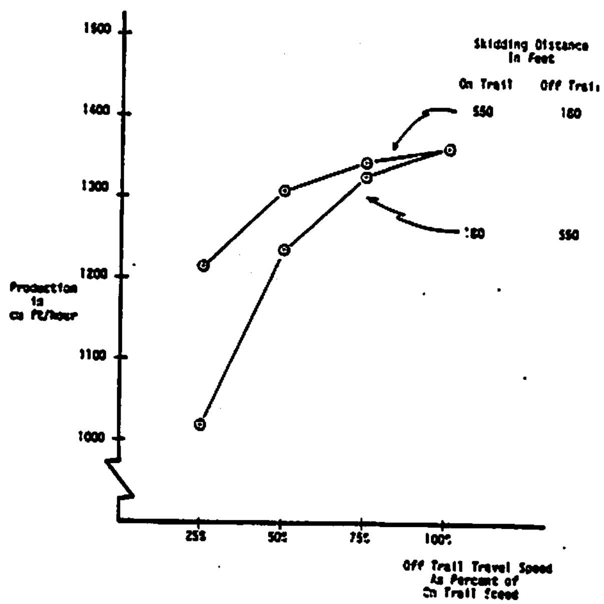
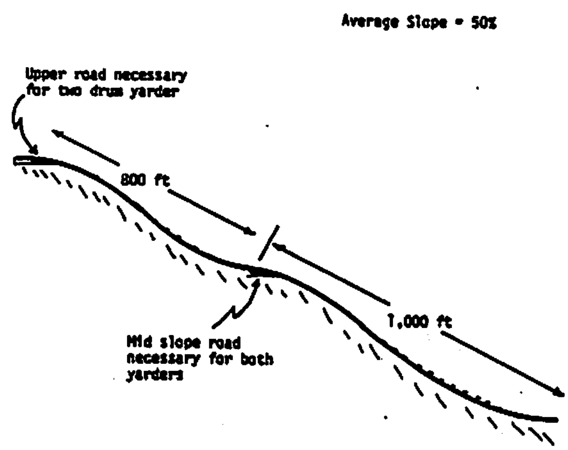


Figure 7: Typical cross section of terrain on slopes averaging 1,800 feet from ridge top to bottom.



The profile of the slope and the slope distance present several problems for yarding. Yarding could be effectively done above or below the critical terrain point near midslope, but load sizes would be very limited if yarding was attempted from the ridge top to the bottom with a single span of cable. The desire to use single span yarding equipment common to the region and the slope limitation at midslope dictate the need for a midslope road to log the lower portion of the slope. Production planning questions relate to the upper portion of the setting. Material could be yarded downhill to the midslope road, but downhill yarding requires a three drum yarder and downhill yarding is generally not as efficient as uphill yarding. An alternative to downhill yarding would involve construction of a road at the ridge top so that material on the upper slope could be yarded uphill.

Analysis is complicated by the need to consider the costs of loading and hauling in the decision. The number of logs scheduled for removal from an average yarder setting in this area exceeds the available decking area, and logs must be hot-loaded onto trucks as they are yarded. The resulting logging system will consist of the yarder, a loader, and an appropriate number of haul trucks. The impact of felling on the decision can be ignored.

The third drum necessary for downhill yarding adds \$75,000 to the cost of the yarder. Reduction in production because of downhill yarding can be varied through an input variable that reflects the ratio of uphill yarding time to downhill yarding time. The ratio of uphill yarding time to downhill yarding time in this comparison is 0.8 (Johnson 1984). The site is located 52 miles from the process point: 40 miles on pavement, 10 miles on gravel, and 2 miles on an unsurfaced spur road. The harvest prescription calls for removal of

400 pieces per acre. Landings are limited to the haul road and have a capacity for 2 machines and 100 logs.

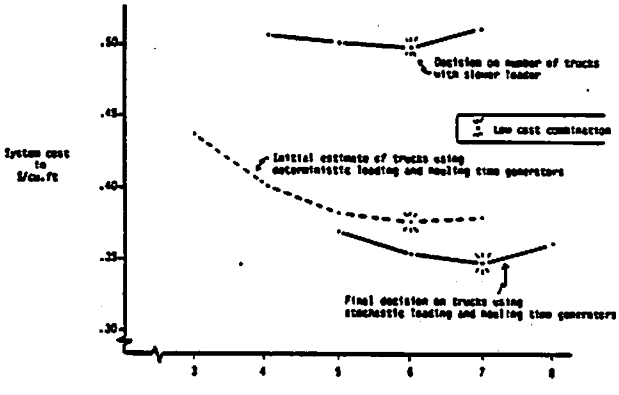
Loading of logs as they are yarded requires an adequate number of trucks in the system. If the number of trucks is too small the loader waits for trucks and the accumulation of logs at the landing causes delays in yarder operations. Too many trucks in the system can be costly because of the idle time of trucks waiting for loading. An optimal number of trucks will maintain a proper balance between yarder and truck delays.

A two stage process was used to determine the optimal number of trucks through simulation. The first stage of the analysis simulated operations on a smaller site with loading and hauling times that were calculated from deterministic equations rather than from probability distributions. Results of these runs are presented as the middle curve in Figure 8. Lowest cost is experienced when 6 trucks are used in the system. The cost differences between 5, 6, and 7 trucks, however, are not large. The analysis was repeated using probability distrubutions to generate loading and hauling times. These results are presented as the lower curve in Figure 8. The curve shows 7 trucks as the best number to run when loading and hauling conditions are more variable. The extra truck is apparently needed to fill gaps that the variable production conditions create.

The harvest area simulated included four, one hundred foot corridors so that results would reflect the impact of setup times on production. The two-drum yarder was tested over both 800 foot and 1000 foot yarding distances. Costs of these two variations were added to obtain a total logging cost over the study site. Up and downhill yarding from a single road was accomplished with one set of simulation runs.

Logging costs and delays for the three cases are presented in Table 3. Cost per cubic foot and cost per piece are lower for both of the uphill settings than for the combined operation. This is expected since the three drum yarder has a higher initial cost and has slower yarding speeds in the downhill setting. Loading and hauling costs are similar for all cases. The differences in total costs can be traced to differences in yarding costs. System delays produced by subsystem interactions can also be seen in Table 3. The yarder is blocked by logs a higher percentage of the time on the 800 foot uphill set than on the other two. Shorter yarding distances on the 800 foot set allow faster yarder turn times. The increased production could not

Figure 8: Simulated system costs in dollars per cubic foot as a function of the number of trucks in the system.



be fully utilized, however, because of the limited capacity of the landing.

Total costs including roads were calculated by projecting road costs over the 400 foot width of the setting. Cost of the midslope road was estimated at $35,000 per mile or $2652 for the 400 foot segment needed in the simulated setting. The ridgetop road was estimated at $25,000 per mile or $1894 for the simulated setting. Total system costs with roads are presented in Table 4. Use of the two drum yarder with midslope and ridgetop roads is shown as the least cost option.

SUMMARY AND CONCLUSIONS

Production planning for a timber harvesting operation must be conducted around a physical environment that is constantly changing. Design tools that can assist with this production planning process must be flexible. They will have to be adapted to variations in terrain conditions, the layout of the harvest area, the equipment used in the logging subsystems, and the location of the work functions. A general, flexible simulation model can fit this requirement and can provide valuable information for many of the steps required in managing a timber harvesting operation. SAPLOS was designed with these objectives in mind.

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Table 3: Production, delays, and costs simulated for two types of yarder on uphill and mixed settings.

	YARD UPHILL 800 ft	YARD UPHILL 1000 ft	YARD UP AND DOWNHILL
PRODUCTION			
ACRES	7.346	9.183	16.529
CU.FT.	106,669	132,219	241,824
PIECES	2,940	3,672	6,611
DELAYS - %			
YARDER			
LOG BLOCK	19.2	13.6	13.4
LOADER			
WAIT FOR TRUCKS	23.6	19.5	21.6
WAIT FOR WOOD	0.0	2.9	2.3
TRUCKS			
WAIT FOR LOADING	24.2	24.3	24.0
COSTS			
SKIDDING			
$	9,143	11,557	25,734
$/PIECE	3.11	3.15	3.89
$/CU.FT.	.0857	.0874	.1064
LOADING			
$	5,279	6,718	12,210
$/PIECE	1.80	1.83	1.85
$/CU.FT.	.0495	.0508	.0505
HAULING			
$	23,655	29,575	53,786
$/PIECE	8.05	8.05	8.14
$/CU.FT.	.2218	.2237	.2224
TOTAL			
$	38,077	47,850	91,730
$/PIECE	12.95	13.03	13.88
$/CU.FT.	.3570	.3619	.3793
COMBINED:			
$	85,927		
$/PIECE	13.00		
$/CU.FT.	.3597		

Table 4: Comparison of the logging and road costs two yarders simulated for a 16.53 acre setting.

	UPHILL 800 FT AND UPHILL 1000 FT	DOWNHILL 800 FT AND UPHILL 1000 FT
LOGGING COST	$85,927	$91,730
ROAD COST	4,545	2,652
TOTAL	$90,472	$94,382
$/ CU.FT.	.379	.390
$/ PIECE	13.68	14.28

SELECTION OF DESIGN FACTORS IN CABLE LOGGING: An Economic Approach[1]

John Sessions, Marvin R. Pyles and John W. Mann[2]

Abstract: The design factor for cable logging system payload calaculations in the western United States has traditionally been set at 3 to 1. It is used in an effort to consider uncertainty of loading, strength and wear characteristics of wire rope, economy, and safety. The 3 to 1 ratio has become a standard with little consideration given to the varying probabilities and costs of failure for different logging system components. This paper presents an economic approach to selection of design factors for cable logging systems using a simulation procedure. A design factor which maximizes net revenue is determined by simultaneously considering revenue, production, operating cost and safety. This conceptual simulation model is used in an example to select the optimum design factor for a tailspar. The intent is not to provide an actual working model but to promote discussion on how cable system design factors could be selected.

Should the design factor used for cable logging operations consider the size and distribution of the felled and bucked timber as well as harvest unit geometry? Further, should design factors be constant for all components of the cable system or should they vary according to the probability and costs of component failure?

Over the past 15 years, the degree of analysis used in planning cable logging operations has increased dramatically. Solution of complex static payload calculations for skyline systems by microcomputers has become routine (Nickerson, 1980). The evolution of these solution techniques has seen weightless line models replaced by rigid link models, which in turn have been replaced by catenary solution models. However, for these improvements in logging planning and operations to be meaningful, the design factor used in calculating payloads or interpreting the results must have a rational basis. We feel that the knowledge of cable logging system parameters has reached the point at which discussion of this topic is appropriate. In an effort to stimulate such discussion, we suggest an economic approach (Freudenthal 1956) to setting cable system design factors.

Design factor can be defined as the ratio of maximum capacity to allowable load. The more common term "factor of safety" can be used synonomously with design factor, and is also used to represent the operating condition: the ratio of maximum capacity to applied load. Maximum capacity may be defined as a mean value from a population, or some lower limit.

The objective in selecting a design factor is to insure satisfactory performance of the cable system. Considerations for selecting engineering design factors should include uncertainties in loading, variability of structural materials, accuracy of the analysis used in the design process, quality of construction and maintenance, and consequences of failure (Meyerhof 1970, Mann 1984). Satisfactory performance of the system is measured in terms of safety and economy.

The present approach to cable system design begins by using a standard design factor to set allowable stresses in an entire cable system (or for its individual components) or by selecting a design factor based on personal judgement. The standard value of design factor used in the western United States is 3 to 1.

With this paper, we would like to examine an alternative to the existing design procedure. The concept we present uses economic criteria as the basis for selecting design factors where costs associated with probability of failure and with overly conservative designs are considered simultaneously. In this concept, safety is treated as a cost which is an approach that has been used regularly in aircraft and highway design.

ECONOMIC MODEL FOR A SINGLE VARIABLE

The concept of using economics as a basis for selecting design factors can be explained by considering a simple model where the design factor is the only unknown variable and the ultimate objective is to maximize expected net revenue per hour. Expected net revenue per hour, R, can be expressed by the equation,

$$R = V \times P - C, \qquad (1)$$

where; V = value per unit production, \$/mbf,
P = expected production. mbf/hr,
C = cost of production, \$/hr.

Expected production, P, is a function of the expected gross production per yarding hour, p, in mbf/hr, reduced by the downtime per hour of production due to system failure, t. This can be expressed as,

$$P = p \,/\, (1+t) \qquad (2)$$

Expected gross production per yarding hour is obtained as the product of average volume per yarding cycle (turn), v, in mbf, and the number of turns per hour. Turns per hour is developed by dividing the effective yarding hour, EH, in minutes per hour, by the average turn time, CT, in minutes, including all delays not associated with system failure. This is expressed in equation form as,

$$p = v \times (EH/CT) \qquad (3)$$

The expected downtime, t, due to system failure is a function of the probability of failure per yarding hour, P_f, and the average downtime per failure, t_f. This is expressed in general form as,

$$t = f(P_f, t_f) \qquad (4)$$

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At this point the production part of equation (1) is complete and can be expressed as,

$$P = V \left[\frac{v\left(\frac{EH}{CT}\right)}{1 + f(P_f,\ t_f)} \right] \qquad (5)$$

Design factor enters the production component of the net revenue equation as part of the average volume per turn and in the probability of failure. Average volume per turn is influenced by the design factor because the guidelines used in selecting logs that will make up a single turn consider the allowable load on the cable system, which by definition is a function of the design factor. Probability of failure is influenced by the design factor because the closer the operating guidelines are to the maximum capacity of the system, the greater the likelihood of failure.

Cost of production, C, is influenced by the probability of failure of the system, hence it is also a function of the design factor. The expected cost of production could be expressed in general form as,

$$C = g(P_{nf},\ C_1) + h(P_f,\ C_2,\ P_{fi},\ C_3) \qquad (6)$$

where; P_{nf} = probability of no failure

P_f = probability of failure

P_{fi} = probability that if failure occurs an injury will result.

C_1 = expected cost per operating hour including normal rigging and moving time.

C_2 = expected cost per hour due to system failure, downtime, and repair.

C_3 = expected cost per hour due to worker injury.

From this derivation it can be seen that the final form of the expected net revenue equation has the design factor variable in both the positive (production) and negative (cost) terms.

$$R = V \left[\frac{v\left(\frac{EH}{CT}\right)}{1+f(P_f,t_f)} \right] - \left[g(P_{nf},C_1)+h(P_f,C_2,P_{fi},C_3) \right]$$

This is the basis for our model. For the sake of simplicity, the value of wood, V, delivered at the landing has been treated as a constant. A more complete expression of value per unit of production would be a price for logs delivered at the mill. This could be incorporated into the model by including transportation and other handling costs, but it is not necessary to illustrate the concept.

In order to develop the rest of the necessary input for this calculation we now must turn to simulation techniques. Average and maximum turn sizes are simulated, based upon a stochastic distribution of logs in a cutting unit (LeDoux 1984). These simulated turn sizes are then used in a structural model (e.g., Sessions, and others 1985) which predicts component stresses produced by those turns. These predicted stress levels are compared with a sample tailspar to determine if failure would occur. If failure is predicted, associated costs and downtime are incorporated into the net revenue computation.

Tailspar Example

As an example of how this procedure might be used to select an optimum design factor, we will apply the concept to a skyline tailspar, assuming that this is the only part of the system for which a design factor must be selected. A major uncertainty in selecting tailspars is the strength variability of trees (fig. 1). One method used in the design of green timber structures which considers this strength variability is to select a maximum working stress which is some number of standard deviations below the mean strength of the tailspar population (The Wood Handbook, 1974). This minimum stress defines the design factor, and for normally distributed populations, allows calculation of the probability of failure. Selection of this standard includes some implicit but unstated set of costs. However, the optimal design factor from a maximum net revenue viewpoint may not be at an arbitrary number of standard deviations from the mean. This is where the proposed simulation comes into play.

To determine the optimal design factor for a tailspar, we suggest the following procedure.

Step 1. Obtain the strength distribution for the available tailspar population (fig. 1). For this example we are using the average distribution for Douglas-fir (The Wood Handbook, 1974). Ideally this would be obtained from combined strength tests of green tree sections to reflect strength influencing characteristics, such as the presence of knot whorls, growth rate, heartwood to sapwood ratio, etc.

Step 2. Based on the tailspar rigging geometry, determine the relationship between skyline tension and maximum combined stress in the tailspar (fig. 2).

Step 3. Using an appropriate technique of skyline profile analysis, obtain the functional relationship between the ratio of skyline tension to turn weight and position along the skyline span (fig. 3). Implicit in this relationship is the log geometry during yarding, which for this example is one end suspension.

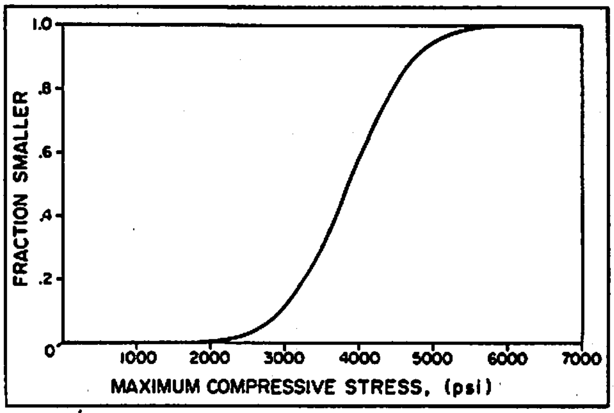

Figure 1--Strength distribution of green Douglas-fir trees shown as that portion of the population (y) that has a compressive strength smaller than a given value (x).

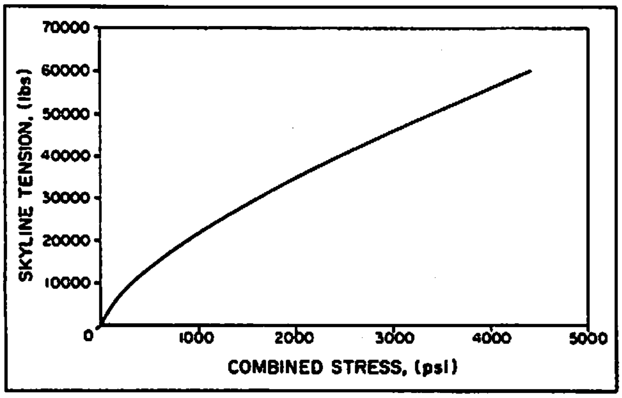

Figure 2--Skyline tension and the maximum combined stress in a 12 inch dbh tailspar that results from such tension.

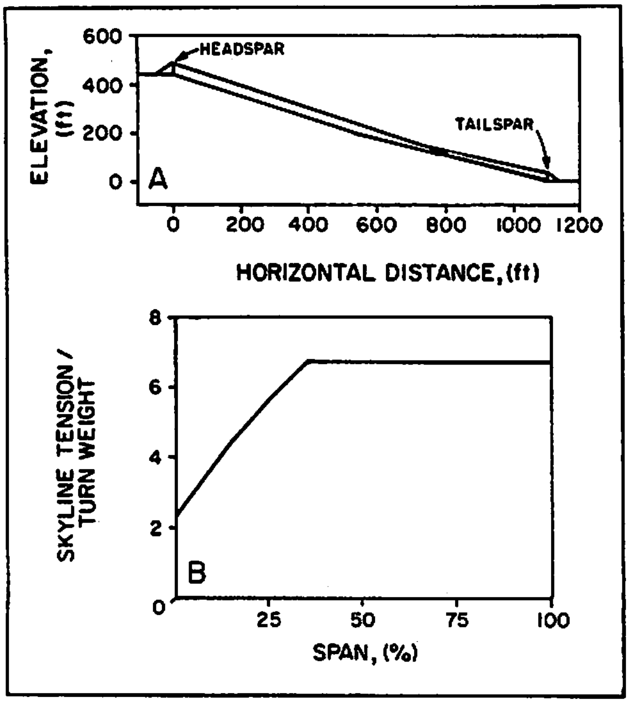

Figure 3--a) Skyline profile dimensions used for the example, and b) the skyline tension to turn-weight ratio resulting from a load being applied at various positions along the skyline span.

Step 4. Select a maximum design stress from the tailspar strength distribution, and using the relationships from steps 2 and 3, determine the turn weight that will produce this stress for varying postions along the skyline span. These turn weights become the operational guidelines; they are the maximum log weights that are to be combined in each cycle of operations according to position along the skyline.

Step 5. Randomly select a tailtree from the distribution developed in step 1.

Step 6. Simulate the turn weights and tailspar stresses that result from the operational guidelines. This simulation is based on the distribution of logs in the harvest unit. For our example, we used a removal volume of 12 mbf per acre with an average tree dbh of 12 inches. The size distribution of trees is shown in figure 4. Felling pattern and the subsequent log locations were obtained from the YARDALL model (Sessions 1978). Assumptions used in this model are that the trees would be bucked into 40 foot maximum length logs with the top merchantable log having a small end diameter of 5 inches.

Step 7. Following simulation of each turn weight, if stress caused by the load exceeds the strength of the tailspar selected in step 5, the tailspar is assumed to have failed and another tailspar drawn at random from the population is used to continue logging of the cutting unit.

Step 8. Accumulate production and downtime statistics. For this example we assumed that a broken tailspar resulted in 4 hours average downtime and that a replacement tailspar was always available immediately adjacent to the broken one. No possibility of injury or costs of injury were included in the example, but must surely be considered in practice.

Step 9. Since the procedure is stochastic, an acceptable value is obtained by repeating these steps for a number of sample tailspars until a stable production rate is reached for each design factor.

Step 10. Calculate expected net revenue per hour for the design factor selected after a suitable sample has been simulated.

Step 11. Repeat the procedure until the maximum net revenue is identified.

For this example the optimum design stress is about 2500 psi (fig. 5a). This corresponds to a design factor in the tailspars of about 1.6 based on a mean compressive strength of 3870 psi. Expected net revenue for this example is shown in figure 5b. It is based on a timber value at the landing of $55 per MBF which includes only this value of yarding the timber. An hourly operating cost of $175 was used to represent a 4 drum, 1 inch skyline machine with a 50 ft. tower, being operated by a 5 man crew. As can be seen in figure 5b, too high or too low a design factor can have an undesirable effect on net revenue.

Multiple Variables

This procedure could be extended to accomodate multiple variables including all the components of a cable logging system (various line segments, anchors and intermediate supports) if the strength distributions and costs of failure for those components can be estimated. For each assumed set of design factors a maximum allowable load is established, the yarding operation is simulated, and the net revenues are calculated. During simulation as each turn is yarded the potential failure of each design component is checked by comparing its allowable stress to that created by the load.

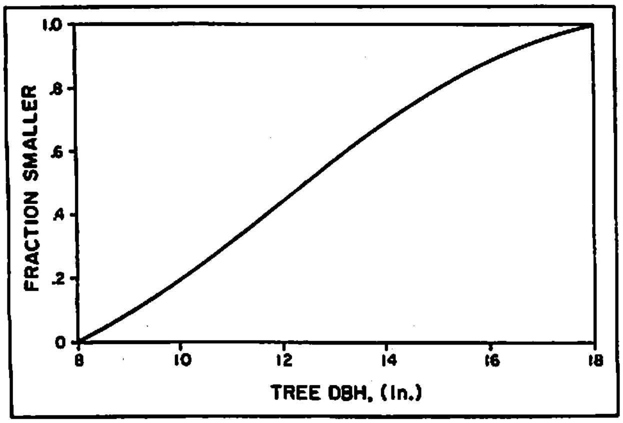

Figure 4--Size distribution of yarded trees shown as that portion of the population that is smaller than any particular tree DBH.

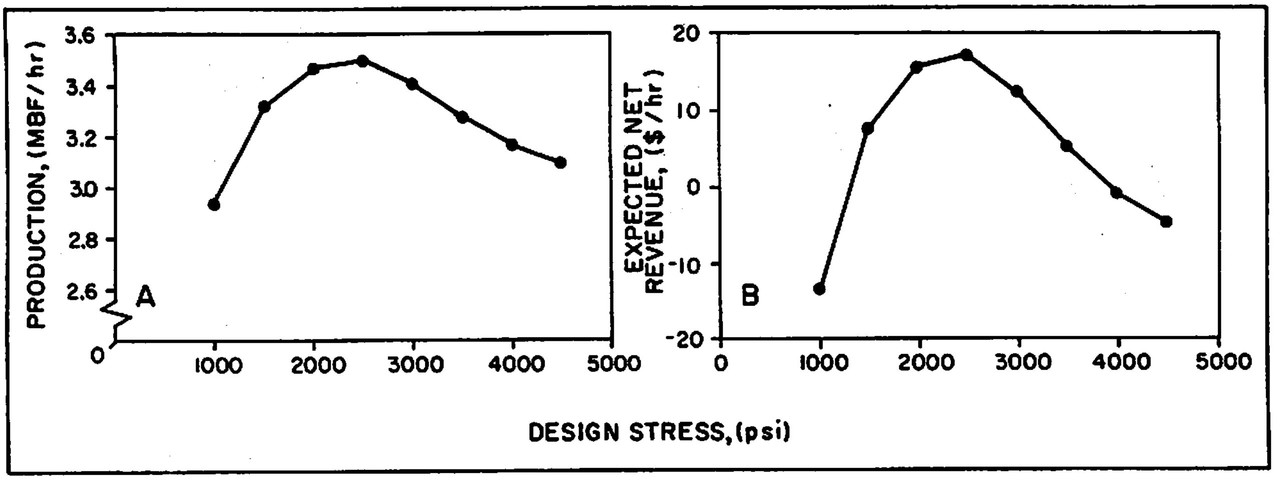

Figure 5--a) Production in MBF per hour vs. tailtree design stress, and b) net revenue for varying design stresses.

Summary

An economic model to calculate the optimal design factor for cable logging systems has been suggested. This approach combines revenues, production, operating costs, and safety costs to maximize net revenue.

This model is not an actual working tool that could be put to use in operational planning at this time. It is a concept that is intended as a starting point for continuing discussions among forest engineers on the topic of cable system design factor selection.

Using this model for a given component of a cable logging system--in this case the tailspar--design factors may differ even if the probabilities of failure are the same. This can occur if the availability and cost of tailspar substitutes differs.

If the probability and costs of failure vary for separate components of the system, there may be a number of different design factors. For example, the design factors for skyline, mainline, guylines, chokers and tailspar may all differ depending upon the probabilities and costs of failure for each separate component.

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Cable Yarding on Environmentally Sensitive Areas in New York State[1]

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Abstract: New York's predominately urban population has had a long and continuing interest in its forests and how they look. A sizeable portion of New York's wood resource is located on steeper slopes. Cable harvesting has the potential for providing less environmental effects and increasing the timber land base while maintaining competitive harvesting costs. This study evaluated the technical, economic and environmental feasibility of operating the Clearwater yarder on New York's sloped forestland. The Clearwater is a moderately small skyline yarder developed by the USDA - Forest Service. A detailed time study was employed to determine productivity. Yarding damage to the residual hardwood stand was sampled. Cable yarding was found to work well on steep slopes where environmental concern and even local ordinance preclude harvest by conventional skidding methods. The Clearwater was not cost-effective during the study period, primarily due to a low machine utilization rate resulting from a time-consuming breakdown. With potentially obtainable utilization rates, the use of the Clearwater or similar machines should also be economically as well as environmentally feasible.

New York is often viewed as a large urban state. With a total population of 17.6 million and a land area of 30.3 million acres, it easily qualifies on both accounts. A high percentage of the population is located in the southeastern portion of the state, partially accounting for the fact that the state is over 60 percent forested.

New York's predominately urban population has had a long and continuing interest in its forest resources. This interest dates back to 1885 with the passage of legislation, later reinforced by a constitutional amendment, which placed all state lands within a defined (blue line) area into a "forever wild" category. This blue line area has become known as the Adirondack Park and the state lands within as Preserve lands. No harvesting is permitted on Preserve lands. Private lands within the blue line have become the focus of various harvesting regulations. Harvesting on these lands has truly become a forest operation on politically and environmentally sensitive areas.

[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

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The environmental concerns of New York's population have also resulted in the passage of some 22 town ordinances regulating harvesting. Some of these town ordinances are in the heavily populated areas. Contrary to many western situations, where the harvesting operations may be remote to the population centers, operations in New York State are often within view of villages and cities. New Yorkers are concerned about how the forests look, whether public or private. Cable logging may be a means of improving the way a forest looks after harvesting.

While a small percentage of the 14.4 million acres of commercial forestland in New York is on slopes greater than thirty percent, an inordinately high growing stock volume per acre can be assumed if one draws an analogy between the steep land of the State and western North Carolina (Deal 1980). Cable logging may also be a means of extending the timber land base to these steeper areas while addressing the concerns for adverse harvesting impacts.

The Clearwater Yarder was evaluated in terms of its environmental and economic feasibility while operating on New York's sloped forestland. This cooperative study was conducted by the SUNY College of Environmental Science and Forestry and the United States Forest Service - USDA, funded jointly by the USFS and the New York State Energy Research and Development Authority, and supported by International Paper Company.

THE CLEARWATER YARDER

The Clearwater is a three-drum yarder, designed and built by the Missoula Equipment Development Center in Missoula, Montana. The machine was rigged in a live skyline configuration. The haulback drum was not used in the study. Figure 1 shows the Clearwater rigged for use.

Figure 1 -- Clearwater rigged for yarding.

The skyline used was nine-sixteenths inch diameter, with three-eights inch diameter mainline. The 3-53 Detroit diesel (100hp.) provides skyline drum pulls of up to 7,500 lbs. and line speeds of up to 500 feet per minute. The mainline drum provides line pulls of up to 3,500 lbs. and line speeds of up to 1,000 feet per minute. Power is transmitted through a hydrostatic transmission. The line pulls would classify the Clearwater as a small to medium-sized machine.

The Clearwater as used in this study was mounted on a surplus Army 2 1/2-ton all-wheel drive truck. The unit without truck weighs 13,000 pounds. The cost of the Clearwater ready to mount on a truck or trailer, complete with a small Christy carriage and cables, is $87,000.

The Christy slackpulling carriage was used on the project. The Christy carriage uses a moveable stop on the skyline for positioning the carriage. When traveling along the skyline, the mainline is locked to the carriage. When the carriage strikes the stop the carriage locks to the stop and the mainline is released, allowing the mainline to be pulled laterally to the log turn.

One-way voice and horn communications between the chokersetters and the yarder operator were accomplished by the use of a Talkie Tooter.

STUDY SITES

The Clearwater operated on two different sites. One site in eastern New York provided production, cost, and stand damage data. The second site, located in western New York, provided stand damage data. The yarder was operated at both sites by professional logging crews.

Eastern New York

The eastern New York site was located on land owned by International Paper Company near the village of Ticonderoga. The area was on a slope that averaged 30 to 35 percent with small pitches over 50 percent. Numerous large rocks covered the slope, with some over five feet in diameter. This site was located within the Adirondack Park "blue line".

The vegetation on the site was mixed hardwoods, approximately 70 years old. Average volume on the data collection corridors was 2,000 cubic feet of pulpwood and 3,000 board feet of sawtimber, International scale, per acre. Timber characteristics are summarized in table 1.

Table 1 -- Summary of timber characteristics of the Ticonderoga site.

		Per Acre			
Species	Ave. Dbh	Ba	Pct.	T/a	Percent
Birch	9.7	32.1	30.0	62.1	26.8
Aspen	9.7	30.0	28.0	50.4	21.7
Sugar Maple	8.3	17.5	16.4	46.7	20.2
Basswood	8.3	17.2	16.1	45.4	19.6
Beech	7.7	5.0	4.7	15.4	6.6
Other	8.9	5.1	4.8	11.8	5.1
Ave. or total for site	9.0	106.9	100.0	231.8	100.0

All corridors were laid out using a hand compass, clinometer and hip chain. All corridors were approximately 400 feet in length and provided a maximum lateral reach of 75 feet. Deflection and payload analyses were run for each corridor, using a program called LOGGER (Nickerson 1980). Assessment of the visual impact of the harvesting operation was modelled thorugh a computer program with graphic output called PERSPECTIVE PLOT (Nickerson 1980a).

Data were collected on five corridors. Three of the five corridors were partial cut, while the remaining two corridors were clearcut. Timber was marked for the study by International Paper Company personnel. Approximately 55-60 percent of the basal area was removed in the partial cuts.

Western New York

The western New York site was located on private land near Olean. The study area was on a convex hillside with a 20 to 40 percent slope.

Vegetation was composed of 70 percent sugar maple (Acer saccharum Marsh.), 15 percent beech (Fagus grandifolia Ehrh.), and 15 percent other species such as northern red oak (Quercus rubra L.). The average basal area was 130 square feet before the cut and 72 after the cut. Average DBH was 10 inches before cutting and 9 inches after cutting, with individual trees ranging up to 24 inches in DBH.

Eight corridors were laid out, cut and yarded: four of these were under 200 feet in length and four were between 500 and 600 feet long. All corridors were selectively cut. No production data were collected on this site.

THE STUDY

The small size of the deck areas required removal of the yarded logs to provide work space. Each operator used a cable skidder to move the yarded material away from the deck to a location convenient for slashing or loading on highway trucks. Yarding was stopped momentarily when material was being choked and moved, thus detracting from the performance of the yarder.

Initial training of the professional logging crews was provided by personnel from the Missoula Equipment Development Center. A crew of four people operated the Clearwater during the production study: the operator, two chokersetters and a chaser on the deck. Two people alternately operated the yarder and swing skidder, switching jobs during the work day. Thus a total logging crew on the site during the study was five people. The logging crew moved, setup, and took down the yarder as part of their production responsibilities.

A continuous time study was made of the eastern New York operation by measuring six production elements: outhaul, lateral outhaul, hook, lateral inhaul, inhaul, and unhook. Delays were timed as they occurred. This was basically a tree length operation, with bucking cuts made only where weights of individual trees would have exceeded the load capacity of the yarder. All trees on a corridor were felled before yarding began. All felled trees and logs were measured before choking. Stand damage was obtained by a sampling system using rectangular plots.

ENVIRONMENTAL ASPECTS

Soil disturbance from cable yarding is minimal. As in conventional logging, haul roads and landings account for the greatest soil disturbance on the site. The average spacing between logging roads is about 150 feet in the East for skidder and tractor operations. As demonstrated in western New York, road spacing can easily be maintained at over 600 feet with a yarder such as the Clearwater. Because the yarder is confined to the roads and landings, soil disturbance off the road occurs only from the logs being yarded. In most cases the front end of the log was lifted off from the grounds so, except for the leveling of a few hummocks, only the litter layer was disturbed. The area of exposed mineral soil was negligible, occurring only on occasional corridors with convex slopes. From an environmental standpoint, the most obvious benefit of the Clearwater is its ability to reduce the need for bulldozed roads over those presently needed for skidder operations. Figure 2 illustrates a typical corridor, in western New York, after cable yarding.

Figure 2 -- Typical logged corridor in western New York site.

Injuries from both felling and yarding were measured at each of the two sites. Most of the yarding injuries were in the form of skinned bark. The percentage of serious injuries caused by yarding was under 10 percent at both sites for individuals and basal area. Damage caused by the cables occurs higher in the tree than damage by skidders, resulting in over 45 percent of the total yarding injuries occurring above 4 feet from the base of the tree. Figure 3 shows tree damage along a corridor. The direction of felling is a primary factor affecting yarding stand damage.

Figure 3 -- Tree damage along a corridor.

The use of cable yarders such as the Clearwater does not automatically result in reduced residual stand damage. Operator experience and technique are of great importance. The stand damage resulting from the use of the Clearwater in this study falls within presently accepted levels.

The skyline corridors accounted for over 20 percent of the total area of the stand. While the crowns from trees adjacent to the trail will probably occupy this area rapidly, minimizing a loss of stand production, the trees cut in this area are removed mechanically rather than according to silvicultural guidelines.

Of great importance is the perceived appearance of the logged area by those concerned with adverse harvesting impacts. Several of these individuals, when viewing the area, expressed comments such as "it sure looks good down there".

RESULTS - PRODUCTION AND COSTS

To be acceptable for use on environmentally and politically sensitive areas, a harvesting system must not only meet environmental constraints, but be economically sound. Time study data are important in determining economic feasibility. Table 2 shows the total delay-free cycle and element times for the eastern New York site. Results are shown in the following tables as a composite of both partial and clearcut areas.

Table 2 -- Delay-free element times (minutes).

Element	Mean	Maximum	Minimum	Percent
Outhaul	0.27	0.80	0.01	8
Lateral Outhaul	0.84	2.49	0.00	25
Hook	0.91	4.16	0.01	27
Lateral Inhaul	0.22	1.85	0.00	6
Inhaul	0.54	2.37	0.15	16
Deck	0.63	6.20	0.10	18
TOTAL CYCLE	3.40	8.98	1.39	100

The figures are based on 561 observations. Delays (described below) are not included.

The yarding cycle time depends largely on the yarding distance, number of pieces per turn and the weight or volume per turn. Table 3 shows the mean, maximum and minimum values for outhaul, inhaul and lateral distances; and the weight, volume, and number of pieces per turn encountered during the study:

Table 3 -- Values of production variables.

Element	Mean	Maximum	Minimum
Outhaul/Inhaul (ft.)	241	490	40
Lateral outhaul/ Inhaul (ft.)	37	97	0
Pieces per turn (no.)	1.8	5	1
Weight per turn (lb.)	1748	6071	109
Vol. per turn (cu.ft.)	34.4	131	1.9

During the data collection period, the Clearwater Yarder produced 19,288 cubic feet or 241 cords of wood (80 cubic feet per cord). Figured on a weight basis, the amount of wood yarded was 490 green tons.

Delays

Delays usually account for a significant portion of a scheduled work day in the woods. The first and most significant delay is set up and take down between corridors. The average time necessary to complete this task was 96 minutes. The shortest time necessary to move between corridors was 80 minutes, while the longest move time was 129 minutes.

The various delays encountered with the Clearwater are detailed in tables 4 and 5.

Table 4 -- Production delays in minutes.

Types	Number	Mean	Max	Min
Hangups	79	4.2	23.1	0.9
Move Stop	51	2.3	4.9	0.9
Stop Not Locking	13	1.3	5.0	0.3
Tangled Mainline	36	2.2	11.5	0.7
Waiting on Skidder	71	2.0	6.5	0.1
Slipped Choker	7	2.0	2.9	0.9
Move to New Corridor	5	96.5	129.0	79.8

Table 5 -- Nonproductive delays in minutes.

Type	Number	Mean	Max	Min
Broken Mainline	11	60.4	244.5	4.8
Loose Hydraulic Hose	2	4.7	5.9	3.6
Fix Stop	4	1.9	2.8	1.1
Miscellaneous	20	3.5	32.5	0.3
Broken Skyline	1	1,140.0	-	-
Machine Warmup, Maintenance		986.4	-	-

The Clearwater was scheduled to operate 79.8 hours during the data acquisition period. Nonproductive delays amounted to 36.4 hours, while productive delays accounted for 11.6 hours. The actual productive time was therefore 31.8 hours, resulting in a utilization rate of 40 percent.

Note that a major nonproductive delay was the skyline break. This was a rare event and should be depreciated over some life expectancy period. Without the skyline delay, the utilization rate would have been over 60 percent. Thus a more representative utilization rate would be between 40 and 65 percent -- probably around 60 percent.

Costs

A machine rate of $43.88 per scheduled hour was calculated (see table 6) based on actual labor costs and other data from the study as well as standard estimating procedures. Table 7 illustrates the production rates and cost per cord for the composite study and for the partial cut and clearcut areas. The composite utilization rate of 40 percent was usec to determine all per cord costs. If the skyline break is not included, the composite cost per cord based on a 60 percent utilization rate would be $9.62. The partial and clearcut costs would have been reduced to $8.81 and $10.45, respectively, per cord.

Table 6 -- Machine rate per scheduled hour

Yarder	
Fixed Cost	$8.64
Operating Cost	4.38
Labor Cost	29.06
	$42.08
Truck	
Fixed Cost	$0.80
Operating Cost	1.00
	$1.80
TOTAL	$43.88 per SH

Table 7 -- Production rates and costs

	Composite	Partial	Clearcut
Production-cords/PH	7.6	8.3	7.0
Cost - $/cd. (40 pct. utilization)	14.43	13.22	15.67
Acres	6.6	4.0	2.6
Volume harvested (cu. ft.)	19,288	8,677	10,611

Interestingly, the partial cut resulted in a lower per cord yarding cost based on raw data. Regressions developed for each of the corridor sets show that there is statistically no difference in production between the two treatments. Hook times and lateral outhaul times were greater for the clearcut corridors. The immense amount of slash in the clearcut areas appeared to affect the mobility of the chokersetters.

Swinging material away from the deck cost an additional $8.28 per cord based on a machine rate of $25.17 per scheduled hour for a new 100 hp skidder. Since the swing production depends on the Clearwater production, a 40 percent utilization rate was used. A 60 percent utilization rate would result in a cost for swinging of $5.52 per cord. An old depreciated skidder would further reduce costs of swinging.

DISCUSSION

The study showed that:

- The Clearwater was able to yard effectively on both partial and clearcut stand treatment areas.

- Yarding stand damage was somewhat less than when using conventional skidding.

- Soil disturbance was judged to be less than with conventional skidding.

- The cable yarding technique proved to be easily learned by personnel accustomed to conventional logging techniques, with a minimum of training. (More planning of the cable yarding operation is necessary than for skidder operations, however. Successful cable loggers must also become familiar with the planning needed.)

- Cable yarding produced an average of 7.6 cords per productive hour on terrain considered marginal or inoperable by conventional logging standards.

The cost of moving wood with the Clearwater during the study was greater than expected. Roadside wood, tree length, over $30.00 per cord leaves little room for profit considering the need for subsequent bucking and hauling, stumpage, access roads, and corridor layout and planning.

Increasing the utilization rate would lower the cost per cord for yarding. If the skyline break did not occur, or if it were considered a rare event and not included, the utilization rate would have been over 60 percent. Also, the crew operating the yarder was good in spite of the fact that none had been involved previously with cable yarding. However, more time with the yarder would have resulted in some added "finesse" that could reduce the number and length of delays and probably the number of trees damaged and the seriousness of the injury. Hangups, snags and tangles could probably never be eliminated but they could be reduced and further increase the utilization rate and further reduce residual stand damage.

The use of an old skidder for swinging coupled with the achievement of a 70 percent utilization rate could reduce swing costs from $8.28 per cord to $2.85. In addition, eliminating one person at the landing, while maintaining the 70 percent utilization rate, would likely result in a profitable operation.

While costs and environmental aspects are major factors in the acceptance of any new machine, other considerations may also be important. The roles of a yarder operator and crew, and a skidder operator are different. A skidder operator has a varied day, where part of the time is spent making up a load, an activity requiring a high level of physical energy expenditure. The rest of the time is spent in travel or decking which requires less physical exertion. The yarder operator performs a repetitive operation with a high level of attention if not physical exertion. Choker setting is a demanding job, requiring a constant physical exertion with few diversions. With an average turn time of 3.4 minutes, the choker setter has about 3 minutes to find and choke an average of two logs before the lateral outhaul begins. Several of the loggers felt that the day went faster when operating a skidder.

CONCLUSION

It would appear that there are currently situations, both environmentally and economically, where use of the Clearwater (or similar cable yarder) would be feasible in New York. If harvesting regulations become more widespread and/or constraining then cable yarding may be more acceptable. Interest in cable yarding in New York continues. This interest is best summarized in the concluding paragraph of an article in the Northern Logger and Timber Processor about this project by Johnson (1984):

> "If in the future it becomes necessary to place a monetary value on environmental damage (or lack of it), the knowledge gained ... will be helpful ... And that is the kind of information that will pay off for loggers in the long run."

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Harvesting Cost and Stand Damage Comparisons of Cable Thinning Techniques: Herringbone Strip Thinning versus Conventional Thinning.[1]

Loren Kellogg and Mike Hargrave[2]

ABSTRACT: A multi-discipline research study has been designed to provide answers for a wide range of questions related to management of young western hemlock (Tsuga heterophylla)-Sitka spruce (Picea sitchensis) forests. This paper summarizes results for that portion of the completed project concerned with harvesting cost and stand damage comparisons between cable thinning techniques (selective narrow and wide residual tree spacing, and herringbone strip cutting). Felling production rates were 249.50 ft^3/hr for the narrow treatment, 287.98 ft^3/hr for the wide treatment and 281.45 ft^3/hr for the strip treatment. Yarding production rates were 449.20 ft^3/hr for the narrow treatment, 513.36 ft^3/hr for the wide treatment, and 558.47 ft^3/hr for the strip treatment. Cost analysis indicated that, for approximately the same volume removal, strip thinning was the cheapest method. Stump to truck logging costs were 31 percent lower for strip thinning compared to selection thinning with the narrow treatment. Costs for the wide treatment were in-between those for the strip and narrow treatments. Residual tree scarring levels from yarding were 84.78 ft^2/acre, 91.64 ft^2/acre and 17.57 ft^2/acre for the narrow, wide and strip treatments, respectively. Regression analysis showed that yarding damage (scar area per turn) was correlated with the number of times the carriage was repositioned during lateral yarding, carriage clearance above the ground, angle of the log with respect to the mainline, who was the rigging slinger and who felled the timber.

Forest managers often consider commercial thinning in immature stands to capture mortality and stimulate growth of residual trees. High harvesting costs are a major component in the decision concerning commercial thinning. Thus, silvicultural methods and harvesting systems for young forests must be evaluated simultaneously for cost efficient management.

The thinning prescription (tree size, volume and pattern of removal) is an important variable affecting cost (LeDoux & Brodie, 1982) and residual stand conditions (Caccavano, 1982). Nearly all past thinning prescriptions in the Pacific Northwest have followed a selective system. Strip thinning, an alternative method to selection thinning, can also be used. Trees are removed in adjacent clearcut strips spaced at a desired distance providing alternating cut and leave strips. This method has been popular in plantation management on gentle terrain. Herringbone thinning is an alternative form of strip thinning where additional cut and leave strips are created at an angle to the main corridor (fig. 1).

The thinning prescription affects unit layout, harvesting cost and residual stand conditions. Unit layout cost with strip thinning may be lower than conventional thinning because tree marking can be eliminated (Hamilton, 1980). Commercial thinning harvest cost can also be reduced. Various studies have shown increased felling and yarding production and lower harvesting cost with strip thinning compared to selection thinning (Aulerich 1975, Kramer 1974, Twaddle 1977). Felling operations are improved because of easier felling within strips and fewer tree hangups. Yarding operations are improved because logs are located in extraction paths, producing high payloads and fewer yarding hangups.

The potential effects from scarring residual trees in commercial thinnings include loss of growth, loss of volume to decay, loss of quality, increased risk to diseases or insect attacks and negative aesthetic impacts. These potential impacts, however, vary considerably between stand types, harvest planning practices and logging methods (Benson and Gonsior 1981, Burditt 1981, Caccavano 1982). Tree scarring in western hemlock -Sitka spruce stands are of particular concern to managers because of their thin bark and susceptibility to a root disease, Fomes annosus.

Most past cable logging damage studies have been post harvesting analyses without identifying actual activities causing damage. These studies are helpful in determining damage levels; however, in order to identify methods and techniques that minimize damage, it is necessary to analyze on-going operations. Some studies during logging have been conducted in large timber stands with partial removal (Fieber et al. 1982, Miles & Burke 1984). Similar work is needed in smallwood thinnings.

The amount of individual tree and stand growth following thinning is highly dependent on the initial stand structure, stand age at the time of thinning, intensity of cut, frequency of thinning, and thinning method. Studies have shown less basal area growth and reduced stand yields following strip thinning compared to selection thinning (McCreary and Perry 1983, Kramer 1974, Hamilton 1974, 1980,

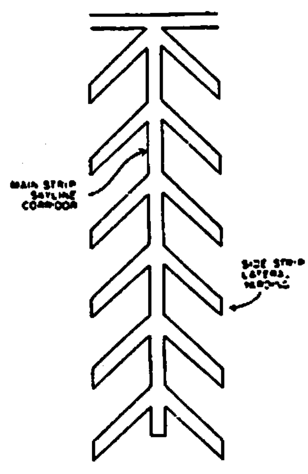


Figure 1--Herringbone thinning pattern.

[1]Presented at the 8th Annual Council on Forest Engineering Meeting. Tahoe City, California, August 18-22, 1985.

[2]Instructor of Forest Engineering and Graduate Research Assistant, respectively, Oregon State University, Corvallis, Oregon.

LeDoux 1983). Tree response to strip thinning occurs mainly within a short distance from strip edges.

Clearly, young growth stand management decisions must involve silviculture, harvesting and economic components. Data is currently lacking that provides detailed silvicultural effects and financial returns from commercial thinning with different prescriptions, particularly in western hemlock-Sitka spruce forests. Western hemlock-Sitka spruce stands are one of the world's most productive forest types, growing in a 2,000 mile-long strip along the Pacific Coast from Oregon to southeast Alaska. Careful and intensive management of these stands will help maintain productive forests and increase financial yields.

The flow chart in figure 2 shows research project topics addressed in this study. Harvesting production/cost and stand damage during logging results are summarized in this paper. All log volumes are reported in cubic feet. For conversion to board feet, in this study there were 3.4 board feet per cubic foot. Additional detailed analysis and results for these topic areas are documented elsewhere (Hargrave 1985, Kellogg et al. In Preparation).

The logging analysis and stand damage study together with additional silviculture and economic analysis (to be completed at a later date) will provide information to managers for comparisons of alternative management strategies for young western hemlock-Sitka spruce forests on steep terrain. The structure of this study and portions of the results should also be applicable to other regions where commercial thinning is conducted.

STUDY SITE AND METHODS

The research project was located on Cascade Head Experimental Forest, Siuslaw National Forest, northeast of Lincoln City, Oregon. The site is highly productive with good soil types and abundant moisture throughout the year. The timber stand resulted from natural regeneration. It was precommercially thinned at age 15 and was 30 years old during this commercial thinning study. Four thinning treatments, designated by the U.S. Forest Service, were replicated four times.

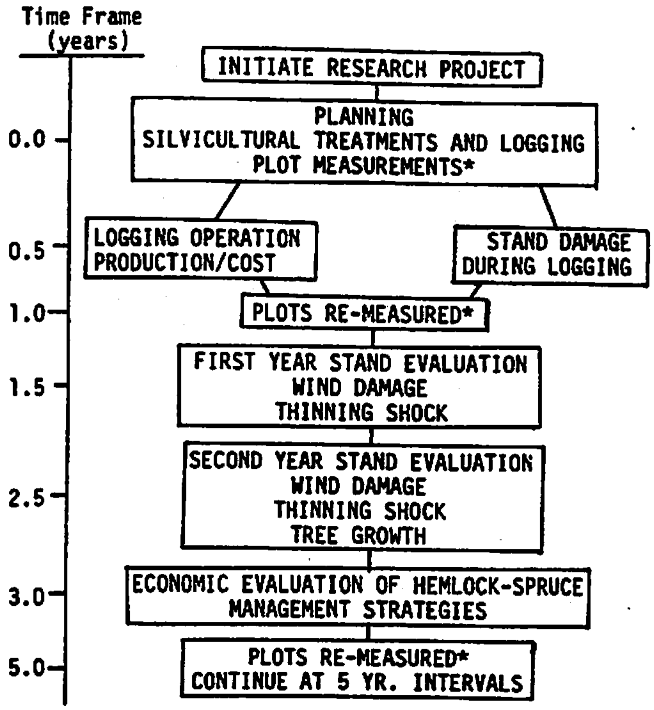
Thinning treatments involved two selection methods resulting in a narrow and a wide spacing of residual trees. The third treatment, a herringbone design, required twenty-foot wide lateral cut strips located at a 45 degree angle to the main corridor; thirty-foot wide leave strips (no thinning) were left between cut strips. The fourth treatment was a control where no thinning occurred. Tree marking, in all treatments, was completed by U.S. Forest Service sale layout personnel. A detailed timber cruise was conducted after logging; stand data results are summarized in table 1. Volume removal ranged from 50 to 66 percent. Three conifer species were present: western hemlock (72 percent of total trees/acre), Sitka spruce (21 percent) and Douglas-fir (*Pseudotsuga menziesii* (mirb.) Franco)(7 percent). Average stand diameter at breast height before thinning was 14.8 inches; average total tree height was 74 feet.

The Oregon State University (OSU) Forest Engineering research group planned and layed-out skyline roads for logging within each thinning treatment. A payload analysis was completed for each road using the HP 86 computer and "Logger" program. This information was provided to the logger. Approximately 45 acres were thinned and 27 skyline roads were required.

The logging contractor subcontracted the felling operation; four experienced cutters completed the work. Trees were felled, limbed on three sides and bucked in the woods prior to yarding. All cutters were highly productive but had varying degrees of ability in commercial thinning (eg. felling to lead). Productivity of two cutters was measured in detail for the three treatments.

Yarding and loading was accomplished with an experienced and highly productive crew. A Madill 071 yarder and Danebo MSP carriage were used in conjunction with a Bantam C-366 hydraulic heel boom loader[3]. The Madill 071 is a five drum yarder with a 48 foot tower and 284 horsepower engine. A slackline system was rigged with the MSP carriage. The hooktender prerigged corridors for most of the project. Tailtrees were used on three corridors and an intermediate support was needed on one. Adequate deflection was obtained in the remaining corridors by taking advantage of the topography. Excessive limbing on the landing required two chasers and the hooktender filled in when a second chaser was not available.

Time-study data was used as a base for the production analysis conducted in this study. Multiple linear regression techniques were used to develop models to predict delay-free cycle times and production rates for the felling and yarding



*US Forest Service Responsibility
(long term tree and stand development study)
Topics without an * are the responsibility of OSU

Figure 2--Project topics for western hemlock-Sitka spruce study.

Table 1--Timber Stand Data.

Variable	Control	Treatments Narrow	Wide	Strip
Residual Stand				
Trees per acre	208	89	67	114
Basal area per acre, ft^2	198	95	66	100
Volume per acre, ft^3	6,186	3,069	2,129	3,024
Prescribed tree spacing, ft		18 x 18	24 x 24	
Actual tree spacing, ft	14.5 x 14.5	22 x 22	25.5 x 25.5	
Thinning Removal				
Trees per acre (pct.)		119(57%)	141(68%)	94(45%)
Basal area per acre, ft^2 (pct.)		103(52%)	132(67%)	98(49%)
Volume per acre, ft^3 (pct.)		3,117(50%)	4,057(66%)	3,162(51%)

operations. Delays and road changes were recorded separately and summarized by categories.

Detailed stand damage measurements were made during felling and yarding on nine skyline roads (three per thinning treatment). Damage variables measured were types of damage (tree scarring or breakage), cause of damage (logs, skyline or carriage), location of the damaged tree in the stand and scar measurements. These variables were correlated with 12 independent yarding variables. Regression analysis was used to identify significant harvesting variables affecting scar area per turn. In addition to the detailed study, stand damage measurements were made on 18 additional skyline roads to determine differences in damage levels between thinning treatments.

PRODUCTION RATES AND COSTS

Production rates for felling and yarding are shown in table 2. Delay free cycle times and production rates are based on average conditions for the study (table 3).

For felling and bucking, the wide selection treatment was the most productive. Results for strip thinning were similar to wide spacing; narrow spacing was the least productive. Hourly cubic foot production increased 12.8 percent with strip thinning over the narrow treatment and 15.4 percent with the wide treatment over the narrow treatment.

Yarding results showed that strip thinning was the most productive; wide and narrow treatments were similar. Hourly cubic foot production increased 24.3 percent with strip thinning over narrow spacing. The main contributing factor was turn volume. Approximately one additional log (15.4 ft^2) was yarded per cycle for strip thinning over the narrow treatment. There was no significant difference (95 percent confidence level) between yarding cycle times for the three thinning treatments. The average hourly yarding production rate for all treatments is equivalent to approximately 4.5 truck loads per 8 hour day. There were an average of 57 logs per load. Average loading time was 24.5 minutes and the average round trip haul time was 2.64 hours.

Harvesting cost comparisons between thinning treatments are shown in figure 3. Costs are based on August 1983 values (time when the study was conducted) and include all equipment ownership and operation costs. These costs, however, exclude a profit and risk factor, sale layout and administrative cost. In addition, there were no major road construction requirements for this project. Felling and bucking cost per cunit was reduced 11.4 percent with strip thinning over the narrow treatment and 13.4 percent with the wide treatment over the narrow treatment. Yarding and loading costs were reduced 19.6 percent with strip thinning over the narrow treatment; narrow and wide treatment had similar costs.

Table 2--Production rates and predicted cycle times for felling and yarding (includes delays and road changes)

	Felling Treatments Narrow	Wide	Strip
Delay-free time (min. per tree)	4.97	4.19	4.31
Delay time/tree (minutes)	.85	.85	.85
Total time per tree (minutes)	5.82	5.04	5.16
Production rate - ft^3/hr	249.50	287.98	281.45
(trees/hr)	(10.31)	(11.90)	(11.63)
	Yarding Treatments Narrow	**Wide**	**Strip**
Delay-free time (min. per cycle)	4.03	4.16	4.21
Delay time/cycle (minutes)	1.85	1.85	1.85
Yarding road changes (min. per cycle)	1.64	1.64	1.64
Total cycle time (minutes)	7.52	7.65	7.70
Production rate - ft^3/hr	449.20	513.36	558.47
(logs/hr)	(27.4)	(31.3)	(34.1)

Table 3--Summary of Felling and Yarding Variables (all treatments combined).

		Felling mean	range
Move distance	(ft)	25	0-236
Slope	(pct.)	31	0-90
Tree Volume	(ft^3)	24.20	2.33-91.33
DBH	(in)	13.5	6.0-27.0
		Yarding mean	**range**
Slope distance	(ft)	256	0-795
Lateral distance	(ft)	36	0-140
Slope	(pct.)	30	0-95
Turn volume	(ft^3)	64.93	2.78-198.94
Logs/Turn		4.0	1.0-9.0

[3]Mention of trade names is for identification only and does not constitute an endorsement or recommendation for use.

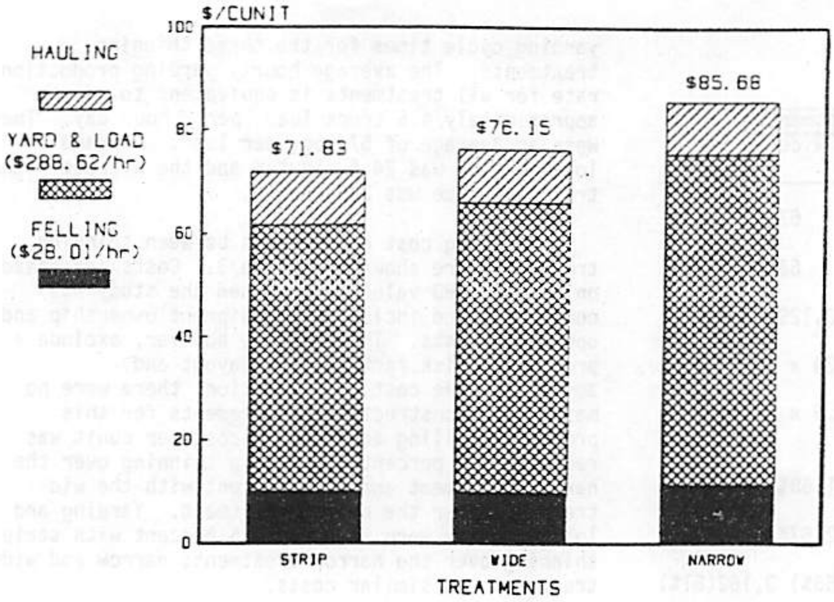


Figure 3--Total harvesting cost for three thinning treatments.

STAND DAMAGE

The selective thinning operation resulted in high levels of residual stand damage but a significantly reduced level in the strip treatment. Yarding damage sustained in the nine detail study corridors was 84.78 ft^2 scars/acre for narrow spacing, 91.64 ft^2 scars/acre for wide spacing, and 17.57 ft^2 scars/acre for the strip treatment. For the entire project (27 skyline roads), 12 percent of the trees in the residual stand were damaged from yarding in the strip treatment; narrow and wide treatments were damaged 47 and 61 percent respectively. The majority of stand damage occurred during yarding; only 3.1 percent of the scars measured were caused by felling, 7.9 percent from loading activities around the landing, and 5.4 percent from line damage outside the logging units.

Incidence of decay from logging scars is related to both scar size and location on the tree (Wright and Isaac 1956, Wallis et al. 1971). Small scars are less likely to become decayed than large scars. Also, as the height of the scar above ground increases, the frequency of infection decreases. Characteristics of stand damage from this study are summarized in table 4. For all treatments, scar height above ground ranged from zero to 38 feet; 23.2 percent were located within one foot of the ground, 59.2 percent between one and seven feet and 17.6 percent over seven feet. Scar length ranged from 0.10 to 19 feet, scar width from 0.10 to 2.8 feet and scar area from 0.02 to 14.00 square feet. Scars in which the bark was removed but the sapwood was undamaged comprised 63 percent of all scars observed.

The majority of yarding damage (66.6 percent of total scar area) occurred within twenty feet of the skyline corridor centerline (figure 4). The distribution of damaged trees vary between treatments. Most damage in the strip treatment was limited to a rub tree at the edge of the lateral strip and main corridor. In the narrow and wide treatments, all skyline corridor boundary trees had a higher potential of being rub trees. Also there was a greater risk of damaging trees away from the corridor in the narrow and wide treatments compared to the strip treatment.

Using regression analysis, we identified five significant operational variables from 12 measured variables that influenced scar area per turn. Scar area per turn reflects the total amount (ft^2) of residual tree damage per yarding cycle (all tree scars per cycle). Only a small amount of the total variation in residual damage (21 percent) was explained by the five variables. Significant (95 percent confidence level) variables were the number of times the carriage was repositioned during lateral yarding, carriage clearance above the ground, angle of the log with respect to the

Table 4--Stand damage characteristics from yarding.

Treatment	Statistic	Scar Characteristics Height	Length	Width	Area
		(ft)	(ft)	(ft)	(ft)
All	max.	38.00	19.00	2.80	14.00
	mean	4.51	1.37	0.38	0.57
	min.	0.00	0.10	0.10	0.02
	stand dev.	4.93	1.67	0.27	1.04
Narrow	max.	24.00	15.00	2.10	13.01
	mean	4.08	1.47	0.40	0.65
	min.	0.00	0.10	0.10	0.02
	stand dev.	4.20	1.81	0.27	1.20
Wide	max.	30.00	14.00	2.30	14.00
	mean	4.58	1.28	0.37	0.51
	min.	0.00	0.10	0.10	0.02
	stand dev.	4.78	1.41	0.27	0.92
Strip	max.	38.00	12.00	2.80	9.10
	mean	4.69	1.29	0.36	0.50
	min.	0.00	0.10	0.10	0.02
	stand dev.	5.88	1.50	0.27	0.84

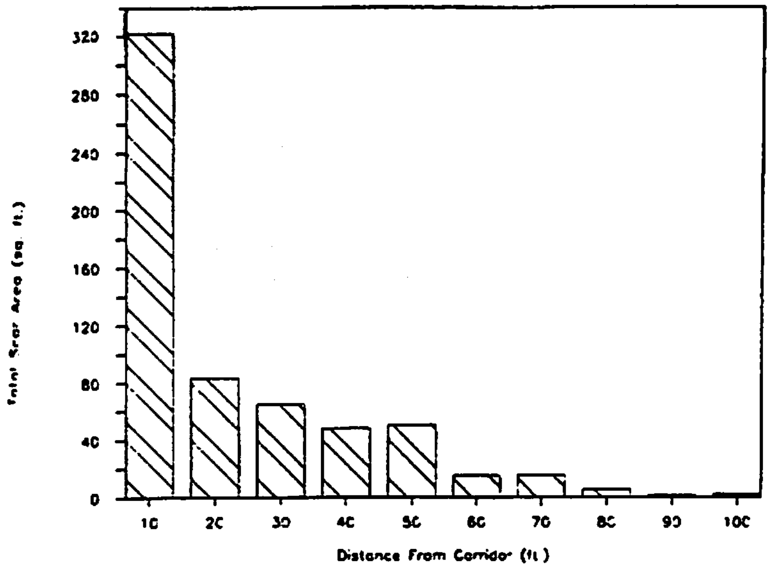


Figure 4--Scar area distribution from corridor centerline.

mainline, who was the rigging slinger and who felled the timber.

A skyline carriage is often repositioned to a new location along the skyline during lateral yarding. This yarding technique can be used to avoid hangups and tree damage or as a corrective measure to free logs hung up during lateral yarding. In this study, scar damage per turn increased as the number of carriage repositions increased thus indicating that the technique was used mainly as a corrective procedure once hangups occurred.

Scar area per turn increased as carriage clearance above the ground increased. This result is contrary to some past studies (Fieber et al. 1982). However, it does suggest that in thinning, log control is improved when only one end is lifted above the ground. As ground clearance increases and logs become fully suspended above the ground, log control may be reduced.

Log angle with respect to the mainline reflects the degree of turning into lead that a log must achieve during lateral inhaul; when the angle is small, there is less chance for tree scarring (figure 5).

Rigging slinger and cutter variables identified in the regression analysis show the influence that crew members can have on logging damage levels. Two different rigging slingers were used during this study. One had considerable experience in both clearcut and thinning operations while the second had experience as a chaser and choker setter but limited experience as a rigging slinger. Scar area per turn was lower for the more experienced rigging slinger. Similar results occurred with the cutters. During the study, we recorded the areas felled by each cutter and their experience in felling and yarding both old-growth clearcuts and smallwood thinnings. Scar area per turn during yarding was different depending on which cutter felled the particular area. While the experience level did not correlate directly with the amount of damage, there was a general trend towards lower damage levels with the cutters that had more years of experience in smallwood felling and yarding.

DISCUSSION/SUMMARY

In this study, thinning treatments had a significant effect on harvesting cost. All thinning patterns resulted in a large removal, especially the selective wide spacing (66 percent volume removal). The wide spacing appeared similar to some shelterwood treatments. Thinning removal and residual stand volumes were similar for selective narrow spacing and strip thinning. Therefore it is appropriate to use these two treatments for comparison of harvesting cost with the same thinning intensity but with different techniques. Wide space thinning cost was in-between the narrow and strip treatments.

Felling and yarding cost per cunit were 11.4 percent and 19.6 percent lower, respectively, for strip thinning over selective narrow spacing. Felling costs were lower primarily because of a significant difference in cutting cycle time between treatments. There was not a significant treatment effect on yarding cycle times. The main difference was attributed to higher payloads achieved with the strip treatment compared to selective thinning. In strip thinning, logs were concentrated in extraction paths making it easy to hook more logs per turn yet not increase total yarding time compared to the selection treatments. There was a combined harvesting cost savings with strip thinning over

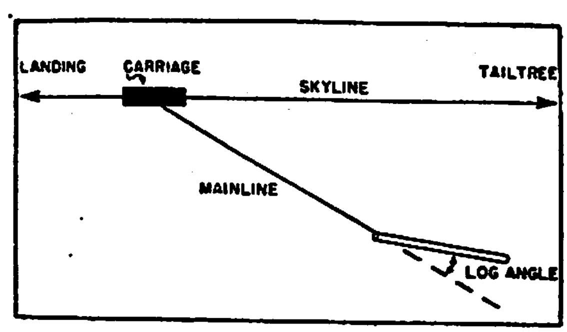


Figure 5--Log angle (aerial view).

selective narrow spacing of 31 percent. These savings are higher that those reported by Aulerich (1975) but similar to other studies (Kramer 1974, Twaddle 1977, Terlesk and Twaddle 1979, Hamilton 1980).

In this study, the high levels of residual stand damage can be partially attributed to logging during early summer when the tree cambium was actively growing and the bark was loose. Also, there were different damage levels between thinning treatments and operational variables. Damage was considerably less for strip thinning compared to selective narrow and wide space thinning. Both selective thinning treatments had similar levels of damage. Damage in all treatments primarily occurred during yarding. Two-thirds of the damage occurred within twenty feet of the skyline corridor.

This study identified variables that demonstrate the importance of good planning and logging practices to minimize stand damage. Many of these practices are dependent on skills and decisions made by logging personnel. For example, felling to lead with the skyline corridor and a proper carriage location during lateral yarding are important to reduce damage levels.

This study also revealed the difficulty in identifying and quantifying operational variables causing damage. Many of these variables are interrelated with specific stand conditions and crew factors that vary with each turn and hour of operation.

Similar research studies on stand damage levels and operational techniques related to damage are needed to address the question of cost versus benefits. Some studies have shown small potential impacts from volume loss at final harvest caused by decay from an earlier entry (Shea, 1960, 1961; Hunt & Krueger, 1962; Wallis & Morrison, 1975; Parker & Johnson, 1960; Goheen et al., 1980; Chavez et al., 1980). A majority of future forest management practices in the northwest will be concerned with smallwood and short rotations. Other potential negative impacts due to reduced growth, reduced forest product values and aesthetic impacts should also be considered. However, these effects may not be significant in all areas and may vary by forest type.

The question, then, is what are the significant benefits from reducing stand damage during thinning entries and how do they compare with additional harvesting costs incurred? In many cases, conscientious planning and logging can reduce damage but this requires well-trained people given appropriate incentives to reduce damage levels.

Management goals for young forests involve more than minimizing commercial thinning harvesting cost. Stand responses must also be closely evaluated. Stand damage from thinning with different treatments, future wind damage, sunscald, tree growth and stand yields are additional important considerations. This study has shown harvesting cost and stand damage differences between thinning techniques of herringbone strip thinning and conventional selective thinning. The next step is an overall silvicultural and economic evaluation of these three thinning techniques but that is beyond the scope of this paper. It is, however, part of our overall western hemlock-Sitka spruce research project.

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Site Impacts for Three Inexpensive Cable Yarders[1]

Harry Lee and Mike Bellitto[2]

ABSTRACT

This study investigated the site impacts of three types of inexpensive cable yarders. A Koller K-300 with intermediate support capability and a hydraulically clamping carriage and a shop built, two-drum Idaho jammer rigged both as a ground lead with a squirrel block and as a live skyline with a nonclamping mechanical carriage were observed on three strip clearcuts and one shelterwood on two silt loam soils in northern Idaho. Change in bulk density, exposed mineral soil, residual slash, and residual damage to leave trees were recorded. Changes in soil bulk density for a crane mounted, single-drum jammer operating in the Idaho batholith near Smith's Ferry, Idaho were also recorded. Statistical analysis was used to determine if bulk density changes were significant, and to determine if there were differences in compaction between the systems. Amount and distribution of soil disturbance and residual slash were determined and compared for the systems. Number of damaged leave trees and type of damage were recorded in the shelterwood harvest.

No significant compaction was recorded on units which were logged during dry weather in the northern Idaho units. Significant compaction was recorded on the single drum jammer site in the batholith and some portions of the shelterwood logged in wet weather. Areas which showed compaction were yarded with the logs in full contact with the ground. Results indicated no difference in the impact of skyline and ground lead systems on dry soils. Ground lead caused more serious compaction on moist soils. Both systems demonstrated ability to provide adequate exposed mineral soil for natural regeneration. Operations with the Koller provide the capability of controlling amount and location of exposed mineral soil by varying the amount of deflection in the skyline. There was no difference in the amount of residual slash left with either the skyline or the ground lead. Both systems had excellent results for residual damage in the shelterwood. Most of the damage associated with the Koller was in areas where the turn could not be controlled.

INTRODUCTION

Due to increased concern with environmental effects of timber harvesting and decreasing land base, the use of cable systems in the Pacific Northwest has increased in the last 20 years. This increase has been accompanied by dramatic improvements and development of different types of cable yarders. Cable yarders are now available in a variety of sizes and configurations.

[1] Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

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While the effect of skyline and ground skidding on site productivity is well documented, there seems to be some disagreement on the effects and usefulness of different systems. Timber harvesting causes changes in the characteristics of the site. Compaction, soil disturbance, residual tree damage and slash (residual organic debris) are all important factors in establishment and growth of planted and natural seedlings. These factors also affect productivity and value on selection cut and thinned stands. These impacts tend to vary considerably depending on site conditions such as slope, moisture, soil type, aspect, and timber size. Very little information is available on site impacts from inexpensive cable systems or yarders with intermediate support capability.

Because of lower timber values, increasing concern with site impacts and lack of knowledge of the site impacts of small, inexpensive and intermediate support yarders, this study was devised to assess impacts on several specific sites. The overall objective was to examine three different small yarder configurations operating in clearcuts and shelterwood units.

The type of logging system can have a major effect on the amount and type of site impact as a result of harvesting operations. In general, cable systems have been found to cause less soil disturbance, compaction and residual damage than ground systems (crawler tractors and rubber tired skidders). Cable systems which provide more lift to the log (helicopter, balloon and skyline) are generally considered to cause less disturbance and compaction than systems without ability to suspend logs (ground lead jammer and high lead). There doesn't seem to be a concensus as to how logging systems affect residual damage. It appears that control in lateral skidding and yarder mobility are more important than ability to suspend logs.

Koller K - 300 Yarder

The K - 300 is a small skyline yarder produced in Austria. The model used in this study has two drums and a 23 foot tower mounted on a trailer with a trailer hitch. Power is provided by a Mercury V-6 gasoline powered engine. Line sizes are 5/8 inch for the skyline and 3/8 inch for the mainline. The skyline drum holds 1150 feet of 5/8 inch skyline. The mainline drum holds 1150 feet of 3/8 inch mainline and is capable of a maximum line speed of 984 ft/min.

The carriage, manufactured by Koller, is hydraulically cycling providing the ability to clamp to the skyline for lateral yarding. It is designed with an open side which allows it to pass an intermediate support. The ability to clamp to the skyline, allowing greater control in lateral yarding, makes the Koller well suited for thinning and shelterwood cuts. Ability to pass an intermediate support allows use of the Koller on convex slopes or benches where conventional skylines can not gain adequate deflections.

KWIK Yarder

The KWIK yarder is a shop built, two drum, truck mounted yarder powered by a Ford 351 cubic inch gasoline engine that provides 100 net horsepower. The drums are driven by an automatic transmission. The carrier is a 6x6 truck. An angled A-frame spar reaches 24 feet above the ground and overhangs approximately 10 foot behind the truck. It is supported by three guylines. The American Junior drums spool 1000 feet of 5/8 inch line on one drum and 9/16 inch on the other.

The KWIK Yarder may be rigged as a groundlead system by connecting the two lines with a squirrel block and using the 5/8 inch line as a haulback. It may also be rigged as a live skyline with gravity feed by rigging the 5/8 inch line as a skyline and the 9/16 inch line as a mainline.

Single Drum Jammer

The single drum jammer is fairly common in southern Idaho. Bulk density samples were taken from a unit on Boise Cascade land which was being logged by a Linkbilt 98 to facilitate uneven age management. The yarder can spool about 1200 feet of 3/8 inch cable, but yarding distances are normally limited to about 150 feet. Ease of mobility makes the single drum jammer very useful in partial cuts despite its lack of lateral skidding capability. The yarder can be easily positioned so the turn may be pulled straight up the slope. The ability to swing the tower allows the operator to guide logs around obstacles, thus reducing residual damage. Swing capability also makes this system very economical, since it can be used as a loader (Kochenderfer and Wendel, 1980). This also allows decking to the side, thus avoiding the decking problem experienced with the other two types of yarders.

Site Description

The experimental unit is a 22 acre watershed on the Flat Creek unit of the University of Idaho experimental forest. The treatments included 3 strip clearcuts, of 2.0, 1.9, and 1.3 acres, seperated by narrow leave strips and a 4.2 acre shelterwood cut.

METHODS

Yarding

Unit 1 was logged using the KWIK yarder rigged as a live skyline. The carriage was a McAllister block. Unlike the other two clearcut units, which utilized a single corridor, the yarder was moved several times and two different tail trees were used due to the draw running the length of unit 1. This resulted in the fan shaped skidding pattern characteristic of high-lead yarding.

Unit 2 was logged using the Koller yarder and carriage. An intermediate support was rigged at the slope break, providing sufficient clearance to clear the bench at the top of the unit. One tail hold and one main corridor were used, moving the yarder only as often as necessary to prevent becoming deckbound.

The Koller yarder and carriage was also used for Unit 3. An intermediate support was rigged at the slope break. Unlike Units 1 and 2, where the tail tree was at the bottom of the slope, the tail tree for this unit was located on the other side of the draw.

The shelterwood unit was seperated into two parts. A 2/3 - acre section in the southeast corner of the unit was yarded using the KWIK yarder as a ground lead system with a squirrel block. External yarding distance was 250 feet. The remaining 3.5 acres were yarded to 3 landings by four corridors using the Koller yarder. Corridors three and two were tied off in the draw. Both corridors had intermediate supports at the slope break (225 and 200 feet respectively). External yarding distance was 625 feet for corridor three and 475 feet for corridor two, with maximum lateral skids for both corridors of approximately 60 feet. Corridor one ran across the draw and was tied off at the northeast corner of the unit. Due to the steep slope on this corridor (45%) and the increased deflection from placing our tailhold out of the draw, this corridor didn't require an intermediate support. Corridor 4 was placed to log the north end of the unit and pick up the timber across the draw which could not be reached by the other three corridors. External Yarding Distance was 270 feet with maximum lateral skid distance of 70 feet. The tail tree was placed near the draw, at the northwest corner of the unit. Due to the short skidding distance and constant slope, this corridor required no intermediate support.

Sampling

Continuous sampling transects were laid out at random intervals across each unit. Bulk density samples were taken before and after logging at each plot. Slash and disturbance were estimated using a variation of the classes set up by Dyrness (1965). They are:

1. Undisturbed - Litter still in place and no evidence of compaction.
2. Slightly disturbed - Three conditions fit into this class:
   a. Litter removed and undisturbed mineral soil exposed;
   b. Mineral soil and litter intimately mixed, with about 50% of each; and
   c. Pure mineral soil deposited on top of litter and slash to a depth of 2 inches.
3. Deeply disturbed - Surface soil removed and the subsoil exposed. Seldom covered by litter and slash.

The three slash cover classes are:

1. Heavy - Entire square foot covered with slash at least one foot deep.
2. Light - Ten percent or more of the area covered with slash less than one foot deep.
3. Absent - Total slash cover less than ten percent.

A 100% cruise determined volume and number of stems in cut and leave trees. After logging the leave trees in the shelterwood were surveyed for residual damage. number of trees scarred were recorded, position of each scar on the tree (butt, bole, or top) and position of each tree relative to the corridor.

Due to lack of time and funds observation of the single drum jammer was limited. The system observed was on Boise Cascade land near Horseshoe Bend, Idaho. This area is located in the Idaho batholith. The soil was a coarse sandy loam derived from coarse, granitic bedrock. They tend to have low cohesion and poor aggregate stability. These soils are highly susceptible to ercsion due to these factors combined with steep slopes and frequent high intensity rainstorms (Kidd, 1964). Habitat type is Douglas-fir/ninebark. Slopes were very steep (80 - 100%). The sites were located on the breaks above the North Fork Platte River.

TABLE 1—Average bulk density change for each unit and results of paired-t tests to determine if these values are significant.

Unit	Mean g/cm^3	Standard error of mean	Calculated t
1	.04	.013	2.81*
2	-.01	.020	-0.33
3	.03	.019	1.50
4#	.07	.025	2.66**
5##	.04	.031	1.36

#Koller shelterwood

##Jammer shelterwood

*Significant at alpha = .01

**Significant at alpha = .05

Table 2—Bulk densities for logged areas using single drum jammer and adjacent undisturbed areas and t-test to determine if bulk densities are significantly different.

Bulk Densities	g/cc
CONTROL	.77
LOGGED	1.06
CHANGE	.28
PERCENT CHANGE	38

DEGREES OF FREEDOM	7
POOLED STANDARD DEVIATION	.187
CALCULATED t	2.188
$t_{7,.05}$	1.895
$t_{7,.025}$	2.365

$.025 < p < .05$*

* This shows that the bulk densities for the logged areas are significantly higher than for the undisturbed areas at alpha = .05.

ANALYSIS

Overall compaction on the northern Idaho units was not heavy enough to affect productivity (Table 1). The single drum jammer caused compaction which will probably affect productivity (Table 2). When the northern Idaho units are broken down into "in" and "off" corridor (Table 3) we see that the KWIK yarder used as a ground lead has significant compaction in the corridor. The Koller units had more compaction in the corridor, but not enough to affect productivity. Also, the area in the corridor for the ground lead unit accounted for 21 percent of the unit, while the area compacted for the Koller was about 1 percent of the unit.

TABLE 3—Average change in bulk density for plots in the corridors and out of the corridors and results of paired t-tests to determine if the changes are significant.

	Plots	Mean g/cm^3	Standard error of mean	T
In	9	.12	.11	3.06*
Out	15	.00	.04	-0.08

*Significant at alpha = .05

TABLE 4--Percent of each unit in each disturbance class and exposed mineral soil. Exposed mineral soil is determined by totalling light and heavy disturbance.

UNIT	DISTURBANCE CLASS (%) 1	2	3	EXPOSED MINERAL SOIL (EMS) (%)
1	75	17	8	25
2	62	28	10	38
3	88	2	10	12
Shelter				
Jammer	76	20	4	24
Koller	72	24	4	28

Table 5—Areal Slash Distribution by Units

Unit	Class 1 pct. (Heavy)	2 pct. (Light)	3 pct. (Absent)
1	63	35	2
2	34	33	32
3	56	34	10
4	58	42	0
5	54	46	0

Table 6—Residual Damage for Koller and Jammmer Yarded Shelterwoods

Damage	Crown #	Crown pct.	Bole #	Bole pct.	Butt #	Butt pct.	Total #	Total pct.
Jammer	1	1.6	4	6.5	0	0.0	5	8.1
Koller	2	0.5	32	7.4	1	0.2	35	8.1

Table 7—Residual Damage by Corridors in Koller Yarded Shelter Wood

Corridor	Butt	Bole	Crown
1	0	10	1
2	0	6	0
3	1	7	0
4	0	9	1

Slash

All the units except Unit 2 have high concentrations of slash. Slash on Unit 2 was very well distributed. There appeared to be no difference between skylines and ground lead yarding in slash concentrations. It appears that areas with more disturbance have a better distribution of slash. It is broken up and spread out by the action of the log. Tree length yarding appears to result in smaller slash concentrations due to less bucking in the woods, also the longer pieces tend to be in contact with the ground more, thus breaking up and redistributing slash concentrations.

Residual Damage

Both systems caused very little residual damage. Most of the wounds to residual trees were located on the bole. There was no difference in the two systems. Lack of residual damage is probably related to the fact that both systems lack power to keep logs suspended for long distances. This results in the turn being yarded in contact with the ground. The log did not whip around on inhaul and strike leave trees along the edge of the corridor. This is supported by the observation that damage was concentrated in areas where the turn could not be kept in a narrow track during inhaul, due to logs being lifted off the ground or sidehill yarding where the logs tended to slide downhill.

RECOMMENDATIONS

Overall, the Koller skyline appears to be preferable to the groundlead systems in this study. When properly used the Koller showed no significant compaction on dry or wet soil. The ground lead configurations caused significant compaction on wet soils.

The Koller can create the desired amount of soil disturbance depending on site conditions. On areas where scarification is required for natural regeneration and potential erosion is not a problem, rig the tail tree low, so logs are yarded in contact with the ground. In areas where high erosion potential exists, rig the tail tree high, so logs can be flown for a portion of the turn, minimizing exposed mineral soil.

The areas where heavy compaction existed were logged in the fall, when the soil was wetter. Moist soil is more susceptable to compaction. This explains the lack of compaction on the other ground lead unit (Unit 1).

Table 4 shows the percent of each unit in each disturbance class and the amount of exposed mineral soil (EMS). Unit 2 had the most EMS, while Unit 3 had the least. Unit 1 did not have as much as was expected for a ground lead, however the disturbance was limited to the corridors. This resulted in channels which promote water flow, thus increasing erosion potential. The fact that Unit's 2 and 3 were almost identical except for the position of the tail tree, yet varied widely in disturbance, is due to lower deflection on Unit 2. This demonstrates the versatility of the skyline which is not possible with a ground lead.

Table 5 shows the distribution of slash on each unit. The units with the most disturbance had the smallest accumulations of slash. This is probably due to the logs dragging and breaking up piles of slash.

The two systems had similar results for residual damage (Table 6). Both systems compared favorably to results for other studies. However in the jammer section of the shelterwood there was no skidding outside the corridor due to limited lateral skidding capability. So in effect this unit consisted of two small strip clearcuts. Most of the damage in the Koller section was in corridors 1 and 4 (Table 7). The damage on corridor 1 was in the part of the span where the turn was flying. The damage on corridor 4 was due to yarding on a hill. The turn rolled downhill during inhaul. Nine of the ten damaged trees on this corridor were below the corridor.

CONCLUSIONS

When cable logging in dry weather there appears to be no appreciable compaction for the Koller yarder or the KWIK yarder. Some compaction was associated with the corridor in the Koller units, however the area impacted was limited to a five foot wide strip and amounted to approximately 1% of the area in the units. None of the units logged in dry weather were compacted significantly enough to affect productivity.

Units logged during wet weather showed areas of compaction. The ground lead yarded unit was heavily compacted in the corridors. Due to the large percent of area in corridors, there is probably enough compaction to cause a decrease in productivity. Heavy compaction on one corridor in the Koller shelterwood was probably due to a lack of deflection, which resulted in logs being yarded much like a ground lead. The higher soil moisture content during yarding resulted in more impact due to compaction for the ground lead than for the skyline.

Soil Disturbance

All of the units except Unit 3 had an adequate percent of the area in exposed mineral soil to satisfy requirements for natural regeneration. Most deep disturbance was associated with the corridor. Unit 2 had significantly more disturbance than the other units. This was due to convex (benchy) slopes, which recquired yarding the log in contact with the ground for most of the turn.

An Evaluation of Cable Yarding Bunched Trees on Steep Slopes[1]

Barry Carson, Charles N. Mann, Peter Schiess[2]

Abstract: Bunches of whole trees created by a walking feller-buncher on slopes from 10 to 70 percent were evaluated in a study on the Quilcene Ranger District, Olympic National Forest in July and August 1983. Bunch dimensions and characteristics as a function of slope, together with hook time and hooking production, were determined in a cable yarding operation.

Bunches were characterized by dimensions (width, height, circumference), number of trees per bunch and ease of choking. Bunch size varied between slope classes. On steeper slopes bunches were much less wide. An average 45 trees per bunch were counted on slopes less than 40 percent and 28 trees per bunch on slopes steeper than 40 percent. Bunch integrity, however, expressed as the ratio of cross sectional area of stems to the total end area of the bunches was the same for all slope classes considered.

A total of 171 bunches were observed during the cable yarding operation. Yarding production averaged between 177 to 238 trees per scheduled hour. Hook time varied greatly among the areas from 1.78 minutes per bunch to 3.21 minutes. However, if expressed in terms of the number of stems hooked per minute, differences between slope classes were judged to be insignificant.

As the timber industry in the northwest moves into harvesting second growth timber, technology must be adapted to changes in timber size and higher piece count since these factors have a great influence on yarding production and cost. The problem of harvesting smaller trees has been dealt with on flat ground by mechanized felling and bunching which greatly improves skidding production. Grapple skidders can acquire large numbers of small stems with relative ease.

With the development of the concept of steep slope feller bunchers, the opportunity for increasing yarding production of small trees on steep slopes is a real possibility. Large payloads can be achieved by consolidating these many stems into a unit that is well suited for efficient material handling. However, on steep slopes where grapple skidders cannot operate, bunches of stems must be hooked with chokers and cable yarded. Furthermore, simulation studies have indicated that yarding bunches with a large yarder is more cost effective than yarding unconsolidated scattered stems with a small yarder (Schiess and Martin 1982). However, the feasibility of yarding bunched material on steep slopes has not been field tested.

The major unknown factor in cable yarding bunched trees is the hook time element in relation to bunch sizes or number of trees. The other time element of the yarding cycle such as inhaul, outhaul and unhook are presumably not different from a conventional cable yarding operation. Once this relationship is established, better production estimates can be made for yarding small trees.

It is the objective of this study to define the factors that influence hook time of bunched trees and, secondly, to determine the bunch weight attainable with a prototype steep slope feller buncher.

Study Area

In July and August of 1983, detailed time studies were conducted to evaluate the yarding of bunches on steep slopes. This research was carried out on the Quilcene Ranger District, Olympic National Forest.

The study area is located on the Olympic Peninsula about 20 miles west of Quilcene, Washington. The land is within an extensively burned area destroyed 75 years ago. After the fire, natural regeneration was prolific, which resulted in severe overstocking. The overstocked condition still exists with stocking generally exceeding 3000 stems per acre. Total biomass of the standing trees was estimated at 227 tons per acre, fresh weight (Gholz and others, 1979). The stand consists of a mix of Douglas-fir (*Pseudotsuga menziesii*, (Mirb.) Franco), western hemlock (*Tsuga heterophylla*, (Raf.) Sarg.), and a few western red (*Thuja plicata*, Donn ex D. Don), and yellow (*Chamaecyparis nootkatensis*, (D. Don) Spach) cedars. Over 50 percent of the stems are 4 inches or less DBH and average DBH is below 5 inches. The test site of approximately 4 acres was situated on a west facing side hill. Slopes ranged from 10-40 percent on the area below the mid-slope road to 40-70 percent on areas above the mid-slope road (Fig. 2).

Harvesting Operation

The bunches at the test site were created by the Spyder steep slope feller-buncher (Fig. 1), a proto-type machine built in Europe which was originally designed for excavating (Schiess and others, 1983; 1984). The bunches were laid along the contours in rows running up and down the slope. The letters (O, B, R) on the map in Figure 2 show the location of the bunches and correspond to colors (orange, blue, red) painted on the butts of trees in the bunches. The colors were used to help identify bunches during the yarding so that hook time could be correlated with bunch characteristics. Five areas delineated on the map identify different felling-bunching operational techniques. Area 2 was felled and bunched while moving uphill only. Area 5 was felled and bunched moving downhill only. A combination of uphill and downhill movement in area 4 was tested. Felling was done in both directions in area 1 and 3 and every other row was winched to the next one by a winch mounted on the spyder. This is apparent in Figure 2 where large gaps between consecutive rows occur in these areas.

The yarding was performed by a Washington TL-6 yarder rigged in a highlead configuration (Fig. 3). The yarder worked along the mid-slope road. Material brought to the road side was either cold decked or loaded directly onto log trucks as full trees by a Cat 235 log loader. A D-8 caterpillar tractor mounted with a twenty-foot spar was used for a mobile tail spar on the area below the road. This made road changes quite efficient. Average yarding distance below the road was

[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985

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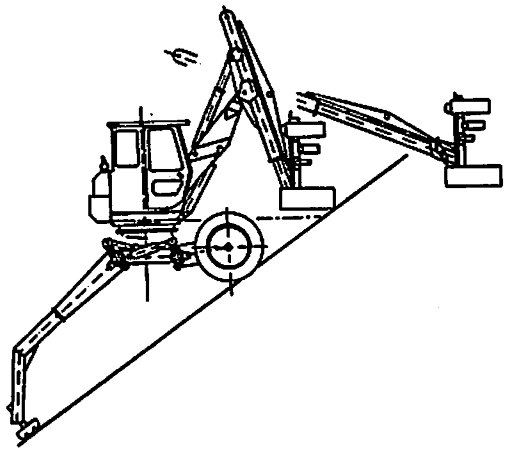


Figure 1--The Kaiser X5M Steep Slope Feller Buncher

approximately 150 feet. On the area between the mid-slope road and upper road, tail trees were rigged along the upper road for each corridor. Here, the yarding distance averaged 210 feet. The yarding crew consisted of an engineer, 2 chokersetters, chaser and a rigging slinger. During normal operations, two 18 foot chokers were attached to the butt rigging. However, after the bunches were yarded, an additional choker was added to the butt rigging for hooking scattered stems. This was often a very time consuming operation, since the Forest Service yarding specifications called for yarding all material larger than 1 inch top diameter and 10 feet long.

DATA COLLECTION PROCEDURE

<u>Bunch Measurements</u>

All bunches in the area were numbered and the butts painted with one of three colors in order to insure proper identification during yarding. Each bunch in which the butts were not covered by the tops of other bunches was measured. The height of each was measured at the butt end of the bunch. The highest vertical

Map of the Quilcene test area. Letters denote bunch location created by the Spyder Steep Slope feller-buncher. Areas 1-5 represent different operational felling-bunching techniques. Bunches were yarded to the mid-slope road.

Figure 2--USFS Spyder Quilcene Test Site Map

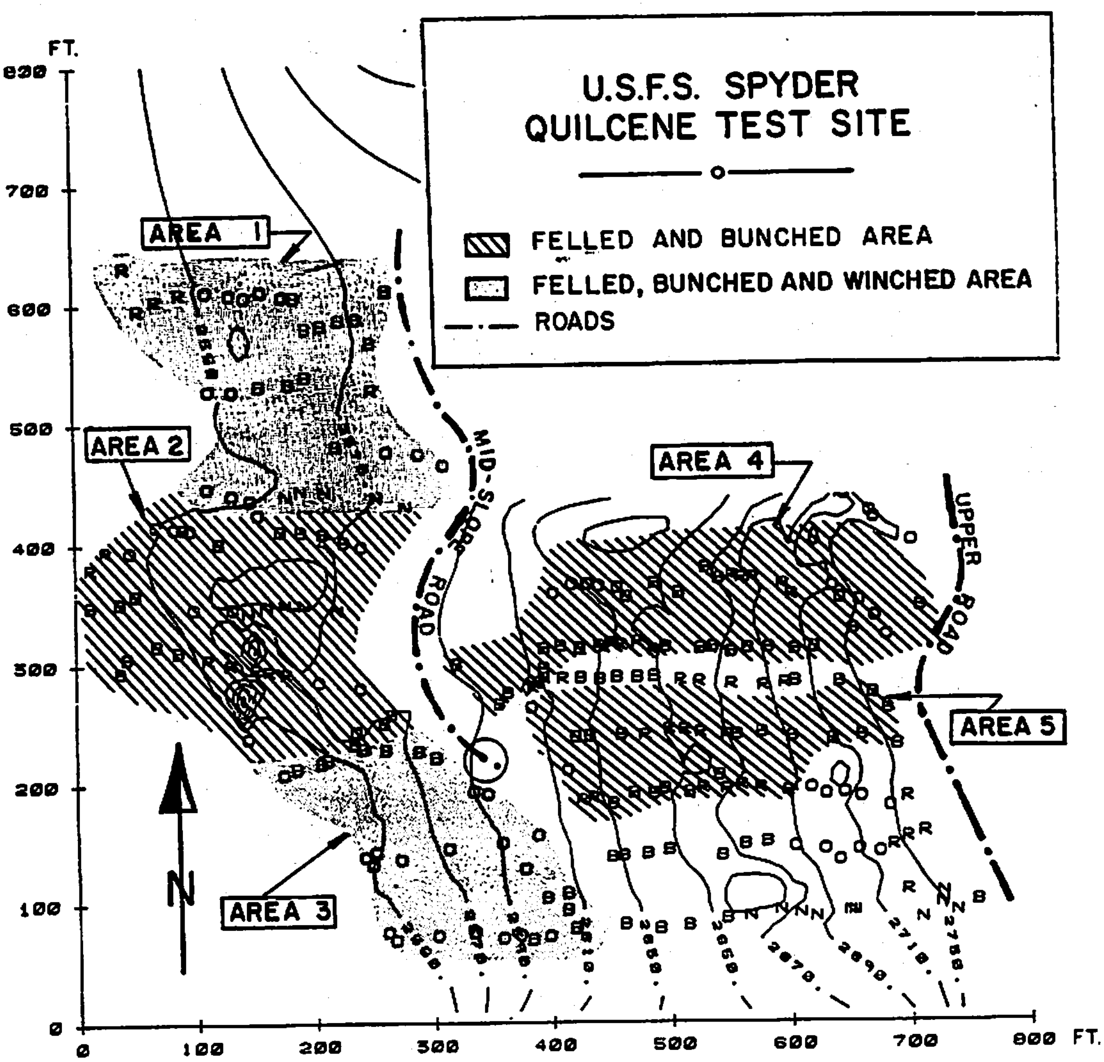
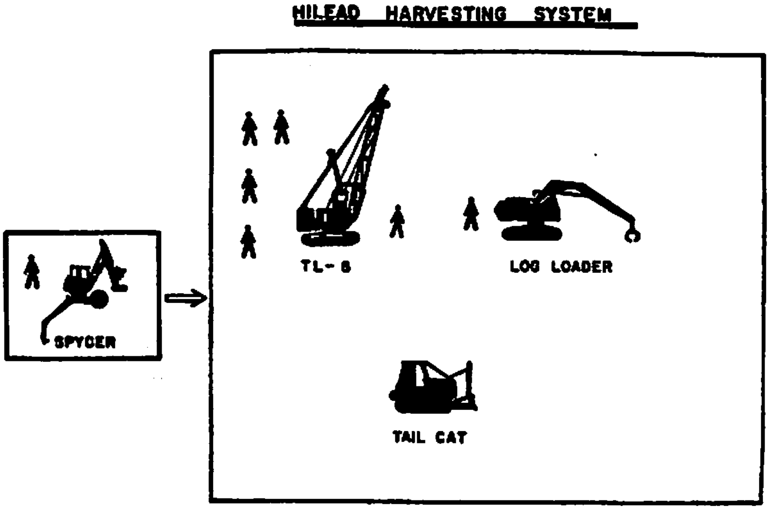


Figure 3--Equipment Used in the Yarding Operation



distance between the ground and the top butt was the measurement taken (Fig. 4). The width of each bunch was measured along the slope and the outside perimeter was determined by stretching a tape over the bunch as close as possible to the point where the chokers would be set. All the stem butt diameters for each bunch were tallied, and a three level assessment of "ease of choking" was recorded. The three levels are described as follows.

Levels of "Ease of Choking"

1 -Clearly easy to choke, possible to see light and a clear path in which to thread choker underneath.

2 -No clear path underneath bunch, possible to thread choker through bunch without excluding many stems.

3 -Impossible to feed choker under bunch or choke majority of the stems with a single choker.

A stadia survey of the bunches provided coordinates for locating the position of each bunch on a topographic map of the area (Fig. 2).

Yarding Time Study

During the yarding of the bunches, all productive and non-productive operational elements were timed and recorded. Four elements of productive time were separated out. They include outhaul, hook, inhaul, and unhook. Characteristics of each turn that were recorded included bunch number, number of chokers, and yarding distance. Turns which were only for clean-up were designated and summarized in the production study.

RESULTS

Spatial Distribution of Bunches

The distance between rows of bunches averaged approximately 45 feet, excluding the areas where bunches were winched together by the Spyder. Within each row the bunches averaged 18.6 feet center to center. However, there was a 2.7 foot difference in average spacing between the bunches above and below the road. Above the road where the slope was 40 percent or greater, the spacing between bunches was 17.8 feet. Below the road where slope was 40 percent or less, the spacing between bunches was 20.5 feet. This resulted in larger bunches in the lower areas (1, 2, 3).

The areas above the road (Areas 4-5, Fig. 2) averaged more than 50 bunches per acre while the areas below the road (Areas 1-3, Fig. 2) averaged less than 40 bunches per acre (Table 1). The difference is due to wider spacing between bunches within each row, as well as to the winching of bunches together, called pre-bunching.

Bunch Size Characteristics

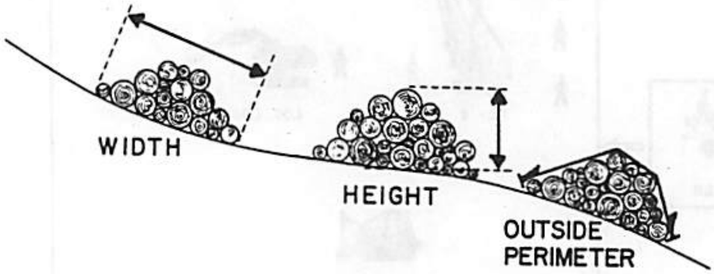
Bunch size varied largely between slope classes. On the steeper areas, the bunches were less wide. Table 2 shows that on average, bunch widths were 2.5 feet larger in the lower areas than the upper areas. This was due, in part, to closer spacing of bunches, somewhat lower stocking, and no winching activity in the upper areas.

The total circumference of the bunches can be determined by adding the width to the perimeter value. The difference in bunch height between slope classes amounted to only a few inches, so difference in bunch circumference was due entirely to differences in width. The average circumference was 25.2 and 20.3 feet for the lower and upper areas, respectively. This figure gives an idea of the length of chokers needed. If one choker were to have been used to hook an entire bunch, it would

Table 1--Bunch Distribution by Test Area

Area	Acreage	Number of Bunches	Bunches Per Acre
1	0.994	34	34.2
2	1.024	39	38.1
3	0.696	28	40.2
4	0.792	42	53.0
5	0.556	28	50.3

Figure 4--Definition of Bunch Measure Techniques



have had to be at least 25 to 30 feet long. Even at those lengths, nearly half the bunches would still require longer chokers, since bunch widths were fairly evenly distributed about the mean (Fig. 5). Also, it is clear from Figure 5 that there was a great variation in bunch width with the largest variation occurring on the lower areas. This variation complicates the hooking procedure, since each bunch or group of bunches must be handled according to bunch size, number of chokers and choker length. Consequently, minimizing the variation would have allowed for better planning and more effective hooking methodology.

Diameter Distribution Within Bunches

The stem count per bunch decreased, as did the bunch dimensions, with increased slope. Bunches above the road on the steeper slopes had substantially fewer stems per bunch. Table 3 shows the average number of stems in each 1 inch diameter class was less for bunches on the steeper slopes. However, the distribution of number of stems in each diameter class varied little between the two areas. This shows that the diameter distribution was fairly constant, regardless of the slope class.

The stocking was different on the two slope classes. By multiplying the bunches per acre by the average number of stems per bunch, stocking per acre was obtained. This calculation yields a stocking of 1666 stems per acre on the lower half, as compared with 1434 stems per acre on the upper area. These results were

Table 2--Bunch Dimensions by Slope Class

Slope Class %	0-40	40>
Units	1, 2, 3	4, 5
Bunch Width (ft.)	10.0	7.5
Bunch Perimeter (ft.)	15.2	12.8
Bunch Height (ft.)	4.2	3.9
Ease of Choking	2.3	2.1

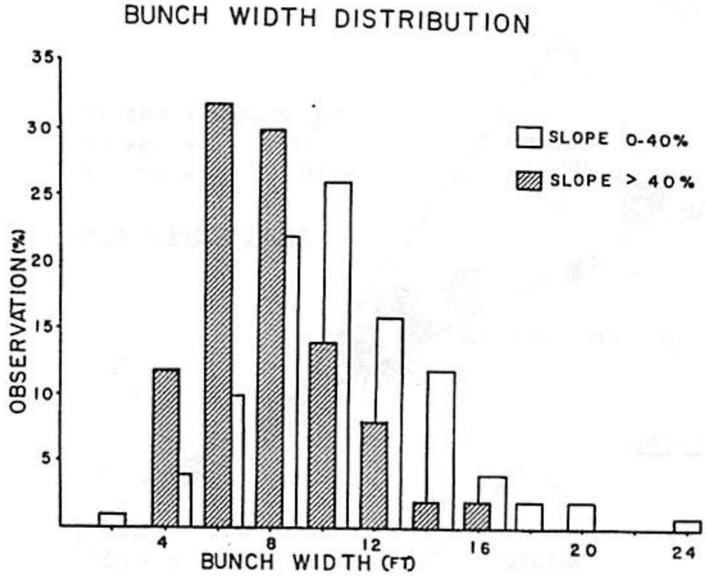
far less than determined by a Forest Service cruise prior to harvesting. While the results of the Forest Service cruise aren't entirely comparable since diameter was measured at breast height, a comparison is valuable nevertheless. Two-thirds of the difference in the estimates was in the 1 and 2-inch class material (Table 4). The other third of the difference was in the 3 and 4-inch classes. For trees over 4 inches, the Forest Service tree talley (596) was nearly equal to the talley from bunch measurements (590).

Two reasons explain the observed discrepancy in stem count. First, smaller stems were hidden or buried in the bunch so that the data collector could not see them. Second, field observations confirmed that small trees, when cut, often broke into small pieces. Therefore, they were being recorded as cut, but were not placed in a bunch. Forest Service records

Table 3--Typical Distribution of Butt Diameters in Bunches by Slope Class

	Slope Class			
	0-40%		>40%	
Butt Diameter inches	Number of Stems	%	Number of Stems	%
1	1.2	3	1.1	4
2	6.6	15	3.1	12
3	7.5	17	4.4	16
4	4.4	10	2.8	10
5	3.1	7	2.0	7
6	3.2	7	1.7	6
7	1.6	3	1.4	5
8	2.1	5	1.2	4
9	.9	2	.8	3
10	1.2	3	.8	3
11	.7	1	.3	1
12>	1.5	3	.9	3
Total Stem Count per bunch	44.6	100	27.8	100

Figure 5--Bunch Width Distribution in Relation to Slope Class



indicated that an average of 2777 trees per acre were cut.

The standing biomass for 3190 trees per acre is calculated at 227 tons (fresh) per acre. Based on the trees counted in the bunches (1519 trees/acre), a standing biomass of 142 tons (fresh) per acre was determined.

Bunch Integrity

In order to quantify how tightly stems in a bunch were packed, a bunch density coefficient was calculated. The bunch density coefficient is the ratio of the cross-sectional area of wood to the total end area of the bunch. The cross-sectional area of the wood was determined by adding the area of all the individual stems within the bunch. The end area was determined by calculating the area of a triangle determined by the height and width of the bunch

Table 4--Comparison of number of trees per diameter class based on Forest Service cruise data and tree count from each bunch.

Forest Service Cruise		Bunch Talley	
DBH	Stems/ Acre	Butt Diameter	Stems/ Acre
1	708	1	18
2	777	2	256
3	610	3	390
4	499	4	267
		5	179
6	375	6	153
		7	72
8	171	8	77
		9	22
10	39	10	37
		11	11
12F	11	12F	34
Total	3,190		1,516

measured in the field. The assumption was made that the stems were stacked to a height with which the angle of repose was equal on either side of the bunch. Figure 6 shows the end view of typical bunches with average dimension for bunches above and below the road. Notice that the slope of the sides of bunches above the road is much steeper than that of those below the road. Apparently, the bunches above the road were prepared more carefully than those below the road. Nevertheless, the bunch density coefficient was on average the same for bunches in both areas. This shows that bunches built on 40-70 percent slopes are as tight and discreet as those on slopes less than 40 percent slope. Furthermore, no significant difference in bunching cycle was found between different slope classes (Schiess and others, 1984) during the felling bunching operation.

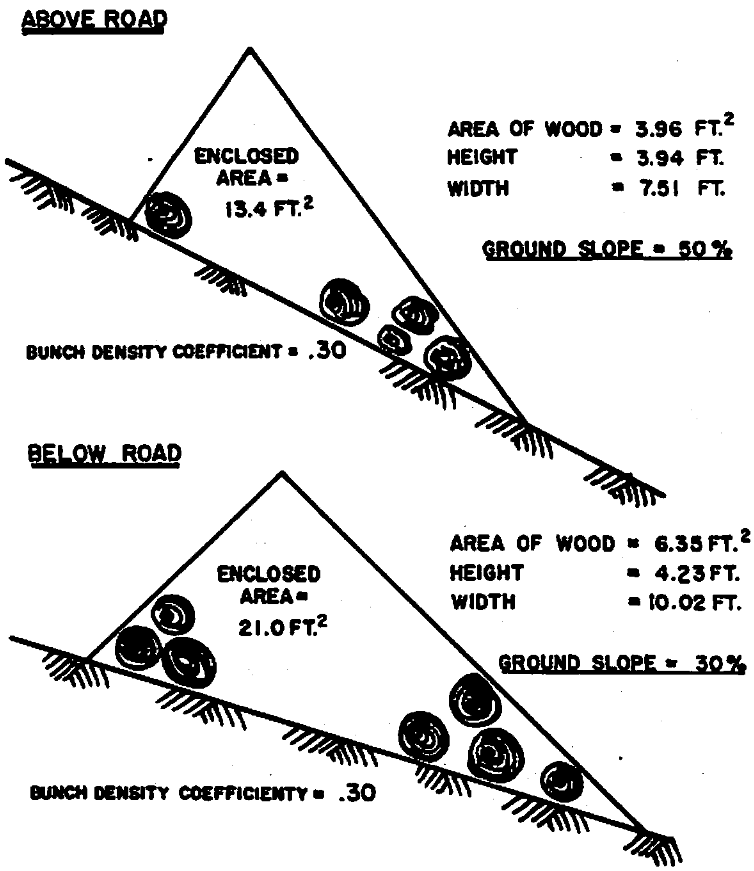
Bunch Weights

One of the primary reasons for bunching small trees is to build turn weights appropriate for medium-sized cable yarders. Typical turn weights, or payloads, can weight anywhere from 5 to 15 kips (5,000-15,000 lbs), depending on deflection. It is generally held that for economically successful cable yarding operations, payloads should be between 10 to 15 kips for large yarders. Large yarders typically have a horsepower rating in excess of 350 HP, with main or sky lines larger than 1-1/8 inch diameter. Medium sized yarders have a horsepower rating between 150 to 350 HP. The average payloads for such yarders should be between 6 to 12 kips.

The above-mentioned typical payload estimates are based on the log weights expected in conventional cable yarding operations. For example, a Douglas-fir log 23 inches in diameter and 32 feet long weighs approximately 5.8 kips. This could be representative of so-called "old-growth" yarding. On the other hand, a log 16 inches in diameter and 32 feet long weighs 2.9 kips, representative of second-growth forest where medium sized yarders are used.

Bunch weights were calculated by dividing the standing biomass by the number of bunches for the area in question (Table 5). For the purpose of this report,

Figure 6--Bunch Density and End Area by Slope Class



the biomass was calculated by determining the tree weight for each tree counted in the bunch tally and summing up the weights. Tree weights were obtained by using the biomass equation from Gholz, and others (1979), correcting it for butt diameters and fresh weight. The resulting biomass thus determined equalled 142 tons (green) per acre.

Bunch weights ranged from 5.5 kips on steeper slopes (> 40 percent) to 7.6 kips on gentle slopes (< 40 percent). The bunch weights on the steeper slopes were comparable to two 16 inch diameter log, or one 23 inch diameter log. If one were to hook two bunches, turn weights of 11 to 15 kips were possible. In other words, payloads appropriate for large yarders could be assembled.

On the gentler slopes, one set of field tests called for the creation of bunches by winching alternate rows of bunches together. The results show that bunch size as measured by weight or dimensions do not appreciably differ from bunches created by the felling cycle only.

Table 5--Bunch Weights by Slope Classes

	Slope Class		
	0-40%		>40%
Number of Stems per Bunch	44.3	46.5[1]	27.8
Number of Bunches per acre	37.2	38.1[1]	51.6
Bunch Weight (Kips)[2]	7.6	7.5[1]	5.5

[1]Bunches created by winching

[2]1 kip = 1,000 lbs.

Yarding Production

A total of 32 hours of the yarding operation was observed while yarding the pre-measured bunches, with 75 percent of this time was spent in actual yarding. The remaining time was classified as delay time, of which 83 percent involved road changes. Table 6 shows the breakdown of the operational time. Clearly, very

Table 6--Yarding Operation Time Summary

	# of Turns	% Time	Min
Productive turns	238	57	1,110
Clean-up turns	103	18	348
Delays		25	487
Totals	341	100	1,948
Delays			
Road change		83.0	
Clear landing		6.0	
Hang-up		3.0	
Add/remove chokers		2.6	
Personal		1.3	
Miscellaneous		4.1	
		100.0	

Total time measured 32:28:36

little time was taken up by non-productive delays. The largest non-productive delay, beside road changes, was time lost waiting for the loader to clear the landing. This occurred most frequently when yarding bunches that were close to the road. During these times, the yarder engineer would delay inhaul so that bunches at the landing could be removed. This was done in order to reduce problems removing chokers, as well as to minimize crisscrossing of stems at the landing.

Clean-up turns are listed separately, since they represent time yarding non-bunched material. This material was usually made up of scattered pieces dropped during inhaul, or material which was not originally bunched. The volume brought in during this time was very small with regard to the time spent yarding it. However, the U.S. Forest Service yarding specification required the removal of all material that was 1 inch top diameter by 10 feet or larger.

Yarding production averaged 8 hours per acre over the 4 acres (Table 7). The average bunch weight over the total area was 3.36 tons per bunch, ranging from 2.68 tons to 4.15 tons per bunch for the study areas. Per turn, an average of 0.72 bunches were hooked for a turn weight of 2.42 tons. Since many bunches had perimeters measuring more than 20 feet, they typically were broken up into two parts for yarding. The major reason was that only two 18 foot long chokers were used during the yarding. Typically, both were used to hook one bunch or, if the bunch was too large, at least one half of it. The overall production rate was 17.7 tons per scheduled hour, or 30.5 tons per productive hour (excluding delays and clean-up turns).

Hook Time in Relation to Turn Size

One of the unknowns in this study was the relationship between hook time and bunch parameters, such as dimension, weight and so forth. Bunch parameters in relation to hook time are listed in Table 8 for each area. Bunches per turn was calculated by dividing the total number of bunches by the number of turns when a bunch or part of a bunch was yarded. Stems per bunch and hook time per turn were recorded separately for each bunch and turn. Bunches per turn was derived from averages since it was impossible to keep track of all the pieces for each individual turn. The formula for determining it is listed below.

Table 7--Production Summary for the Cable Yarding Operation

Total area	4.05 acres
Total biomass	575.1 tons (green)
Total no. bunches	171
Productive turns	238
Average bunch weight	3.36 tons
Average turn weight	2.42 tons/turn
Number of bunches/turn	0.72
Production rate	17.7 tons/SHR
Production rate excluding delays and clean-up	30.5 tons/PHR

$$\text{Stems/min: Hooking Production} = \frac{\text{Bunch}}{\text{Turn}} * \frac{1}{\text{Hooktime}} * \frac{\text{Stems}}{\text{Bunch}}$$

$$\text{Tons/min: Hooking Production} = \frac{\text{Bunch}}{\text{Turn}} * \frac{1}{\text{Hooktime}} * \frac{\text{Tons}}{\text{Bunch}}$$

On average, hook time was longer on the steeper slopes than the gentler slopes. Average hook time for areas 4 and 5 was 2.64 minutes, versus 2.31 minutes for areas 1, 2 and 3.

Hooking production, expressed as tons hooked per minute, averaged 1.03 tons hooked per minute in areas 4 and 5 and 1.00 tons hooked per minute in areas 1, 2 and 3.

The reason for the differences between areas is difficult to explain in extreme detail due to the highly variable nature of the bunches, terrain, brush, operation, weather and work method. Bunch width, for instance, appeared to have only a weak correlation, if at all, with either hook time or hooking production.

Turn weights were typically largest on the steeper slopes, since one full bunch was hooked. The bunch size apparently was better suited to the choker lengths used. The smaller bunches allowed, therefore, for larger turn weights. However, there appeared to be a time penalty, in that longer hook times were required to hook a whole bunch.

Choker length, obviously, has to be matched to bunch size. In this operation a whole bunch could be hooked if the circumference of a bunch appeared to be less than approximately 22 feet. However, two 18 foot chokers were utilized. If the circumference exceeded 24 feet, the bunches were cut in half, as shown in areas 1 or 3, for example.

The ease of choking code, like size measurements, appeared to be fairly unrelated to hooking production evidenced by highest and lowest hooking production having equally difficult ease of choking codes.

Hook time, as well as production, appeared unrelated to slope. The average hooking production rates on slopes 0-40 percent was 11.5 stems per minute versus 10.4 stems per minute on slopes greater than 40 percent. The difference in hooking production is not significantly different with respect to slope. Consequently, due to differences in bunch size according to slope and the ability of chokersetters to adapt to these differences, hooking production on steep slopes is not largely different to that on shallower slopes.

CONCLUSIONS

Bunching trees on steep slopes up to 70 percent appears to be a feasible method of increasing yarding production of small diameter stands. Bunch weights could be assembled that were appropriate for medium yarders. Slope was not found to have a profound effect on yarding production in the range of slopes studied (0-70 percent). However, there were differences in bunch characteristics according to slope. Bunches on the steeper slopes were smaller in outside dimensions and contained fewer stems. Even though these bunches were smaller, the compactness or density was no different than those found on more gentle terrain. In all areas, bunch circumference exceeded that which could have been choked by a single choker. Consequently, no methodical hooking system was ever employed. Chokersetters hooked as many stems as possible, often hooking part of two bunches in a single

Table 8--Hooking Production in Relation to Bunch Parameters

Area	1	2	3	4	5
Hook Time (Min)	1.78	2.57	2.67	2.44	3.21
Bunches Per Turn	0.53	0.75	0.51	1.08	1.00
Stems Per Bunch	38.2	46.5	50.4	27.5	27.8
Bunch Weight (Tons)	4.15	3.73	3.53	2.68	2.82
Stems Per Turn	20.4	34.6	25.7	29.6	27.8
Weight Per Turn (Tons)	2.23	2.80	1.80	2.88	2.82
Stems Per Min	11.5	13.5	9.7	12.1	8.7
Tons Per Min	1.25	1.09	0.67	1.18	0.88
Bunch Width	9.7	10.4	10.1	8.1	6.8
Bunch Perimeter	14.7	16.1	14.9	12.9	12.7
Bunch Width & Perimeter	24.4	26.5	25.0	22.0	19.5
Bunch Height	4.3	4.5	4.0	3.8	4.2
Ease of Choking (Scale 1-3)	1.8	2.7	2.4	1.7	2.5

turn. Best hooking production was obtained in the area where bunches were largest. To increase hooking production, bunch size and choker length should be properly matched.

In the observed study, average turn size was less than a full bunch (0.72). The limiting factor for assembling the turn size appeared to be the hooking procedure employed, rather than the bunch weight. Typically, two chokersetters hooked one turn by helping each other to punch the chokers through or under the bunches. The two 18 foot chokers, in general, were too short to hook one bunch when the average bunch perimeter exceeded 13 feet (Table 8).

Two approaches could be used to fully utilize the payload capacities of the yarder. One could go to pre-setting chokers, using 30 foot long pre-set chokers during the yarding operation. Pre-setting choker is currently done to increase yarding production on a number of operations.

Another approach would be to incorporate the pre-setting into the felling cycle. Safety requirements today require that a second person need be nearby even for feller-buncher operation. Moreover, there are always cases where large trees have to be cut by hand because tree diameters exceed the shearhead capacity. It is conceivable that this person could lay chokers ahead where bunches are going to be placed. The operators would then place cut trees on the chokers. One consideration in such an operation would be the investment in chokers required. Probably, felling operations could not be carried out too far ahead.

Future research should establish if shorter hook times are possible by using preset chokers, either during the yarding, or the felling operation. There is also the possibility that turn size can be increased, presumably without a penalty in hook time. If this were the case, payloads would be limited by the yarder capacity and deflection, rather than by the number of logs or trees per turn, as is the case today in many second generation forests.

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Running Skyline Analysis: Should You Consider Yarder Characteristics?[1]

Bruce R. Hartsough, John A. Miles, Gary W. Darling, and Charles N. Mann[2]

Abstract: Recent observations have found that some skyline units, planned with current analysis programs for running skylines, could not be logged according to the design specifications. Analysis programs usually assume that yarders can tension their operating lines to 1/3 of breaking strength. This has been found to be a poor assumption for many situations. A skyline analysis program was modified to consider actual yarder characteristics. Payloads on actual profiles were analyzed to demonstrate the effects of including the yarder capabilities. The safe working tension assumptions were shown to overestimate payloads by large margins in some, but not all, situations. It is suggested that yarder characteristics must be included for reliable analysis. In addition, this would allow comparisons of yarding speeds and the effects of changing the lengths of the lines.

The use of various models has improved the planning of skyline logging. By using any of the available models, a logging engineer can generally avoid laying out inoperable settings. However, as the models have been refined, the maximum payloads that a planner might estimate for a given situation have tended to increase. For example, early computer models (eg. Carson and Studier, 1973) provided higher precision than the chain and board model (Lysons and Mann, 1967), and the reduced uncertainty allowed higher payload specifications. Consideration of log drag (eg. Carson, 1975) increased the loads predicted by newer computer models compared with the old, flying load models. The authors have recently observed some skyline layouts, planned with the latest computer models, which could not be logged according to the design specifications. For example, logs were not fully suspended when yarded through stream management zones, and one-end suspension was not obtainable on other units.

These problems focused attention on one of the assumptions made in virtually all the computer models: that "safe" working tensions, defined as 1/3 of breaking strength, can be obtained in any of the operating lines. Darling and Ferguson (1985) showed that, for one running skyline yarder, this assumption was not always true. They considered the torque limits at the maindrum clutch and haulback brake during inhaul, and the change in the effective radii of the drums as lines were spooled on or off. This work lead to a more detailed study which modeled the tensioning capacities of fifteen running skyline yarders (Hartsough and others, 1985). The study concluded that, in many situations, "safe" working tensions cannot be obtained. This paper considers some of the implications of these findings.

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PROCEDURE

A skyline analysis program based on Falk's analysis (1981), with modifications by John Henshaw, was adapted to consider the torque-tension-wrap relationship described by Darling and Ferguson (1985), and the yarder characteristic tables developed by Hartsough and others (1985). Table 1 shows the characteristics required for an example yarder equipped with a slipping clutch interlock.

Two machines were selected from each class of running skyline yarder (non-interlocked, slipping clutch interlock and variable ratio interlock; these categories have been described by Carson and Jorgensen, 1974). The machines were chosen for illustration because they had similar headspar heights (14 m to 18 m) and line diameters (19 mm to 22 mm mainlines and haulbacks).

Skyline profiles from the Fourth Water Sale on the Plumas National Forest were selected for analysis. These were not chosen at random, rather they were picked to demonstrate some of the important effects of considering yarder characteristics.

Table 1--Characteristics for a yarder equipped with a slipping clutch interlock

	Drum Specifications	
	Main	Haulback
Barrel Diam, mm	736.6	736.6
Drum Width, mm	762.0	762.0
Line Diam, mm	25.4	25.4
Line Capacity, m	366	857

	Torque Limits	
	Maindrum Clutch	Haulback (interlock clutch)
Torque, N-m	115500	61000
@Pressure, kPa	1100	1100

Torque feedback coefficient: 0.723

Torque bounds at main drum, ignoring interlock feedback

Maindrum Speed (rpm)	Torque, N-m Full throttle	Torque, N-m Closed throttle
0	112150	0
38	59070	-2370
77	32020	-6010
115	22030	-13390
154	15840	-3290
192	10740	-5080
231	4930	-7440
260	0	-10680

Maximum payloads were analyzed over each profile. The payloads were reported as fractions of the breaking strength of the lines in order to eliminate most of the effects of the differences in line diameters between the machines. On the first profile, two cases were considered for each yarder: one assuming that the lines could be tensioned to 1/3 of breaking strength, and a second using the modeled yarder characteristics. On the other profiles, the safe working tension case was run for only a single "average" yarder.

RESULTS

Profile 1

The profile geometry is plotted in figure 1. For all the analyses, the yarders were located at point 1, and a stump-rigged tailhold at point 10 was assumed.

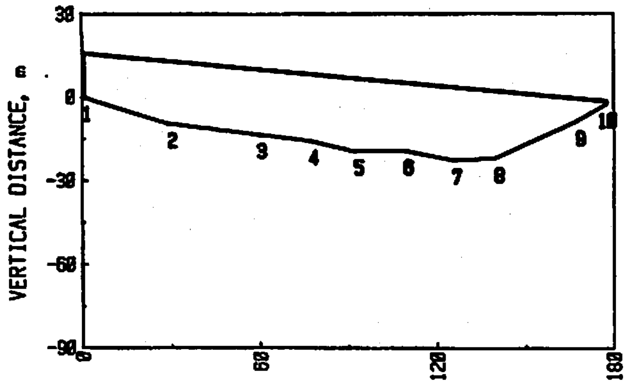

Figure 1--Profile 1.

Figure 2A displays the maximum dragging payloads over the profile for each of the six yarders, assuming safe working tensions as the limiting factors. The slight differences between the machines are mostly due to the differences in heights of the headspars. In all cases, the mainline tensions were limiting.

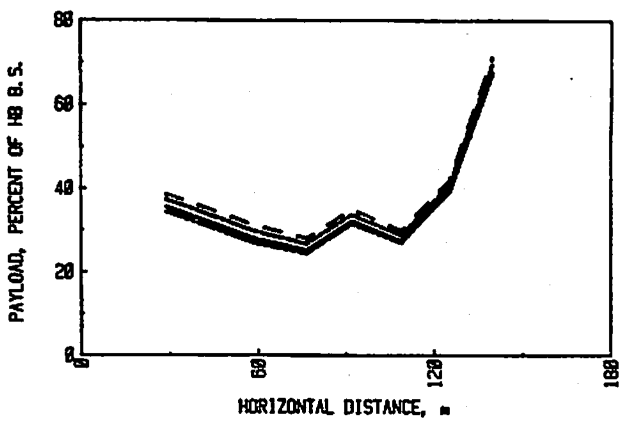

Figure 2A--Dragging payloads on Profile 1. With safe working tensions.

When considering the machine characteristics, the predicted payloads were considerably different (fig. 2B). These analyses assumed that all yarders were equipped with the maximum lengths of lines recommended by the manufacturers, and the mainlines were traveling at 30 m/min. For most points for all the yarders, the factors limiting the payloads were the haulback tensions, determined by the haulback brake or the interlock pressures. For four of the six yarders, the limiting payloads across the span were less than those predicted with safe working tensions by as much as 55 percent.

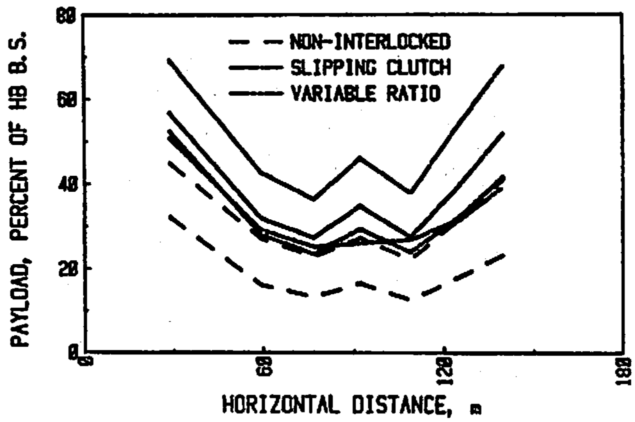

Figure 2B--Dragging payloads on Profile 1. With yarder characteristics.

The tensioning capability of a yarder can be increased by shortening the lengths of lines. This reduces the effective diameters of the drums. A third analysis was run assuming that each yarder was equipped with 300 m of mainline and 600 m of haulback. With the shorter lines, the limiting payloads over the span were 5 percent to 65 percent greater than with full capacities of line (fig. 2C).

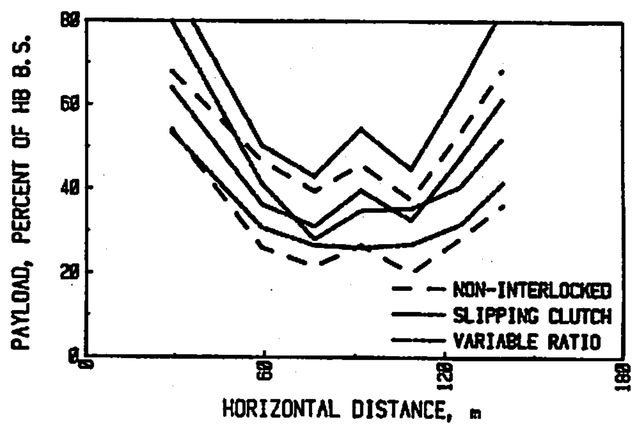

Figure 2C--Dragging payloads on Profile 1. With yarder characteristics, short lines.

The comparisons on this profile show the importance of considering the maximum drum torques and the torque-tension-wrap relationships for the individual yarders.

Profile 2

This downhill profile (fig. 3), with the yarder located at point 1, required a 10 m tailspar at point 10 to develop adequate dragging payloads when assuming safe working tensions. The haulback tension limited the payloads over most of the span. The payloads predicted with the safe tension assumptions are represented by the solid line in figure 4A.

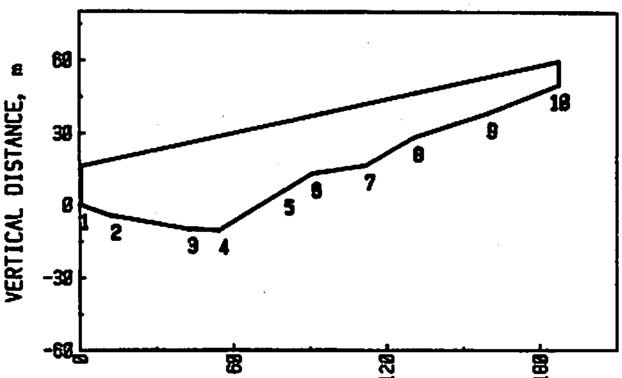

Figure 3--Profile 2.

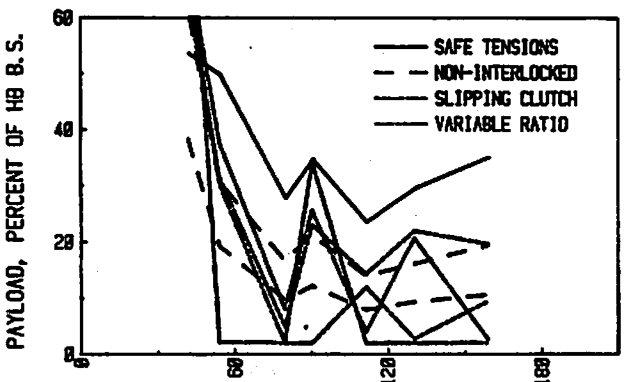

Figure 4A--Dragging payloads on Profile 2. At mainline speed = 30 m/min.

The loads generated with the yarder characteristics are also displayed in figure 4A. Maximum capacities of lines were used and the mainline speed was set at 30 m/min. On this profile, none of the limiting payloads approached that predicted with safe working tensions. For the non-interlocked yarders, the haulback lines were limiting. In this situation, a relatively short span with full lengths of line, the available torques at the haulback brakes did not achieve safe working tensions.

The low payloads predicted at many points on the span for the interlocked machines are due to the characteristics of an interlock. The power from the haulback is fed back to the maindrum. On this downhill profile, the haulback tension is greater than the mainline tension, so the power feedback exceeds the power required at the maindrum. The excess power must be dissipated. Most interlocked machines do not have brakes with the capacity to absorb much energy, and one manufacturer recommends that the brakes not be used when the drums are moving. The braking must be generated by the engine and torque converter. At low line speeds, most yarders develop very little braking torque, so the payloads which can be controlled are very low. Neither the haulback or mainline are limiting at their upper tension bounds. Rather, the mainline is limiting at its lower tension bound.

At higher line speeds, the engines and converters provide more braking. Figure 4B displays the payloads when the mainline is traveling at 150 m/min. The loads have increased for all of the interlocked yarders. However, the higher speeds may not be acceptable. If the yarder is located at the bottom of a downhill span, low speeds are necessary in order to control the logs as they approach the landing. This is also true on the back ends of profiles which cross stream management zones. If the logs are not under control at the point where full suspension is required, their momentum may carry them into the stream. Since the non-interlocked machines do not rely on engine braking, their payloads did not change at the higher speed on this downhill example.

Even at the higher speed, the limiting payloads for all six yarders were less than the safe tension payload. In the higher speed case, the haulback torque was limiting for all of the yarders on most points of the downhill portion of the profile.

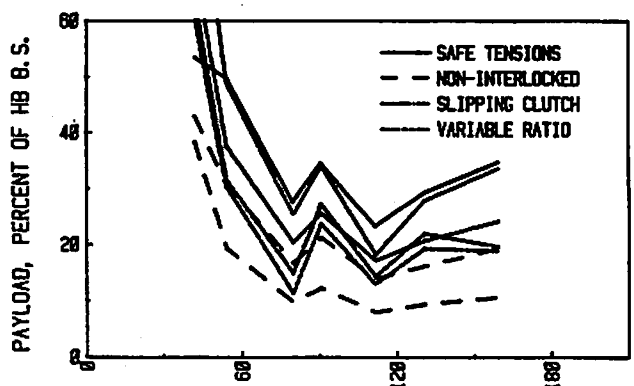

Figure 4B--Dragging payloads on Profile 2. At mainline speed = 150 m/min.

Profile 3

This steep uphill span (fig. 5) demonstrates the situation where the maximum tensions available at the maindrum are limiting, for either the safe tension or yarder characteristic assumptions. However, all of the yarders can tension their mainlines to more than 1/3 of breaking strength. This resulted in large predicted dragging payloads when using the yarder characteristics at low mainline speeds (30 m/min). They exceeded those for the safe working tension assumptions (fig. 6A). For this example, the yarders were assumed equipped with 300 m mainlines and 600 m haulbacks. However, an analysis with longer lines still gave larger payloads, for many of the yarders, than the safe tension loads.

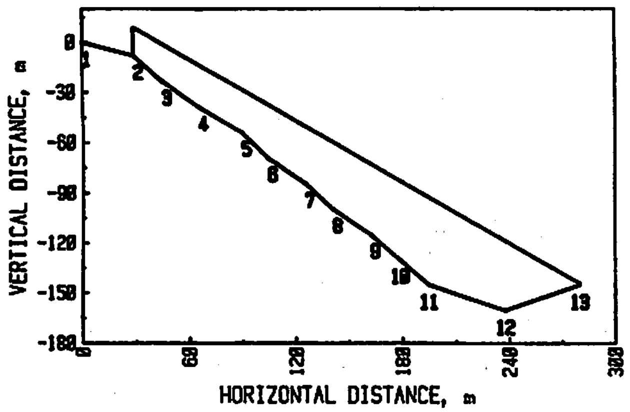

Figure 5--Profile 3.

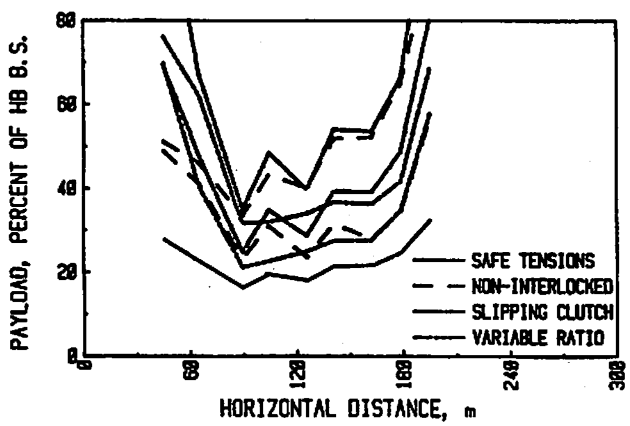

Figure 6A--Dragging payloads on Profile 3. At mainline speed = 30 m/min.

In some situations, longer spans being an example, the planner may be interested in yarding speed for appraisal purposes. A logger may want to select from two or more machines based on their relative average speeds for a given logging unit. Including the yarder characteristics in skyline analysis programs allows the user to consider speed. Figure 6B shows the predicted payloads on Profile 3 when the mainline is traveling at 150 m/min. Because a lot of energy is required to drag the logs up this steep profile, the loads are considerably less than at the lower speed.

DISCUSSION

Should the payloads based on yarder characteristics be used instead of those developed with safe working tensions? From a planning standpoint, the best solution might be to choose the minimum of the two payloads, thus avoiding both unsafe and infeasible situations. Where are the yarder characteristics more of a constraint than safe working tensions? Based on experience with using the payload model, yarders are likely to be limiting:

- on profiles with flat or downhill chordslopes, especially with short spans and suspended payloads, or on profiles with very low deflection. These are the cases where the torque available at the haulback drum tends to be the critical factor.
- on downhill yarding situations with interlocked yarders, including downhill segments at the back ends of uphill chordspans. Here the engine braking is critical, if higher speeds can't be tolerated.
- at higher speeds (greater than 100 m/min) on uphill chordslopes, or on flat chords with dragging loads. In these cases, the torque available at the maindrum may limit the payloads.

FORMATS FOR SKYLINE ANALYSIS PROGRAMS

The skyline analysis model used to generate the above examples was of the payload format, which is most commonly used in planning: the user supplies the desired carriage clearance and the program outputs the maximum payload at each point on the profile. As modified to consider yarder characteristics, the user must also input a yarding speed.

Other configurations may be more useful, depending on the requirements of the user. Wilbanks and Sessions (1985) developed a load path model. The user inputs the payload and control pressure for the interlock or haulback brake, and the model generates the clearance and yarding speed at each point on the profile.

A third format has been developed by Jim Crane, Gary Darling, and Bruce Hartsough, under the guidance of Frank Ferguson, for use on the Plumas National Forest. The user inputs the desired carriage clearance and a design payload. The model calculates the line tensions, speed and required

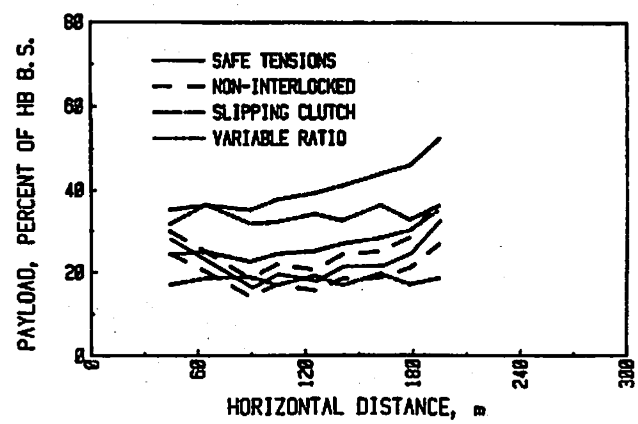

Figure 6B--Dragging payloads on Profile 3. At mainline speed = 150 m/min.

control pressure at each profile point. The model also indicates any points at which the yarder is not capable of supporting the design payload, and any points at which the safe tensions have been exceeded. Table 2 displays an abbreviated example of the output from this model.

FUTURE WORK

The yarder characteristics used in the above analyses have been developed from specifications provided by manufacturers of the various components of the yarders. These specifications may not accurately represent the way the components perform on an operating yarder. For example, torques for some clutches are highly nonlinear functions of temperature, but are usually specified as single values. Some of the most important assumptions concern the engine and converter braking torques for interlocked yarders. In situations where braking was required, the predicted payloads were found to be very sensitive to the torque values. This points out the need to verify the modeling assumptions. Yarders need to be tested under controlled conditions to provide empirical data points to be compared with the modeled tension capacities.

CONCLUSIONS

Use of the safe working tension assumptions for the analysis of running skylines can significantly overestimate payloads in certain situations. Yarder tensioning characteristics must be included in order to generate realistic load estimates. Important characteristics include the torque-tension-wrap relationship for the drums, the clutch and brake torque limits, and the upper bound on torque versus speed for the maindrum. For interlocked yarders, the torque feedback from the haulback drum to the maindrum and the lower (engine braking) bound on maindrum torque are also important.

Including the yarder characteristics allows the planner to make comparisons that were not possible before. For example, how does changing the amount of line on a drum affect the maximum payload? For a given design payload, how do two machines compare in terms of yarding speed?

From a safe planning standpoint, the minimum of the payloads based on a) yarder characteristics and b) safe working tensions should be used.

The assumptions made in modeling the yarder characteristics need to be verified by testing yarders under controlled conditions.

Acknowledgements: This work was partially funded by the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, through Cooperative Agreement #84-401.

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Table 2--Example output from Plumas National Forest Tension-Speed Program

Sale: Wilcox Profile: 1-1
System: Running Skyline
Yarder: Mustang II, Spar Height: 54 ft
7/8 hb, 7/8 ml, 3/4 sp
Operating Line Lengths:
3000 ft of haulback
3000 ft of mainline
Carriage: Danebo MSP, weight: 600 lb

Profile Specs:

Headspar at T.P. #3
Tailspar at T.P. #15, Height: 10 ft
Carriage Clearance: Flying: 50 ft
Dragging: 20 ft
Choker Length: 15 ft
Log Length: 33 ft
Design Load: 12 kips

TP	Tension (Kips) ML	Tension (Kips) HB	Mainline Speed (Ft/Min)	Haulback Pressure (Psi)	Fly	Limits Exceeded Machine Ml/Hb	Limits Exceeded Line Ml/Hb
4	10	6	915	29			
5	9	9	946	34			
6	10	9	886	46			
7	13	16	753	80	F		
8	8	10	598	103	F		
9	24	27	431	146	F	Hb	Hb
10	19	23	543	124		Hb	
11	18	20	571	115			

*Warning: Design load infeasible if machine limit exceeded. Design load unsafe if line limit exceeded.

European Longspan Skylines in North America[1]

John Malone[2]

Abstract: European Longspan Skylines are standing skylines used to harvest small and medium size timber on steep, inaccessible slopes. A single-drum, sled-mounted yarder spools the mainline and is always positioned near the top of the span. They are best suited to yard downhill from 2,000 to 4,000 feet (610 to 1,220 meters), either as singlespan or multispan. Uphill yarding is feasible also, but the development of "flyer systems" using larger yarders is more efficient. Environmentally the use of European-type longspans is desirable because roading requirements are minimal, skyline roads are widely-spaced, and logs are fully suspended along most of the corridor-design features which favor soil and water protection. In partial cut settings, however, the completed skyline roads often give the appearance of "power line corridors," which has been found to be visually unacceptable in sensitive areas.

European Longspan Skylines have been used in North American since 1949. The first trials were made in Quebec, Canada, and New York State using a smaller version of the systems commonly used today (Matson). Later trials using larger equipment were made in British Columbia, Canada, and in the states of Alaska, Washington, Colorado, Oregon, and Idaho in the USA. Yarders, carriages, and specialized rigging used are manufactured by Wyssen and Baco Companies of Switzerland and Gantner Company of Austria.

THE SYSTEM

As standing skylines, European-type longspans are anchored at both ends (i.e. skyline length is not adjusted during yarding cycle). They are two-line systems that depend on gravity for operation. A yarder spooling the mainline is located at or near the top of the span, whether yarding up or down hill. These systems are used predominantly for downhill yarding. The yarder and other typical equipment needed for longspan skyline operations and respective costs are as follows:

Typical European Longspan Skyline Equipment	Estimated Cost[3]
Skyline: 5,000 feet (1,524 meters) of 1-1/4 inch (3.18 centimeters) diameter cable.	$ 14,500
Mainline: 5,000 feet (1,524 meters) of 5/8 or 9/16 inch (1.59 or 1.43 centimeters) diameter cable.	4,500
Spool Truck: transports and stores skyline; usually custom built from a 2 or 3 ton flatbed.	20,000
Yarder: weight 4,400 lbs (2000kg); 80HP diesel engine; sled-mounted; single-drum; spools mainline.	65,000
Carriage: weight 900 lbs (408kg); automatic, time-cycled, self-energized clamp; 4 skyline sheaves; carriage open-sided to pass intermediate support jack; butt rigging attaches to mainline and releases automatically when carriage is stopped; mainline passes through carriage and is pulled manually to lateral yard.	21,500
Rigging: conventional guylines 3-4 per spar tree), blocks and straps; European tree shoes, intermediate support jacks, and skyline tensioning clamp.	16,000
Communications: signal system with 3 transmitters.	6,000
Landing Tractor: used; builds landings and spurs; installs deadmen anchors; used as an anchor.	37,500
Loader: rubber-tired; self-propelled, for medium-size logs.	160,000
Total Initial Investment	$345,000

This type of equipment is well adapted to other types of operations besides logging. Pipeline construction and ski lifts are projects well suited to longspan skyline configurations. Several ski lifts in North American have been built by logging companies using this equipment.

The logging crew generally consists of 6 people, not including the fallers. They are a foreman, yarder operator, chaser, 2 choker-setters, and loader operator. When a new skyline road is being rigged, which takes from 3 to 5 days, the entire crew become the rigging crew. During the yarding phase the yarder operator generally has to hike up the hill much earlier in the morning than the rest of the crew to avoid yarding delays. Also, the yarder operator must wear good ear protection because of the "jet plane" like noise of the air brake during gravity inhaul.

There are two basic configurations used in European Longspan Skyline operations, singlespan and multispan (see Figures 1 and 2). The main difference between the two configurations is the presence of intermediate supports. These configurations remain the same whether yarding uphill or downhill, although more suspension is generally needed for downhill. Lateral yarding also remains the same regardless of configuration or yarding direction - longs are pulled uphill to the skyline (i.e. carriage) at an angle of from 45 to 60 degrees to the contour. The operational differences begin when the turn reaches and automatically releases the carriage.

For downhill yarding the yarder unspools mainline to let the load down using gravity and controls the inhaul with its attachable air brake. Full suspension is required over most of the span for downhill yarding, although it is common to see the load drag at critical points (i.e. where carriage clearance is least along the corridor).

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[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, Calif., August 18-22, 1985.

[2]Forester-Logging Engineer, USDA Forest Service, Wenatchee National Forest, Wenatchee, Wash., USA.

[3]Cost Guide for Empirical Appraisals: December 1984.

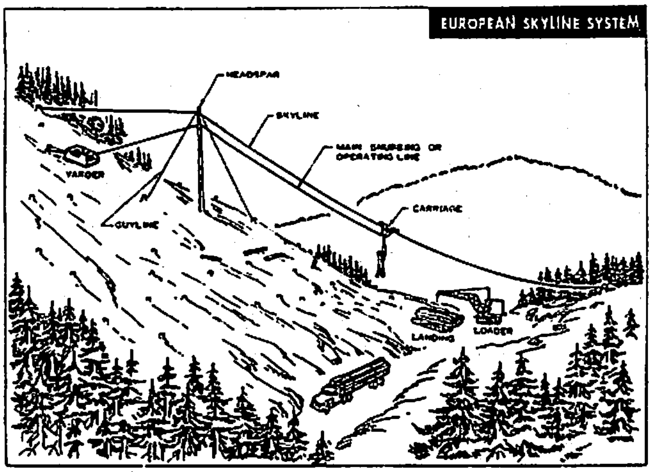

FIGURE 1. Singlespan Configuration (Binkley and Studier)

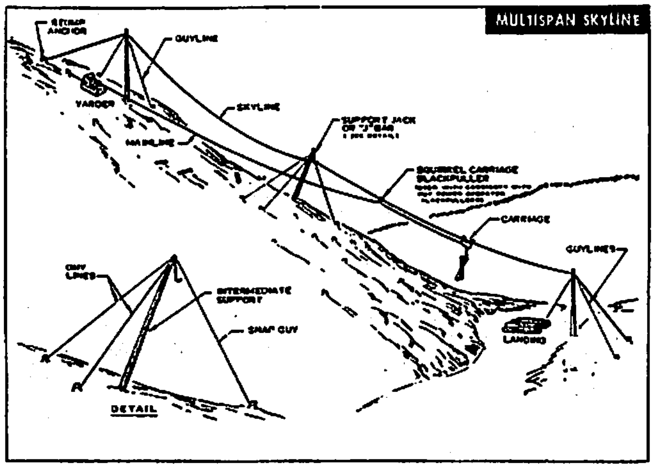

FIGURE 2. Multispan configuration (Binkley and Studier).

If multispan is used, the yarder operator must slow-down the load with the air brake to cross intermediate supports safely.

When yarding uphill the yarder pulls the load against gravity and without need of the air brake. The drum brake on the yarder controls the carriage during gravity outhaul. More log drag is permitted for uphill yarding, although with a fixed skyline length the load usually drags only over a portion of the span.

APPLICATIONS

There are presently 7 known European Longspan Skyline logging companies operating in North America. Three companies reside in north central Washington, 2 companies operate in northern California, 1 company operates in British Columbia, and 1 company operates in Idaho. A few of the personnel have European logging experience. It is common for most of these companies to take logging contracts in locations away from their immediate area.

A typical European Longspan Skyline setting (see Figures 3 and 4) covers about 400 acres (162 hectares), includes about 3 million board feet of timber (340,000 cubic meters), and yards an average distance of 1,300 feet (396 meters) downhill to a road located on the lower one-third of the slope. To start operations the yarder snubs its way from the road to the top of the of the setting where it is positioned above the first skyline road. Skyline deflection is generated by anchoring the skyline on the opposite side of the valley (or draw) bottom, although an intermediate support is needed near the top of the setting on a some skyline roads because of the convex shape of the upper slope. If a needed spar tree is absent or inadequate, a tree can be cut nearby or in the middle or lower part of the setting, skidded to the needed location with the yarder, and erected.

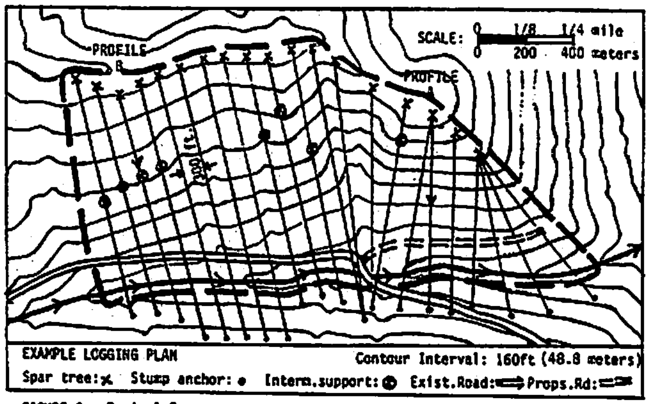

FIGURE 3. Typical European Longspan Skyline setting.

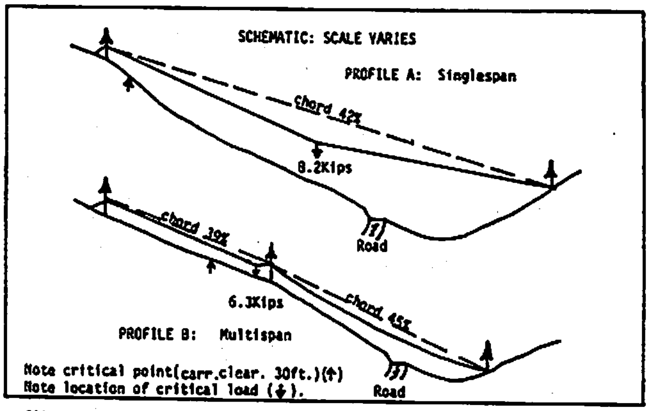

FIGURE 4. Single and multispan profiles (from Logging Plan in Figure 3).

If the road is located at or near the top of the setting, yarding will be mostly uphill. A yarder with more horsepower would be more efficient, but not essential. European manufacturers make larger sled-mounted yarders for this purpose and for yarding larger timber. Payloads are often larger than for downhill because the skyline can generally be lowered some when full suspension is not necessary to control the logs. New techniques, developed by the "Swiss" loggers as well as others, have revolutionized uphill longspan. Two-line gravity outhaul systems (i.e. flyers) similar to European-type longspans are now employed, using conventional yarders and self-clamping carriages.

Alternative systems to European Longspan Skylines are American Longspan Skyline, Helicopter, and Balloon. Lower cost for harvesting small and medium size timber is the main reason for selecting European-type longspan over these alternate systems. Another option is roading the slope at two or more elevations and yarding with short span skylines. This latter alternative is often cheaper and needs to be evaluated along with the other logging methods mentioned above. Environmentally, however, the shortspan skyline option has significantly more impact on soil, water, wildlife, and visual appearance due to its roading requirements.

The economics of European Longspan Skylines are varied. The total picture must be viewed. Factors such as tributary timber and roading miles and cost are critical to the analysis for comparison with other roading/logging alternatives. Table 1 shows how European Longspan Skyline logging costs used for sale planning on the Wenatchee National Forest compare with other systems:

Table 1—Timber volumes, logging costs, and environmental impacts of four logging methods used on the Wenatchee National Forest, Wenatchee, Wash., USA.

Logging Method	Annual Sale Volume MMBF	Annual Sale Volume Cubic Meters	Annual Sale Volume Pct.	Logging Cost[4] $/MBF	Environmental Impact Rating
Tractor	70	7,924	40	78	HIGH due to soil disturb. and roading.
Short Skyline	91	10,300	52	116	MODERATE, but req's a lot of roadings.
Long Skyline	8	906	5	144	LOW, but shows corridors in PC's.
Heli-copter	6	679	3	218	VERY LOW, except for
					except for energy consumed
Total	175	19,800	100		

ENVIRONMENTAL IMPACTS

Timber harvesting results in some environmental impacts regardless of the logging method used or how carefully it's done. On steep slopes the impacts on soil, water, and visual quality become critical. Table one provides an excellent example of an old axiom - "you get what you pay for", or the higher the cost, the less environmental impact that occurs. This appears true for logging costs only. When road costs are added, the cost rankings sometimes change. Soil displacement and instability are the major reasons for selecting longspan. European Longspan Skylines require far less roading and, with their higher skyline and more widely-spaced skyline roads, lateral yard (with care taken) and inhaul with less soil and residual stand damage than shorter skyline systems.

Partial cutting with European Longspan Skylines, however, often results in a series of "power line" appearing corridors. This dramatic change in the landscape is often found unacceptable in visually sensitive areas. Also, there is a lot of skyline lateral excursion because of the very long spans, which can create wider corridors where the skyline is below the tree tops. If deflection is very good, and care is taken to minimize corridor clearing, there is an opportunity to harvest visually sensitive slopes with longspan. Skewing the corridors slightly to avoid direct line-of-sight viewing can also be done to preserve a setting's natural appearance.

PLANNING RECOMMENDATIONS

Prepare Area Harvest Plan

Base the need for longspan on a plan that is selected from two or more roading/logging alternatives. Include tributary timber and discounting for making valid economic comparisons.

Minimum Timber Volumes Needed

Apply longspan in settings where the average skyline road will yard at least 150 MBF. This limitation will help insure that the very high fixed costs for set-up are amortized.

Minimum Chord Slope

Apply longspan in settings where skyline chord slopes are at least 25 percent or more to avoid gravity outhaul, inhaul, or lateral yarding problems. Even with chord slopes 25-30 percent some situations require analysis, such as for pulling (manually) mainline slack through the carriage.

Field Profiles

Survey and analyze field profiles for critical skyline roads, including all multispans. The most critical point on many single spans is located in the upper one-third of the slope, which can usually be eliminated with an intermediate support.

Verification

Field-check the availability of landings, anchors, and spars. In a lot of cases the road structure is all the landing area needed.

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[4]The above costs are based on recent Wenatchee National Forest timber appraisals. They include stump-to-truck, temporary road, overhead, slash treatment, and soil and stream protection costs, but not haul, road building, or road maintenance costs.

Cable Forwarding-Proof of Concept Test Facility Design[1]

W.E. Larsen, M.J. Gonsior and W.R. Taylor[2]

Abstract: A Proof of Concept Test Facility is being designed for development and testing of a conveyor system for forwarding logs. The test facility while small will duplicate field conditions and permit extrapolation to full scale with a high degree of confidence.

Throughout the Intermountain West, there are large tracts of public forest land that are unroaded or insufficiently roaded to enable timber harvesting with contemporary technology. In the Northern Region of the U.S.D.A. Forest Service, about half the commercial forest land is in this status. Many of these tracts are occupied by stands of dead and dying timber, and the managers thereof are faced with difficult problems in gaining timely entry to these stands.

At present helicopters are the only means available for roadless harvesting in rugged, mountainous terrain. However, financial restrictions usually limit the use of helicopters to distances of less than one mile and this is usually only for exceptionally high value timber.

Several efforts are underway world-wide to develop heavy-lift aircraft which would extend financially feasible aerial yarding distances many fold, if initial performance expectations can be realized. Among these developments are the Helistat (Piosecki Aircraft Corporation) and Cyclocrane (a Canadian venture centered in Tillamook, Oregon).

SYSTEM CONCEPT

The proposed system uses a conveyor with hydrostatic drives to bring logs from the woods to a landing. This is a continuous flow materials handling process. It replaces current batch handling processes that use trucks and roads, helicopters or skylines.

The total length of conveyor will be considerably less than the total length of roads for the same logging area since a conveyor can traverse steeper grades than trucks. A typical zig-zag layout for the conveyor system is shown in Figure 1.

A drainage in the Gallatin National Forest, south of Bozeman, Montana, was chosen as a typical tract for evaluating alternative designs. Many different alternatives were investigated. Among the more promising was the cable forwarding system. In this particular drainage the farthest logging area is 5 km from the landing. A system capable of extending 8 km back into the woods would handle many logging areas in Montana. Some grades are as steep as 60% but the average grade would be nearer 25 to 30%. An analysis of a proposed system for this site resulted in the following system parameters:

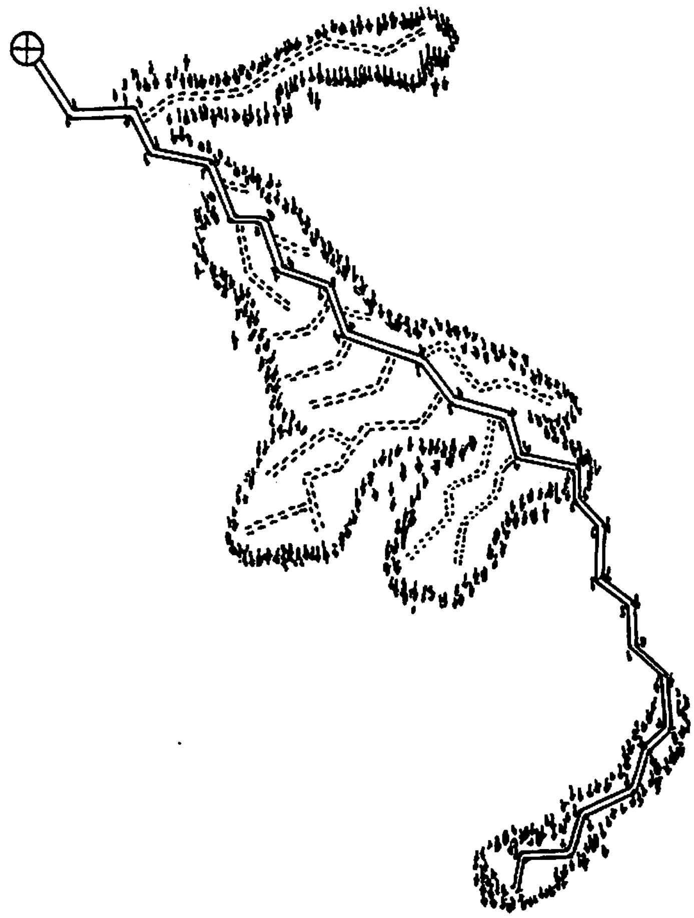

Figure 1. Principle Features of the Cable Forwarding System. The zig-zag parallel lines are moved throughout the logging area to forward loads down slope to the landing.

A 19 mm diameter cable formed in a continuous loop will be supported on towers placed in a zig-zag pattern from the landing to the logging area and back. The logs will be conveyed downhill whenever possible to reduce the need for external power supplies along the line. It may be necessary to add power in some locations, but these powered locations will require access by vehicles or helicopter for service and maintenance. The zig-zag pattern is used so that the cables will pull the sheaves to one side. The chokers used to attach the logs to the cable can then pass around the open side of the sheaves. The cable will be made with a number of individual segments so that they can be easily added or removed to change conveyor length as the conveyor is moved to different locations. The cable segments will be in 150 m lengths and the ends of each cable will be fitted with braided loop ends. Each cable segment would, therefore, change the total conveyor length 75 m. A typical connecting link is shown in Figure 2. It is easily attached or removed by two cap screws. The load is attached around the center groove to prevent cable stress due to point loading.

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[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

[3]Professor and Head, Department of Agricultural Engineering, Montana State University; Research Engineer, USDA Forest Service, Forest Sciences Lab, Montana State University; and Professor of Industrial Engineering, Montana State University, Bozeman, Mont.

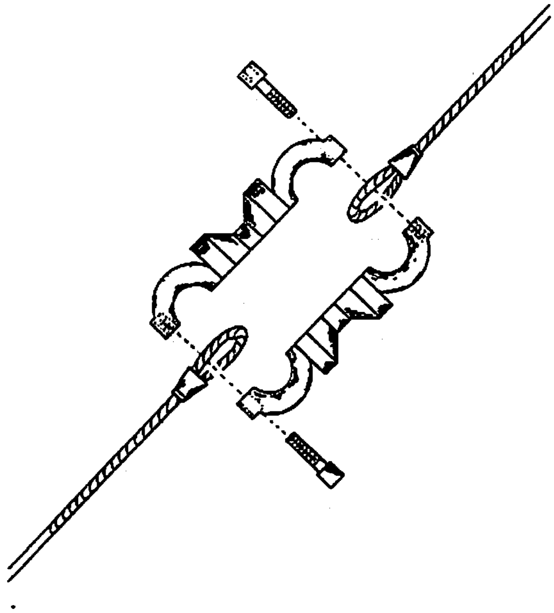

Figure 2. Split Cable Connecting Link. Cable connecting links are used to add or delete fixed lengths of cable. The connecting links also serve as load attachment points.

The cable support towers would generally be spaced at intervals of 150 m or less with a more typical spacing of 75 to 110 m. Cable connectors every 150 m and tower spacings less than 150 m assure that usually there will never be more than one log between any two support towers. Cable tension will be maintained near the maximum design tension to limit deflections between spans to approximately 3% of span. With this configuration the support towers can be 4 to 6 m high. Trees or guyed gin poles can be used as support towers.

A cable reaching 8 km back into the woods with the potential of one load every 150 m and operating at 150 m/min. could handle as many as 53 loads at one time and could deliver one load per minute to the landing. A load would be considered as one to two logs with a weight of 800 to 1000 kg. This length of cable with as many as 53 loads along its length cannot be controlled by a single master control at the landing.

The cable tensions and load control will be obtained by a series of control sheaves spaced along the line. Each control sheave will have its own hydrostatic drive and will serve as a braking (or drive) sheave to control cable speed and tension. The instrumentation package will measure the cable tensions and sheave torque then adjust cable speed to prevent overload on the cable. When cable tension is not limiting, the control sheave will maintain a constant speed as determined by the master control microprocessor. On steep grades, (up to 60%) a control sheave will be placed on each tower. Control sheaves can be placed farther apart as the grades decrease.

A mobile loading device in the woods will be located under the cable to attach the logs to the conveyor cable. This mobile loading device must be able to move through narrow spaces (2.5 to 3.5 m wide) and over grades up to 60%. When in position it becomes a stable working platform that can remove logs from decks along side of the cable, position them under the cable, and then automatically attach them to the moving cable.

The proposed cable forwarding system appears feasible and competitive with alternative logging systems. A Proof of Concept Test Facility is needed as a first stage in system development since many components and concepts needed for the system have not been proven.

The Proof of Concept Test Facility is in the design phase. This test facility will be used to prove the design concepts of the various components and to develop operating parameters for a full scale system. The following design concepts will be developed and proven in the test facility:

1. Design a sheave that will permit passage of a cable connector with attached load when placed on towers located in a zig-zag pattern from the landing to the logging area and return. This sheave must be able to pass the connecting links and the load attaching choker.

2. Design a control sheave that can sense cable tensions and sheave torque, then adjust sheave speed to maintain cable tensions within safe design limits. The sheave design is shown in Figure 3. The support tension Ts, angles and will be measured, then the cable tensions and torque will be calculated. The resulting cable tensions will be used to determine the need to speed up, slow down, or hold the speed on the hydrostatic sheave drives.

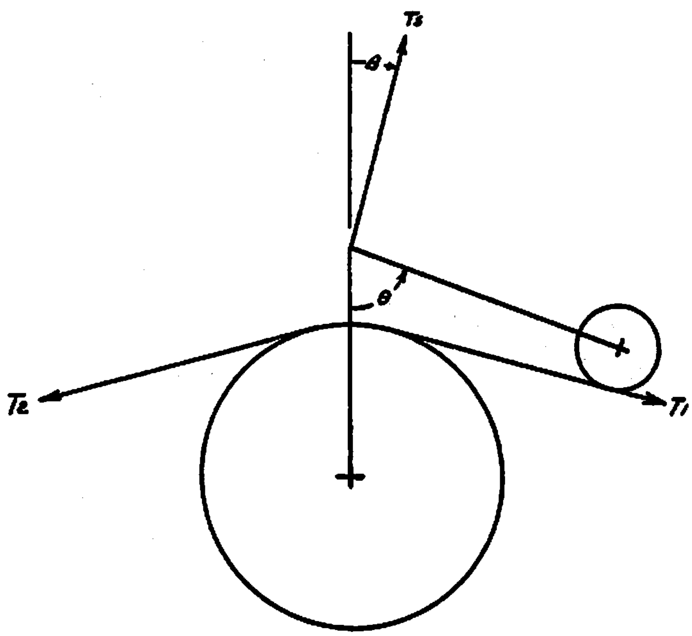

Figure 3. Control Sheave to Measure Tension Ts and Angles θ and β. These measurements are then used to calculate cable tensions T1 and T2, the sheave torque and the wrap angle.

3. Design a load attachment module that can position the logs under the cable and automatically attach the logs at the predetermined attachment points on the cable. The load handling and attachment technique is the primary design factor that will be tested in the Proof of Concept Test Facility. A mobile platform to support the loading module in the woods will not be included in the test facility.

4. Design an automatic unloading device to remove loads from the cable forwarding system at the landing and in the woods.

5. Design a device and operating method for changing the length of the cable system and for controlling cable tension.

6. Design a microprocessor control to interface between the master control at the landing and the individual control sheaves along the cable.

7. Develop operating techniques for loading and unloading of logs, changing cable length, etc.

TEST FACILITY

The Proof of Concept Test Facility consists of a scale model conveyor system with both indoor and outdoor test facilities. The cable scale factor will be 0.5 times the cable diameter. The resulting cable strength will be reduced to 0.25 times the strength of the full size cable. The resulting loads will, therefore, be 0.25 times the design load for the field facility. The design speed of zero to 150 m/min. will be duplicated in the test facility. The power level in the system will, therefore, be 0.25 of full scale. This scale factor was chosen to permit construction of the test facility using readily available components. This system will facilitate testing in a relatively small space yet will permit scaling up to full size with a high degree of confidence.

A 12 x 12 m room will house the indoor test facility but this will still permit simulation of field conditions. The layout for the test facility is shown in Figure 4. The cable segments will be 6 to 9 m long to permit testing of the equipment and to determine the procedure for changing the cable length. Only three pairs of control sheaves will be used. They can duplicate field control conditions and they will be instrumented to measure cable tension and system responses. Each control sheave will be bracketed by a load simulation device which will drive or brake to provide a predetermined force on the cable. This force is a function of cable speed and will be determined by the computer. The loading device will duplicate calculated loads. The actual distance between control sheaves is small but the system will be able to simulate spacings up to 150 m by the way loads are programmed. The system will be able to operate over the entire design speed range. Full power tests will permit testing of the braking and cooling capacity of the hydrostatic drives under full load.

Actual loads up to 225 kg will be attached to the line then moved through three control sheaves and unloaded. This is a very short distance, yet it will prove the performance of the attaching and removal devices and determine the operating procedures. Due to limited space and sharp turns in the test facility the operating speed will have to be limited for these tests. The mobile platform for the loading unit cannot be tested for manueverability, but the position of the loading unit beneath the cable can be changed to study the effect of cable angle of approach on the loading system. A grapple to move logs from the decks to the loading device is not included in the test facility. This type of grapple is presently used in many log handling devices and, therefore, is a proven concept. The primary use of the outdoor test facility will be to permit full speed tests of the load attachment and removal devices and operating procedures.

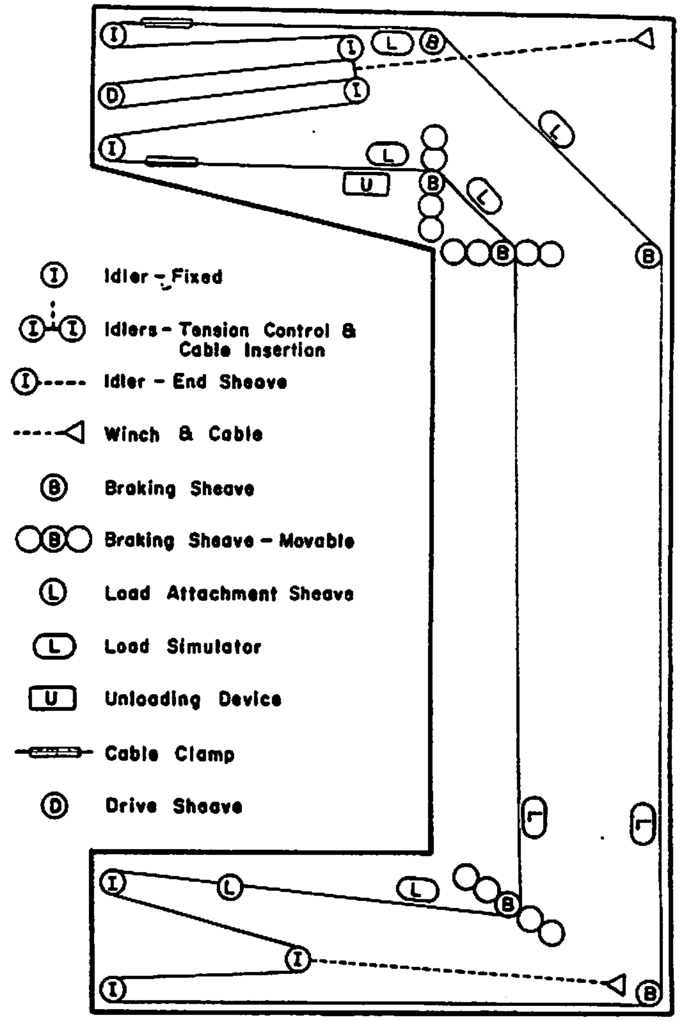

Figure 4. System Layout for the Proof of Concept Test Facility.

Other components shown in Figure 4 include idler sheaves and an end block that enables simulating the procedure for moving the conveyor in the field. This will involve a process of feeding cable segments into or removing them from the system. The cable length adjustment and tension control at the landing or in the woods are controlled by hydraulic winches pulling on an idler sheave on the cable.

The Proof of Concept Test Facility is small, but it will permit simulation of the operating conditions in the field. It will provide a facility for development and testing of the mechanical components, the control system and the operating parameters for a Cable Forwarding System. The scale factor is large enough that extrapolation to full size can be accomplished with a high degree of confidence.

EARLY ACHIEVEMENTS IN DEVELOPMENT OF A SUBSTITUTE EARTH ANCHOR SYSTEM [1]

Briar Cook and Bob Simonson [2]

Abstract: An immediate need for development of a Substitute Earth Anchor System exists in the logging industry where timber harvesting is progressing into cutover second-growth plantations. The development of such a system has been contracted for by the Forest Service, U.S. Department of Agriculture. Equipment is still in the development phase.

Development of a Substitute Earth Anchor System (SEAS) is called for by a rapidly growing demand for earth anchors, which are capable of resisting large static and dynamic pullout loads in soils and rocks of widely varying properties and in rough, steep terrain. These anchors are needed for short-term tie-down applications; e.g., for use on many logging operations and U.S. Army assault vehicles, as well as for the installations such as the mooring mast of the Helistat and a large number of other guyline applications.

The most immediate need for the SEAS exists in the logging industry, where anchors are needed for guylines to secure large yarding towers, and as tailholds for skylines which may span distances of 5,000 ft or more. Requirements for anchors which can resist static pullout loads in excess of 130,000 lb are not uncommon in this industry. Until recently, this demand was readily satisfied by large tree stumps that were available in sufficient number in the areas where timber harvesting took place. Now, however, harvesting is progressing into areas, such as cutover second growth plantations and nontimbered ridges, where large, undecayed stumps are not available. It is primarily for this reason that the Forest Service has a vital interest in the development of the system.

Also because of the wide range of anchoring requirements of the logging industry, the SEAS will be very appropriate and useful for the other applications indicated. The Forest Service decided to expedite the effort by awarding a contract in 1982 to Foster Miller, Inc. of Waltham, Mass. The San Dimas Equipment Development Center (SDEDC) was assigned the task of administering the contract.

SCOPE OF CONTRACT

The scope of the contract is to provide the necessary engineering materials to design, develop, fabricate, and test a safe, reliable, and economical SEAS for cable logging systems. The system is to consist of anchors, anchor installation equipment, anchor field test equipment, soil testing equipment, transportation equipment, drawings of all equipment, applicable documents, and training manuals. Furthermore, an analytical and experimental investigation of the dynamic characteristics of commonly used logging systems is to be carried out to determine the performance requirements for the SEAS. Anchor testing equipment which can be used to test holding capacity of anchors under static and dynamic loading conditions during development is also required. It is anticipated that a family of anchors (sizes and/or types) would be required for the SEAS because of the variety of soil types the anchor will be implemented in and the range of the required anchor holding capabilities. The contract, deals with all but the weakest (SPT blow count < 10) inorganic soils.

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[1] Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

[2] Assistant Manager and Civil Engineer, respectively, USDA–Forest Service, Equipment Development Center, 444 E. Bonita Avenue, San Dimas, California 91773.

The contract is divided into four phases: (1) Dynamic Analysis and Test (DAT); (2) Soil Test Equipment and Methods (STEM); (3) Anchor Test Equipment (ATE); and (4) Substitute Earth Anchor System (SEAS).

DESCRIPTION OF PHASES

Dynamic Analysis and Test (DAT)

The objective of this phase is to develop the information needed for an improved understanding of the dynamic behavior of skyline logging systems, so that the load requirements on man-made anchors can be specified for the SEAS.

The anchors of the SEAS will be subjected to very high static and dynamic loads. The static loads in the cables and, consequently, the static loads on the anchors can be predicted readily by the principles of engineering mechanics and geometry. Dynamic loads, however, are usually more difficult and sometimes impossible to predict without experimentally determined dynamic load data. Such experimental dynamic data must be obtained from tests on systems which have characteristics similar to those of the system for which dynamic load predictions are to be made.

Preliminary to actual field testing, an analytical model (also referred to as a theoretical, mathematical, or computer model) of a typical skyline logging system was developed. A model like this typically consists of a geometrical and mathematical formulation of the structural aspects of a system. This includes the material characteristics and properties of the components of the system such as the length, area, moment of inertia, mass, modulus of elasticity, Poisson's ratio, friction angle, etc. of the guylines, operating lines, towers, anchors, and soil, as applicable. This model is to be used to predict the dynamic response of similar logging systems to a variety of loading and initial cable tension conditions, as well as to make changes in geometry of the system layout. The model can predict worst-case loading conditions and geometric configurations for skyline logging systems and will thus be an aid to field test planning. The model verified that, no matter how the system was loaded, forces above 1 Hz were at very low dynamic amplitude.

Soil Test Equipment and Methods (STEM)

The objective of this task is to (a) identify or develop field soil testing equipment and methods which are most appropriate for the purposes of the SEAS and (b) compile and/or develop the necessary data to correlate field test results with actual soil properties. The following information about soil conditions at the proposed anchor site is needed:

- Depth
- Type (cohesive, noncohesive)
- Condition (degree of saturation)
- Variation of type and condition with depth
- Relative density
- Strength (shear strength, angle of internal friction, unconfined compressive strength).

Ideally, all of this information could be obtained by performing one single test. Realistically, several different tests will be required to develop the information. Some of these tests may consist of visual and manipulatory examination of soil samples to aid in the determination of the type and condition of the soil. Other tests may involve penetrometers, vane shear testers, hand or power augers, rock drilling equipment, seismic instruments, soil resistivity apparatus, nuclear, moisture, and density measuring devices, etc. Whatever is used, the objective is to be certain that it can be used by nontechnical personnel with nominal training to determine the depth, type, condition, and category of the soil.

Anchor Test Equipment (ATE)

The objective of this phase is to develop anchor testing equipment which can be used to test the holding capacity of anchors under static and dynamic loading conditions as required for the development of anchors for the SEAS.

ATE is to provide the capability of accurate and expeditious testing of SEAS anchors during their development. This anchor testing equipment is not necessarily the same as the anchor field testing equipment which will be a component of the SEAS. The equipment to be developed under this phase can conform to less restrictive requirements with respect to the type and condition of the terrain in which it must be operable. In considering the performance requirements, however, this equipment must be adaptable to more stringent requirements than the SEAS anchor field testing equipment. It is conceivable that the SEAS anchor field testing equipment will be a modified version of the anchor testing equipment to be developed under this phase.

The static load requirements of the ATE was set at 200,000 lb to simulate the breaking strength of a 1-3/8-in cable. The dynamic load requirements were determined by analyzing the actual results of a field test on a logging operation. The ATE loading will vary with the frequency from 100 ± 100 kips at 0.1 Hz to 195 ± 5 kips at 5.0 Hz.

Substitute Earth Anchor Systems (SEAS)

The objective of this phase is to produce a complete system consisting of anchors, soil testing equipment, anchor installation equipment, anchor field testing equipment, transportation equipment, documents, and training manuals.

PHASE TASKS

A typical scenario of tasks within the phases are as follows:

- Literature search
- Course of action meeting
- Conceptual designs
- Conceptual design review meeting
- Prototype design
- Prototype design review meeting
- Fabrication and lab testing
- Select test sites and prepare test plan
- Test plan review
- Field test
- Field test review meeting
- Acceptance test
- Final report
- Deliverables.

TECHNICAL EVALUATION TEAM

Due to the size and complexity of this project, an evaluation team was established at the onset of the project. The team consists of three Engineers from the Aerospace Corporation and the following Forest Service employees:

- 1 Industrial Engineer
- 1 Mechanical Engineer
- 2 Logging Engineers
- 2 Civil Engineers
- 2 Geotechnical Engineers.

Through many meetings and decisions, the project is now in its final year. The evaluation team's objective is to analyze all facets of the work performed by Foster Miller, Inc. and through a cooperative effort make decisions to guide the project to the best possible conclusion.

CURRENT STATUS

Dynamic Analysis and Test (DAT)

To evaluate the dynamic behavior of a skyline logging system and to gather the necessary data to develop the analytical model, a field test using a working logging system was conducted in July 1983 (fig. 1). The test site was at the Simpson Timber Company Dry Creek Site near Camp Govey, Wash.

The yarder was a Skagit model BU-739 with 110-ft telescoping tower, three drums, and eight guylines. The skyline was 1-3/8-in; the mainline was 1 in, and the haulback was 7/8-in diameter. The carriage was custom-made by Simpson with two sheaves riding on the skyline. A swivel block with a choker was attached to the mainline, and two chokers were attached to the body of the carriage. The carriage weighed 2,100 lb not including the chokers.

The seven guylines were all 1-3/8-in diameter wire rope made up of various lengths connected by line shackles through hand-spliced eyes. They were anchored to the notched stumps by one wrap with a flat shackle around the guyline. Three of the load sensors were placed "in-line," which means they were midway between the tower and stump anchor. In these cases the guyline ran over the ground, so that loads measured at the stump would be somewhat less than the load in the guyline. The skyline was approximately 1,500-ft long. Two tailhold changes were made during the test series, so three skyline configurations were monitored. The terrain under the skyline allowed full suspension at virtually any point along the skyline for two of the corridors.

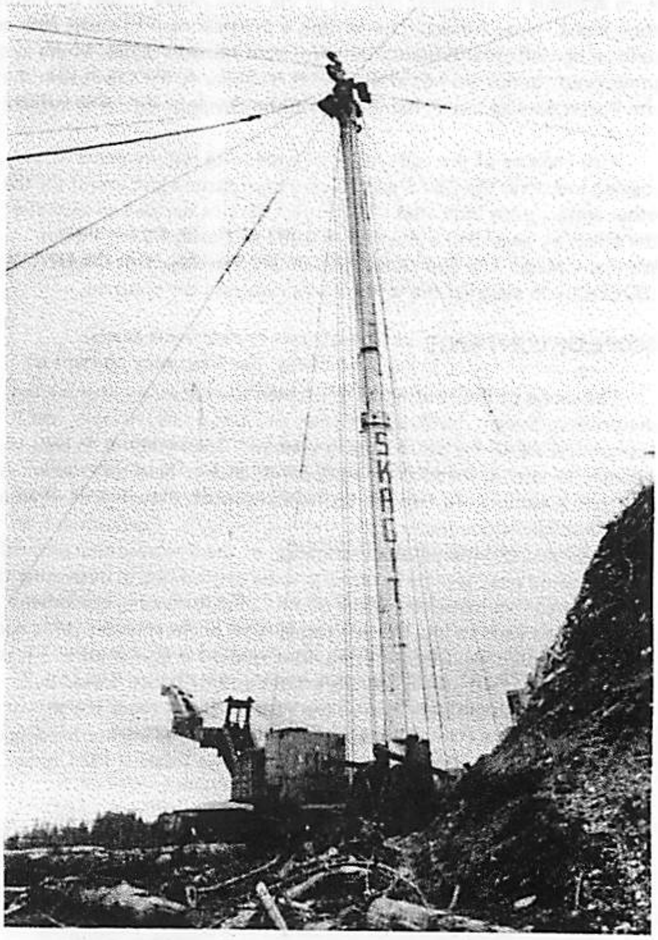

Figure 1. Logging system used in Dynamic Analysis Test.

Soil development was poor with a surficial "O" horizon and an "A" horizon generally less than 2-ft deep. Total soil depths ranged from nil (outcrops) to greater than 20-ft deep in drainage valleys (visual observation of road cuts). The underlying soil mass appeared to be elluvial consisting of well drained, very loose to loose silty sands (SM), poorly graded sands (SP), and silty gravels (GM).

Three types of sensors were used: Cable load, anchor and tower acceleration, and displacement of the cable at the stump anchors. Anchors directly opposite the skyline were the most heavily loaded. For this reason, accelerometers and displacement transducers were placed on these stumps rather than the others. The tailhold was instrumented with a load sensor, accelerometer, and displacement transducer—but because of a failure in the multiplexer system, only the load sensor was used during testing.

The load sensors were straingauged pins which fit into rigging designed to match the guyline stump anchors. The straingauge bridges were temperature compensated and were not sensitive to torque loads developed in the cables.

Accelerometers were used on two stump anchors and at the top of the tower. The "X" direction was parallel to the guyline (or skyline in the case of the tower), and in the horizontal plane. The "Y" direction was perpendicular to the guyline, and "Z" was vertical. The accelerometers were in the ± 10 g range, and were internally damped to avoid ringing. They were attached to the stumps by means of screws. The tower accelerometers were attached to a board which was strapped around the top of the steel tower, above the guyline sheaves.

Displacements were measured by means of "string pots" which are potentiometric transducers (variable resistance devices). The string pots had a range of ± 1 in and were attached to posts 25 to 30 ft from the stump. Steel wire was used to connect the string pots to the stump. The wire was attached to the flat shackle so that the motion of the cable was measured. This included any motion due to the cable cutting through the stump.

Field Test Objectives

The objective of the static tests was to determine the nominal tensions in guylines with various loads on the carriage, with the carriage at various positions on the skyline.

The objective of the dynamic tests was to determine system response to time varying loads; specifically, the frequency content of anchor loads and amplification of input loads.

All of this indepth field testing has led to the completion of the analytical model. The model has been tested at the Forest Service's Pacific Northwest Forest and Range Experiment Station, Seattle, Wash.

Soil Test Equipment and Methods (STEM)

After a very long and involved analysis of the problems associated with gathering soil samples, the solution headed in the direction of combining equipment. Foster Miller, Inc. designed and built what is known as the "STAIR" (Soil Test and Anchor Installation Rig) (fig. 2) This piece of equipment can breakdown into components, perform soil testing, augering, rock drilling, and anchor emplacement.

The basic concepts are modeled after proven commercial units, but modified to fit the exacting needs of the field conditions. The STAIR can resist 4,000 ft-lb of torque, apply a pulldown load of 2,000 lb, has a retract load of 4,000 lb at a stroke of 70 in, and support a slide hammer weighing 140 lb with a stroke of up to 9 ft. The entire unit is assembled with pins, maximizing flexibility and ease of field assembly without special tools. Further refinements are expected as testing continues.

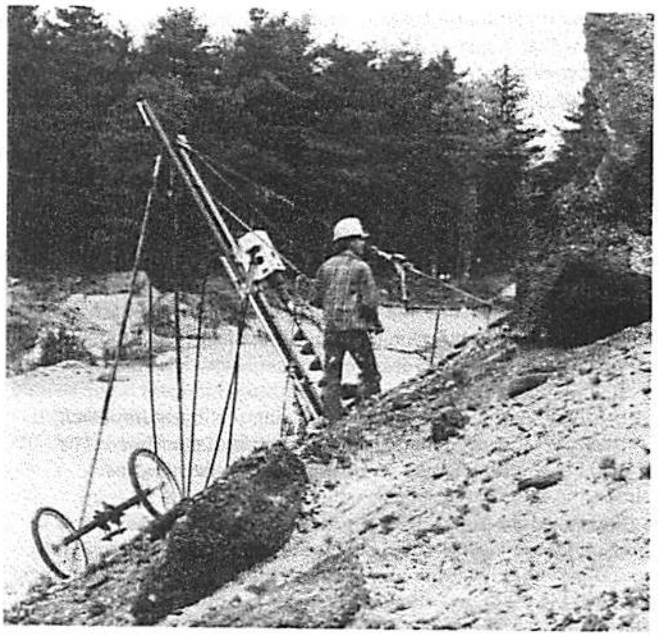

Figure 2. Soil Test and Anchor Installation Rig (STAIR).

The STAIR will perform the standard penetration test (SPT). This was one of the requirements in order to keep soil tests similar within the engineering community. As testing proceeds, soil test methods and procedures will be refined to accomodate the SPT in order for field personnel to have a complete soil test method.

Anchor Test Equipment (ATE)

The preliminary prototype has been completed and its principal features are as follows:

- The preliminary prototype structure is based on two 24-in wide flange beams. The ATE as fabricated has a design load of 200 kips over a clear span of 20 ft.
- The static loading system employs a 14-in diameter by 36-in stroke hydraulic cylinder which transmits load to the anchor head by means of a 2¼-in wire rope.
- The hydraulic system assembled with the preliminary prototype included components of the dynamic loading hydraulic system required to test the response of the system to a step input.
- Although the ATE may eventually require some form of undercarriage/footing, this was not included in the preliminary prototype design, since the requirements for a footing will be strongly determined by the types of anchors to be tested and the test layout.

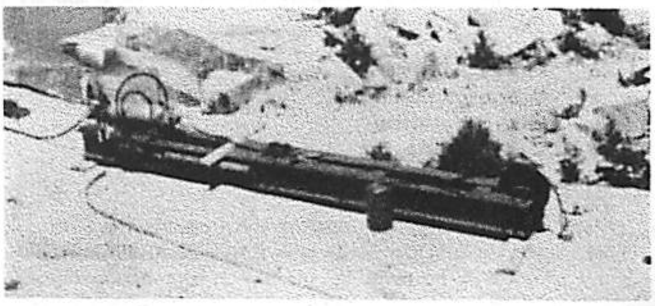

Figure 3. Anchor Test Equipment (ATE) in vertical test configuration.

An instrumentation system capable of monitoring cylinder pressure, anchor load, and anchor displacement was also constructed as part of the ATE preliminary prototype (fig. 3). The ATE has been tested to pull in both the horizontal and vertical direction.

Individual anchors do not need the power of the ATE, but as soon as the individual anchors are bridled together and become a total system, the ATE will serve its function.

Substitute Earth Anchor Systems (SEAS)

This phase of the contract is receiving the most emphasis at this time. Foster Miller, Inc. is installing anchors and field testing the equipment that they have designed.

During the preliminary stages following the literature search, Foster Miller, Inc. presented 14 types of potential anchors. The technical review committee reviewed the anchors and after considering all the parameters surrounding the SEAS program authorized Foster Miller, Inc. to proceed with the following five types—hinge, net, grout, leaf, and buried stake auger. Numerous variations of the five types have been considered. The hinge and the leaf show the most promise.

The hinge type includes various shapes and sizes of tipping plates and a concept referred to as the tree root. The tree root has evolved from a series of grouted tendons to a series of 6-in arrow-shaped tipping plates connected by tendons of chain and cable. The tipping plates are driven into the ground (using a jackhammer) in a radial pattern at a 45-degree angle from the surface. Static capacities have reached 70 kips installed at a depth of 5 ft.

Tipping plates installed at depths greater than 10 ft have exceeded a capacity of 100 kips. Numerous tests are being conducted in various soil types to gain statistical reliability. The Forest Service is working closely with State safety agencies (OSHA's) to develop a reliable product that can be incorporated into the codes.

Figure 4 shows the net better than it can be described. The net shown is only 2-ft deep and 6.5-ft across and it failed at 28,000 lb. Used in certain locations the system has good potential.

To test the resistance of these individual anchors, a piece of equipment was required to pull the individual anchors to failure. The ATE previously mentioned is obviously too big and economically impossible to move from site to site. Consequently, the MATE (Mini Anchor Test Equipment) was born (fig. 5). The MATE has a pull-out capacity of 75,000 lb. Individual anchor capacity exceeded expectations and a second MATE is being fabricated with a capacity of 100,000 lb.

The STAIR unit, described under Soil Test Equipment Methods, is currently being used to install anchors.

Transporting all of this equipment may take many forms. Figure 6 shows the STAIR unit in a compact form and on wheels. The most economical concept for ease of transport through the woods appears to be a torpedo system. The torpedos are constructed of an abrasion-resistant PVC material and are pulled through the woods utilizing the capstan from the STAIR unit. All SEAS hardware breaks down into sizes which fit within the 1-ft diameter torpedos.

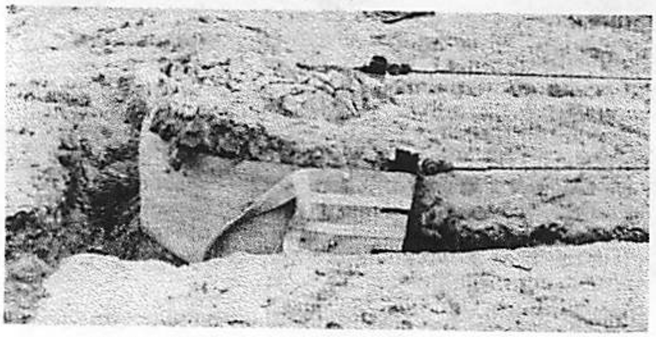

Figure 4. NET type anchor at failure.

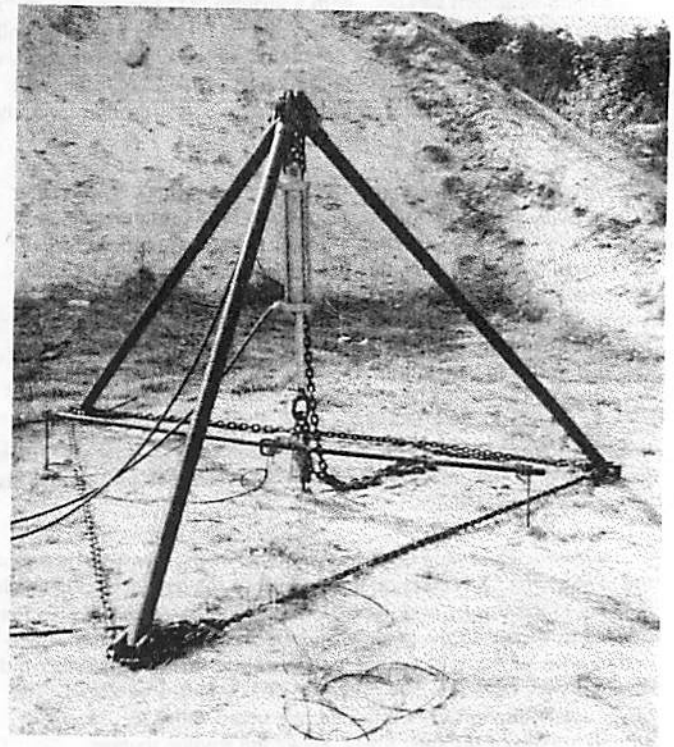

Figure 5. Mini Anchor Test Equipment (MATE).

With the experience of the field tests and the current installing and pulling of anchors, Foster Miller, Inc. soon hopes to proceed down the final path of design and construction of all the various components necessary to supply the logging industry with a total Substitute Earth Anchor System.

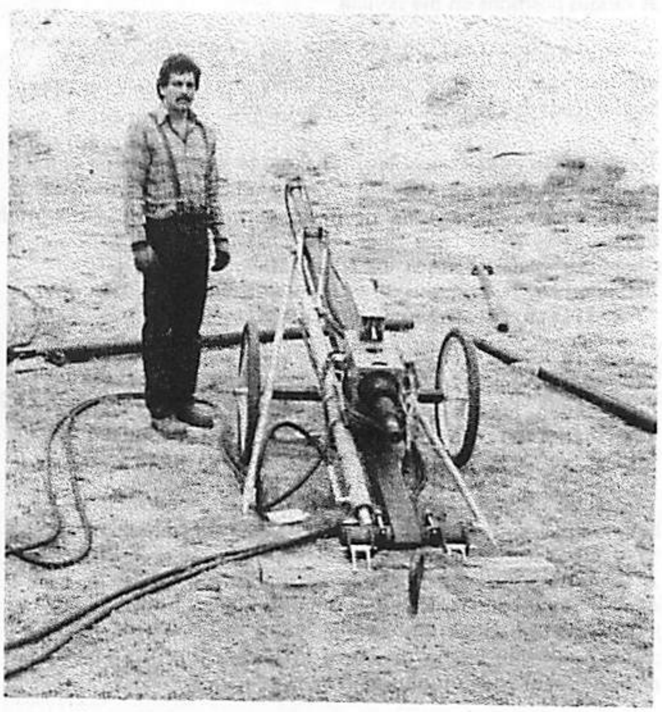

Figure 6. STAIR shown in transporting mode.

Use Of Hydraulic Excavators In Steep Terrain[1]

John C. Balcom[2]

Abstract: In the steep, marginally stable terrain, forest roads must be designed and constructed to minimize the risk of mass soil failure associated with such roads. Four such construction techniques which utilize hydraulic excavators are discussed.

1. Pull-back and end-haul of sidecast material on existing roads and landings.
2. Removal of brush from the road prism.
3. Full bench construction with end-haul.
4. Closing out entire roads by pulling back as much of the sidecast material as the resulting grade width can hold.

In recent years, considerable attention has been focused on mass soil failures associated with forest roads constructed in steep, marginally stable terrain. Road construction changes the slope geometry and alters slope drainage, which in many instances reduces the stability of the slope.

Dyrness (1967) and Fredricksen (1970) concur that road construction is the greatest single cause of recent mass soil failures in the Western states. More recently, Amaranthus, et. al. (1985) indicated that in the Klamath Mountains, roads were the site of over half of the slides which occurred between 1956 and 1976 and accounted for 60 percent of the slide volume.

These and other studies indicate that much of this road related failure is the result of road construction techniques used during the late nineteen-fifties into the nineteen-seventies. Techniques which did not involve such current measures as end-hauling, brush disposal and engineering of fills.

Road construction methods are changing however. Both private and agency land managers alike are regulating changes designed to improve the stability of the final road. The current use of hydraulic excavators in forest road construction is largely a result of these changes. Conventional road construction equipment is not well-suited for cost effective end-hauling or precise handling of excavated material. Nor is it well-suited for sorting and disposal of brush and debris within the road prism. Hydraulic excavators however, do facilitate these and other changes.

This paper discusses four such changes utilizing hydraulic excavators. These four changes make work much more intensive than conventional methods of construction, so information will be presented on relative cost increases and potential cost reductions associated with each change.

SIDECAST PULL-BACK

In construction of forest roads, excavated material is sometimes deposited (sidecast) on the original ground surface just below the final grade. As a result of this construction technique, the geometry of the slope is changed in such a way that the slope below the final grade is less stable than it was originally. This is referred to as "slope loading". Slope loading becomes critical during periods of high rainfall when the weight of this material increases and its effective strength decreases.

By moving along an existing road or landing with a hydraulic excavator, this sidecast material can be removed and hauled to a safe waste area. The effect is reduction of the side slope, and the reduction of the weight resting on the original ground surface.

To date, this technique has been used primarily on portions of road with sloughs, or tension cracks in the sidecast material, or on road systems where road related failures have already occurred. This technique has also been used to reduce the slope of excavated material adjacent to recent failures.

In one example, production for this technique was monitored using an FMC LINKBELT 5400 hydraulic excavator. On a road just constructed using a bulldozer the production rate was 74 yards per hour or $1.11 per yard. Additional dollars per yard must be figured in for hauling and waste area preparation. Typical production on existing roads with some brush disposal required might be in the range of 60 to 70 yards per hour.

REMOVAL OF BRUSH FROM ROAD PRISM

Brush and debris within the road prism is of concern where excavated material is sidecast and where fills are specified. If the sidecast or fill material rests on a lens of brush abd debris instead of bare mineral soil, this material creates a potential failure surface with a factor of safety less than that of soil against soil.

On gentle slopes, a bulldozer is able to scrape this material away from under the fill. If however, the brush and debris is to be removed from steeper slopes, it must be yarded out of the road prism. On one particular road, where brush and debris had to be yarded an average of 400 feet, the cost of brush disposal alone was $1300 per acre of road prism.

Several options for brush disposal exist when a hydraulic excavator is used. In another section of the road cited above, a hydraulic excavator was used to scatter the brush below the road prism at a cost of only $700 per acre of road prism. The hydraulic excavator is also capable of sorting the brush for end-hauling or using the brush to create erosion control windrows at the bottom of the road prism.

In another example, a hydraulic excavator worked along a pioneer road constructed with a bulldozer. The excavator sorted through the sidecast material just below the grade of the pioneer road and removed the brush and debris, scattering it below the road prism at a cost of $880 per acre of road prism. The bulldozer then excavated to final grade using sidecast construction.

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[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

[2]Research Assistant in the Forest Engineering Department, Oregon State University, Corvallis, OR.

Another technique used in the construction of forest roads is full bench construction with end-hauling. With this technique, the full width of the final subgrade lies within the original ground surface. In addition, excavated material is not sidecast, but hauled away (end-hauled) to an appropriate dump site. As a result, slope loading is eliminated. This technique is specified where the side slope is too steep to hold the sidecast material. Where side slopes allow, excavated material is often dumped below the grade of the pioneer road, but is recovered and end-hauled when the road is excavated to grade. As a result of this allowance, bulldozers can still be used to pioneer the road while hydraulic excavators are most often specified for excavation to grade.

Of all the changes involving hydraulic excavators, end-hauling has the highest associated cost relative to conventional construction methods. In one example, excavation involving sidecasting with a bulldozer resulted in a cost of 37¢ per cubic yard, while end-hauling with a hydraulic excavator and dump trucks resulted in a cost of more than $3.00 per cubic yard.

Compared with sidecasting, end-hauling is very expensive. Many factors are involved in this construction technique, but three have potential for significant cost reduction.

1. Optimizing the number of dump trucks.
2. Reducing the swing time between excavating a bucket of material and dumping it.
3. Decreasing the positioning time of the dump trucks.

1. Optimizing the number of dump trucks servicing a hydraulic excavator involves matching the number of trucks to the productivity of the excavator. If too few trucks are used, the excavator is idle part of the time while waiting for a truck to load. If too many trucks are used, the trucks are idle part of the time while waiting to load. Figure 1 shows the cost of excavation in dollars per bank cubic yard as a function of the number of trucks. The least cost of $2.69 per BYC is achieved using five trucks. Figure 2 indicates why. As the number of trucks increases from one to five, the productivity of the excavator increases, indicating that the system is limited by the productivity of the trucks. When more than five trucks are used, productivity of the excavator is the limiting factor. The optimum balance of the system is achieved using five trucks.

2. The second area of potential cost reduction is in reducing the swing time between excavating a buckfull of material and dumping it. Figure 3 shows an excavation method in common use with hydraulic excavators. Note that both the dump truck and the excavator are on the pioneer road. The excavator is excavating to grade on one side and swinging with each bucketfull, to the other side to load the dump truck. Considerable time could be saved if the excavator could excavate and load from the same side. Loading time could be cut in half if this were possible. Figure 4 illustrates such a method. The excavator is on the pioneer road and the truck is on the final grade. In the example cited earlier, changing the excavation method as indicated would increase the optimum number of trucks from five to seven and reduce excavation cost from $2.69 to $2.53 per BCY.

3. Decreasing the positioning time of the dump trucks is the third area of potential cost reduction. This reduces idle time for the excavator. The actual positioning time of a truck is dependent on the positioning configuration at a given point along the road being constructed. Opportunities do exist to shorten this time by creating more turnouts of sufficient width for two trucks to pass (figure 5). The turnouts do not need to be wide enough for the trucks to turn around. The trucks can turn around where convenient, back into the excavation area and wait in the turnout while the excavator is loading another truck. For conventional 10 to 17 yard dump trucks, the required width is about 22 feet. Where the trucks are running on the subgrade (as in the excavation method cited above), and where an 18 to 20 foot wide subgrade is specified, these turnouts involve very little additional excavation. In the example cited above, reducing the positioning time further reduced the cost of excavation from $2.53 to $2.31 per BCY.

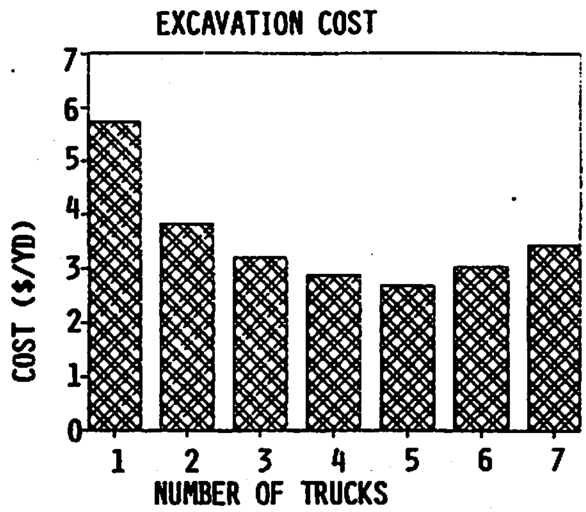

Figure 1--Excavation cost as a function of number of trucks.

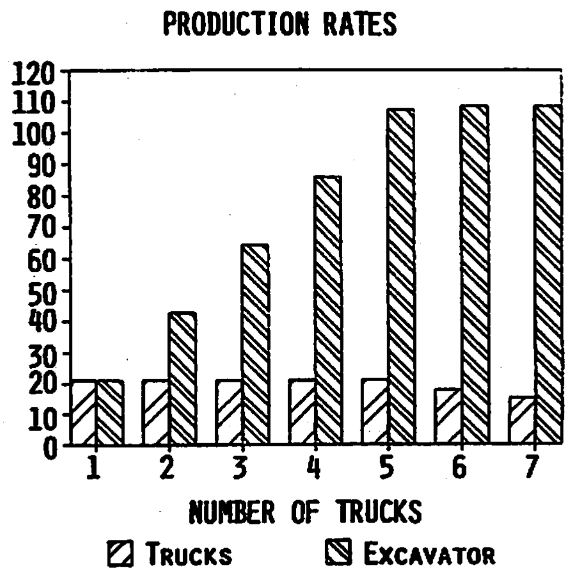

Figure 2--Productivity as a function of the number of trucks.

Figure 3--Excavator and truck on pioneer grade.

Figure 4--Excavator on pioneer road, truck on final grade.

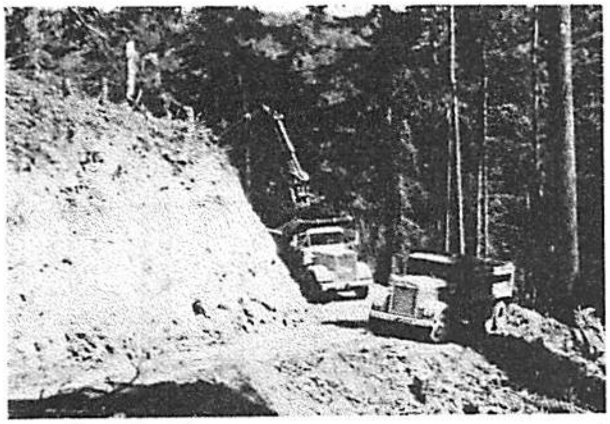

Figure 5--Turnouts decrease positioning time.

Table 1 gives a summary of the potential cost reductions listed above. Eight trucks may seem like too many to be used on one road system, but as many as seven trucks were actually used at one time with no apparent reduction in trafficability. Careful evaluation and control of these three factors on other projects has reduced excavation costs 20 to 40 percent.

Table 1--Summary of excavation cost reductions.

	TRUCKS	$PER BCY	TOTAL pct. REDUCTION
Original	3	3.20	
Opt. Trucks	5	2.69	16
Swing Time	7	2.53	21
Posit Time	8	2.31	28

TEMPORARY ROAD CONSTRUCTION WITH SIDECAST PULL-BACK

Situations arise in forest road construction where sections of road are needed for only one season, possible two, after which time they may not be used again for a number of years. These are often spur roads to landings or roads constructed through skidding units where the road is used as a continuous landing.

Under these conditions, it is desirable to build a low standard road as inexpensively as possible. This means sidecast construction. Once the use of the road is finished, a hydraulic excavator is used to pull back the sidecast material and place it on the road grade. On sections of the road which do not pose as great a threat of failure, sidecast material can be left in place and water bars placed in the grade.

A hydraulic excavator greatly facilitates the construction of such a road in three ways.

1. Brush and debris can be cleared from the areas where the sidecast material is to be left in place.
2. Brush and debris can be placed along the bottom of the road prism to catch the sidecast material. This extends the use of sidecasting to steeper slopes.
3. Logs can be placed below the road prism, reducing the risk of burying them during excavation of the road and eliminating the need to yard them away from the excavation site.

In one example, a hydraulic excavator performed 80 percent of the excavation. Brush and merchantable stems were placed off to the side and excavated material was sidecast to complete a balanced section. The remaining 20 percent of the excavation was completed with a bulldozer (figure 6), which drifted the material an average of 150 feet. Total cost for the construction was 39¢ per yard. In closing out the road (figure 7), about 50 percent of the sidecast material was recovered and placed back on the road. Assuming the same cost per yard as given in the discussion of sidecast pull-back, the total cost of the road in this example is 95¢ per yard.

In addition to the cost savings, this construction technique has two other advantages. First, those using the technique in Oregon have recieved approval from the state forestry agency for such roads to be classified as permanently closed. This relieves the owner of liability to the state for mass soil failures associated with that road. Second, if favorable, the owner has the option through negotiation with the IRS, to expense the cost of that road against that years income. This reduces taxable income for that year.

At present, this technique is fairly new and not widely used. However, safe waste areas are not always readily available, so the construction of temporary roads with sidecast pull-back is on the increase.

Figure 6--Sidecast construction of temporary road.

Figure 7--Section of road which has been pulled back.

CONCLUSIONS

All four of the construction techniques presented here, require precise, intensive handling of excavated material and brush. Hydraulic excavators are very well suited to such techniques and as a result, are being used extensively in forest road construction. In steep, sensitive areas, hydraulic excavators allow construction of cleaner more stable subgrades than could be built using conventional construction techniques.

Certainly, there are many other uses of hydraulic excavators in road construction, and the number of additional uses will almost certainly increase.

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Primary Transport of Wood on Sensitive Sites of the Southeast[1]

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Abstract: This paper reviews potential impacts that the primary transport phase of timber harvesting can have on sensitive sites in the Southeast. Most of the machines and methods that have been or are currently being used to reduce such impacts are discussed from the standpoint of the advantages and disadvantges they offer to reducing sensitive site damage.

Projections show a growing demand for timber products in the decades ahead (U.S. Forest Service 1982). Based on expected increases in the population and economy, demands for timber from domestic forests will increase by over 100 percent. An increased share of the softwood and hardwood markets is projected to come from the South. Timber removals without substained regeneration efforts could have significant effects on net annual growth and wood inventories in the South. To offset an increase in removals, there is a need for more intensive forest management, better utilization, and the conversion of marginal timber lands on steep sites and wetlands to more productive forest.

Within the past decade, more consideration has been given to environmental impacts during harvest. Impacts from logging damage that disturb the soil resource are soil compaction, displacement, and/or erosion. In intermediate silvicultural treatments, damage to the stand and residual trees can have permanent negative effects on the growth of the remaining trees. Damage to the site can result from all functions of the harvesting operation, but the chief concern is the damage caused by the primary transport of the wood from the stump to roadside. The transport function is the most detrimental to the harvesting site and is especially detrimental to sensitive sites, such as steep slopes and wet ground conditions.

SITE IMPACTS

A common soil disturbance associated with logging is soil compaction. Compaction has been described as increased soil density through decreased pore space. Increased soil density can: (1) impede root growth, (2) reduce aeration pore space, and (3) reduce rain infiltration capacity (Foil 1965).

Timberland growth losses resulting from compaction have been reported by Moehring and Rawls (1970) and Hatchell et al. (1970). The losses were attributed to either reduced soil aeration, reduced infiltration of water, reduced root growth, or combinations of these conditions. Lockaby and Vidrine (1984) reported a decrease in young pine survival as a result of soil compaction. Compaction related problems have increased in recent years, primarily due to the increased use of heavy logging equipment during the wet winter season.

Studies have shown that logging traffic can cause increased soil density (Hatchell et al. 1970, Adams and Froehlich 1981). Moehring and Rawls (1970) reported that more severe compaction may occur from traffic on saturated soils than on dry soils. In addition to compaction, logging traffic can also cause puddling. Puddling, a characteristic of wet weather and wetland logging, reduces soil permability to water and air and increases the potential of erosion on steep sites. Other soil disturbances are churning and rutting. Churning loosens the soil and mixes the surface and subsoil layers. Although some benefits of mixing soil layers exists, it is unlikely that they overcome the damages of churning and the associated problems caused by bringing the heavier textured soils to the surface (Shoulders and Terry 1978). Ruts, furrows, and depressions disrupt natural drainage and pond excess surface water on flatwood areas. On steep slopes, mechanical exposure of mineral soil and channelling can result in serious erosion and soil movement, which contributes to site degradation. Following ground skidding, soil losses on slopes were severe until the return of herbaceous cover two years after logging (Dickerson 1975). Sites where soil is exposed, rutted, or compacted are more susceptible to continuing erosion than those where only the litter is removed.

IMPACTS TO HARVESTING

Delays in logging operations are costly. Conditions causing delays may be wet weather or working in marginal areas, such as steep slopes, wetlands, and swamps. Such conditions have two negative effects on timber harvesting economics: (1) loss of production and (2) higher operating costs.

Bennett et al. (1965) and Wren (1966) found significant decreases in production on steep slopes. Koger (1976) used slope as a variable in predicting skidder productivity. The ability of a machine to traverse the ground and carry or skid a load is dependent on the amount of traction that can be developed. Tractive performance of rubber-tired skidders has been studied extensively (Hassan 1977, Phillips and Spray 1966, Richardson 1969, Perumpral et al. 1976, Wismer and Luth 1972, and Iff et al. 1982). Adverse soil conditions and changes in dynamic loads are known to cause losses in traction. The phenomena at the tire-soil interface for varying dynamic loads and travel reductions are not well understood. The reports referenced above document performance factors, but few attempted to predict tractive performance over the range of operating conditions for rubber-tired skidders. Development of prediction methods for improving the traction and trafficability of rubber-tired, ground based systems is currently being investigated.

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Another problem with harvesting marginal sites is an increased hazard to machines and operators. This is especially true for articulated vehicles working on side slopes. A skidder with the rear frame oriented 60 to 80 degrees to the groundslope is most unstable (Gibson et al. 1971). Skidder stability can also affect production (Radforth 1978).

Rubber-tired skidding has an economic advantage, especially for smaller tracts and low-volume trees. Track machines add the capability of working on moderate slopes and wet sites, but usually at lower production levels. The purchase and operation of track vehicles is usually more expensive than rubber-tired skidders.

An alternative to ground skidding and forwarding is cable yarding. Cable yarding has an advantage over ground systems on steep slopes. Small tract size is an added constraint and requires a highly mobile yarder. Low-volume timberlands require specially designed equipment and methods for harvesting. Iff (1979) concludes: for yarders to work in the South, a cable system must be highly productive with a well organized crew and good management to keep cost low.

ANIMAL LOGGING

In this age of high mechanization, animals are still being used in limited applications to move wood from the stump to the landing. Mules are most often used in the South, because of their high heat tolerance. However, both draft horses and oxen are used for skidding (Wackerman et al. 1966 and Anon. 1976). The advantages of using animals are low cost and low stand/site impacts. Very little damage is caused to the site or residual stand. Even after 60 passes, very little disturbance due to animal skidding was evident (Anon. 1976).

Some of the disadvantages with using animals are the shortage of teamsters for working with animals in the woods and the need for daily care. Production is low in comparison to mechanized operations; i.e., a six man crew can average only about 40 thousand board feet per week (Anon. 1976).

RUBBER-TIRED SKIDDERS

Soon after their introduction in the early 1960's, rubber-tired skidders had a significant impact on southern logging operations. The use of rubber-tired skidders brought about production improvements and more steady wood flows. Skidders have proven to be highly flexible machines capable of working on wetlands as well as steep slopes (up to about 30 percent). This flexibility is, in part, due to a large range of skidder sizes and the availability of many different accessory options including a wide range of tire sizes. Skidders range in size from around 70 to 200 horsepower. Depending on skidder size, tire size options range from 18.4-26 to 66/43.00-25. Larger tires sizes and dual tire configurations are available; however, these are not generally recommended by skidder manufacturers.

Skidder productivity is dependent on tree size and terrain conditions. Given good working conditions, rubber-tired skidders are capable of high production rates. However, they also have the capability for high site damage if misapplied. Some landowners have developed reservations about skidders after seeing areas where these machines have caused extensive damage.

Although highly versatible, skidders do have terrain and slope limitations. For example, Koger et al. (1984) reported that an unloaded skidder equipped with 28.1-26 tires became stuck after only two passes over a soft site with high organic soils. As slopes increase above 20 percent, there is a significant decrease in skidder production (Bennett et al. 1965, Wren 1966, and Koger 1976). Because of the limitations of conventional skidders with conventional tires working on sensitive sites, several innovative improvements have been made to rubber-tired skidders that increase their efficency, reduce site damage, and increase year around production capacity.

Wide Tires

Several studies have shown the advantage of using wide tires for better flotation and traction. Mellgren (1984) reported that wide tires were used successfully in field trials in Canada. Burt et al. (1982) found that wide tires on soft soil had better tractive capacity than narrow tires. Hassan (1977) demonstrated the superior tractive performance of a cable skidder with 24.5-32 tires over the same machine with 18.4-26 tires. Rummer and Sirois (1984) reported increased production with 34-inch-wide tires on steep slopes over the narrower 18.4-26 and 23.1-26 tires.

Porter (1984) also reported on the benefits of high-flotation tires. Advantages were: (1) access to more timber, (2) expanded harvesting seasons, (3) decreased soil disturbance, (4) reduced damage to the residual stand, and (5) increased stability and traction on slopes. However, some of the trade-offs of using wide tires included: (1) higher costs, (2) reduced reliability because wide tires were more susceptible to damage and loss of air, (3) greater axle stress, (4) some loss of maneuverability, and (5) dependence on a committed maintenance and support program.

The net traction for rubber-tired machines can be related to the travel reduction (slip) applied through the tire-soil system. Koger et al. (1982) reported that travel reduction was one of the most significant machine parameters affecting compaction. Radforth (1978) observed that the amount of travel reduction for a given tractive effort and tire size increases with increasing slope. Hatchell (1971) suggested that larger tires can reduce soil compaction and disturbance. Lowman et al. (1978) noted that wider tires at reduced inflation pressures will reduce the unit pressure of the tire on the soil for a given load. A second study by Koger et al. (1983) confirmed that reduced inflation pressures for a given tire resulted in less compaction for a given load. However, Rummer and Sirois (1984) found increased compaction with wider tires because operators could increase the log loads.

Dual Tires

Dual tires have recently been introduced for use in wetland logging, especially in the lower coastal plains of the Southeast. In swampy conditions, dual-tired skidders are more acceptable than wide-tired skidders to some loggers because the outer tires can be removed when the soil conditions permit single-tired machine operations. Using standard equipment, single tires improve maneuverability, increase production, and reduce costs over the use of dual tires when they are not needed for flotation on wetter sites.

According to Hassan and Sirois (1984), dual tires provide more stability and offer a smoother ride for the operator. Better traction has been documented for dual tires over standard narrow tires by Southwell (1964) and Koger et al. (1984). Southwell reported that dual tires increased the average pull at high travel reduction rates by more than 25 percent over that achieved by single tires under similar conditions. Koger et al. (1984) reported that skidders with dual tires in swamps were able to skid loads through areas that empty, single-tired skidders could not traverse. Also, the dual-tired skidders on such sites caused less rutting and had greater access to felled trees.

TRACKED SKIDDERS

Before wide tires and dual tires came into use on rubber-tired skidders, tracked skidders were used extensively on adverse terrain and sensitive sites. The main advantages of tracked skidders on highly sensitive sites are lower ground pressures and higher traction with little disturbance to the site. The low ground pressure characteristics have more application on sensitive wet sites than on slopes.

There is a broad range of machine and track configurations available to meet the loggers specific needs. Three main types of tracked machines available for log skidding are: (1) ridged steel tracks (2) flexible steel tracks with front-drive sprockets, and (3) flexible rubber belt tracks. Two general statements can be made about all tracked skidders: (1) compared to rubber tired skidders, they have higher initial cost and (2) maintenance of the track system is more expensive than for rubber-tired machines. Maintenance cost can vary depending on the track system and operating conditions. Some of the characteristics of the track system are presented in the following sections.

Ridged Steel Tracked Skidders

Standard crawler tractors with narrow tracks provide an average ground pressure between 6 and 10 psi. The use of optional LGP (low ground pressure) tracks reduces the average unloaded ground pressure to about 4.6 psi or an approximate 55 percent reduction in the average ground pressure on flat ground. Wimble (1983) points out that average ground pressure should not be the only criteria for selecting a tracked (or rubber-tired) machine for skidding. Ridged track systems can have highly localized ground pressures on uneven ground. In addition, a rear mounted arch or grapple attachment with suspended logs results in higher ground pressures on the rear track sections. Conventional tracked machines were developed for pushing heavy loads of dirt over short distances and at low speeds (less than 6 mph); therefore, the design limits productivity in logging applications.

Flexible Steel Tracked Skidders

Flexible steel tracked skidders reduce localized ground pressures under the tracks. These machines were developed using technology obtained from the United States military. During the early 1960's, there was a need for armored personnel carriers capable of high-speed travel over a wide range of terrain conditions. The resulting design concept utilized torsion-bar mounted roadwheels for supporting the machine on the tracks. These machines used front-drive sprockets as opposed to rear-drive sprockets on ridged tracked crawler. With this system, the top of the track is tensioned so that the track in contact with the ground can flex and conform to uneven terrain. The advantages are higher traction and lower effective ground pressure (Wimble 1983). The average reported ground pressure is 6.9 psi which is similar to a small crawler tractor with 16-inch-wide tracks (McMorland 1985).

Because of the improved track design, generally high horsepower, and good load distribution, flexible steel tracked skidders have the capability of moving large turns of logs over longer distances. The ability to skid for long distances is an advantage in swamp logging because of the problems of finding good landings close to roads (Griffin 1980).

Flexible steel tracked machines have higher initial costs and generally lower reliability. McMorland (1985) reported a 75 percent higher initial cost over a smaller, lower horsepower, crawler tractor. The crawler tractor had 49 percent of the delays charged to the undercarriage, whereas the flexible track machine had 78 percent. Overall down time of the flexible track machines was about 22 percent higher than the crawler tractors.

Flexible Rubber Belted Tracks

Skidders with rubber belted tracks have a high track area to machine weight ratio. This produces relatively low, unloaded average ground pressures of about 2 psi (Bryan 1976). As with the flexible steel tracked units, these machines also use front-drive sprockets. Flexible rubber tracked skidders can be of a two or four track design. Presently, the four track skidders are the higher horsepower units.

Generally, the higher horsepower machines also have a better weight distribution when loaded because the log load is supported well over the back set of tracks. On the smaller two track machines, the fairlead is normally mounted on the back of the machine. This produces an unbalanced load condition during skidding, creating higher ground pressures on the rear sections of the track. This characteristic reduces the benefits of the low, unloaded average ground pressures on the two tracked machines. Because of the light, more flexible belted tracks, both types of machines are capable of high ground speeds (Northcross 1980).

FORWARDERS

Except for some special cases, the use of forwarders in the South is limited to short logs and pulpwood length bolts. The advantages of these machines are: (1) good maneuverability in partial cuts and thinnings with little damage to the residual stand, (2) high payloads, (3) clean wood during wet, muddy conditions, and (4) a self-loading/unloading system. Presently, there are about four manufacturers of forwarders in the United States. These companies produce only two-axle machines. Several European machines that have been tested in the United States are equipped with three or four axles.

As with rubber-tired skidders, the two-axle machines have been equipped with both wide tires and dual tires. Research studies have not been completed on forwarder systems using wide or dual tires, but applications by some contractors indicate the wide tires provide better floatation and traction. Chains can also be used to improve traction but may cause more damage to the site.

CABLE YARDING

Although cable systems were used for swamp logging in the Southeast, there is little use at this time because of improvements to the lower cost, high flotation, ground equipment. However, there should still be a place for specialized, hybrid cable yarding systems to oversome operational problems on particularly sensitive sites (Anon. 1985).

The main use of cable yarding systems in the South is for steep ground along major rivers in the upper coastal plains and in the Appalachian mountain region. In these areas, the major use is for harvesting public timberlands where there is increased concern for environmental impacts (Patric 1984). The greatest advantage for cable yarding in the Southeast is the reduced site disturbance and erosion compared to ground skidding on steep terrain (Carvell 1984, Sherar and Koger 1984, and McMinn 1984). In addition to reduced site impacts and the ability to yard wood on steep slopes, cable yarding systems are less sensitive to wet weather logging conditions.

The disadvantages of cable systems are the higher costs per unit of production and the greater need for preplanning to match the yarding capabilities with the stand/site conditions. A good job of preplanning requires the skills of a trained specialist with a knowledge of cable mechanics. Small southern timber (averaging 10 to 15 inches dbh) can be harvested from steep sites using smaller yarders in the 100 to 125 horsepower range.

BALLOON LOGGING

Even though the terrain in the South is not like that of the mountainous Northwest where ballon logging is typically used, there are some large areas of inaccessible timber in the southern swamps. A solution for harvesting swampy lands could be the use of load carrying balloons to lift logs over obstacles. When ground transport is impossible, the balloon can be used without regard to soil conditions. Balloon harvesting showed a slight economic advantage over conventional systems in a mixed hardwood pulpwood stand (Trewolla and McDermid 1969). In a more detailed review, Trewolla (1969) suggested the use of hot-air balloons. To further improve productivity and reduce costs, he recommended studies for better felling methods, determining optimal yarding distances, and efficient operating techniques.

Ballon logging minimizes soil disturbance because the logs are lifted clear of the ground during yarding. Dyrness (1972) reported a comparison of soil surface disturbance following tractor, high-lead, skyline, and balloon logging. He reported that the proportion of area deeply disturbed and compacted was much lower for the balloon logging method. Yarding with the balloon virtually eliminated gouging, dragging, and other types of site damage.

HELICOPTER LOGGING

Though not extensively used, helicopter logging has been tried in the South for special applications. In cases where high quality timber is isolated, aerial removal may be justified. Anon. (1979) reported on an operation in the swamps of South Carolina. Good production was reported with short haul distances. In another report by Bryan (1979), the operation proved necessary because the boggy terrain and deep mud made it impossible to log with conventional equipment.

SUMMARY

In summary, there are several methods for in-woods transport on sensitive sites in the South. These range from the use of animals to high technology aerial systems. The need is for further development of systems with capabilities matched to the wood needs of industry. Such systems will have to perform at a reasonable costs while doing as little damage to the forest sites as possible.

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PRODUCTIVITY AND SOIL COMPACTION EFFECTS OF PRIMARY TRANSPORT SYSTEMS IN THINNING LOBLOLLY PINE PLANTATIONS[1]

David W. Sanders, R. K. Matthes and W. F. Watson[2]

Abstract: Rubber tired skidders often cause excessive damage to the residual stems in thinnings and to fragile soils. The Nordfor tilt winch and Farmi winch mounted on a farm tractor seemed to be alternative machines for primary transport which could overcome these problems. Production studies were conducted on these two machines at two locations and residual soil damage was assessed after each operation. Both machines were found to be very costly to operate. The Farmi winch caused significantly greater soil compaction while the tilt winch actually tilled the soil as the logs were hauled in and thus reduced soil bulk density. The ruts caused by both machines would be unacceptable on the fragile soils. The Farmi winch might be suitable for small landowners to use in thinning their own stands.

INTRODUCTION

Thinning has become an important aspect of maximizing monetary returns from pine plantations. Thinning has increased in importance for preventing growth stagnation in overstocked pine plantations that are being carried to a sawlog rotation. The increased demand for wood as an energy source and the current strength of the paper market has given rise to thinnings on more and more acres.

The typical mechanized thinning operation usually consists of chainsaws or fellerbunchers, cable or grapple skidders for primary transport, and a loader or chipper. The primary transport function is the most expensive of these operations and is the most damaging to the soil and the residual stand. Smaller machines have been suggested as a way to decrease soil and stem damage during primary transport. This paper presents the results of a study of two alternative machines, the Nordfor tilt and Farmi winches, which should cause less damage than a skidder in a thinning operation.

The Nordfor tilt winch, from Sweden, is a high lead yarder mounted on a skidder or forwarder. It utilizes the carrier's engine to operate a hydraulic pump and two hydraulic motors which power the mainline and the haulback winch. The carrier and tilt winch are positioned perpendicular to a yarding corridor in a plantation. The machine yards all of the stems that it can reach in that corridor and then is moved on to the next corridor. Two operators are required when the tilt winch is being utilized for primary transport.

The Farmi winch, from Finland, is a one man operation. It is designed for small landowners and farmers who own small tracts of timber. The Farmi winch uses a farm tractor as its carrier and thus, provides for the landowner a low investment machine as a means of primary transport when thinning. The Farmi winch is available in many different models for various sized tractors and job applications.

The Farmi components (winch, vertical column and pulley, notched hauling beam and stabilizer legs) are attached to the three-point hitch. The power take off (PTO) of the tractor provides power to the winch. The logs are winched into place behind the tractor and then transported by the tractor to the deck. The winch enables the operator to use the farm tractor as if it were a cable skidder. The JL 306 model Farmi winch was used for this study. This model requires a 25 hp or larger farm tractor as its carrier. A 45 hp and a 62 hp tractor were used in the study.

Soil compaction is of particular interest in the Yazoo Little Tallahatchie drainage system of Mississipppi. Severe soil loss occurred in the YLT area during the early 1900's because of the fragile soil, land clearing, and poor management practices. In 1944 Congress passed an Act requiring the United States Department of Agriculture to install upstream flood prevention measures in the Yazoo and Little Tallahatchie Rivers. Since, the Yazoo-Little Tallahatchie Flood Control Project (YLT) was initiated, over 500,000 acres of loblolly pine seedlings have been planted on severely eroded privately owned lands within the YLT. The litter cast from pines almost totally eliminates soil movement, surface runoff, and helps the soil to start reconstruction (USFS, 1977).

Harvesting operations could cause severe disturbance to the soils in these stands. Because YLT soils are so fragile, these possible damages increase the importance of soil studies on machinery involved with harvesting operations. Some research has been completed on the YLT area concerning soil erosion associated with timber harvesting. Sawtimber and pulpwood operations have been shown to cause significant disturbance during harvesting (Dickerson, 1968). Thinning and clearcutting operations were studied for their effects on the forest floor of loblolly plantations (Dickerson, 1972). Runge (1973) studied sheet erosion in these pine plantations.

The tilt and Farmi winch systems seem to offer the greatest potential for improving the thinning operations in the heavy loess soils, which occur in the YLT. The loess soils which extend along the Mississippi River are particularly fragile. Time studies were made to determine the productivity of the machines. Predictor equations were developed for the machine cycle times which were then used to project cost per unit of production. Soil bulk density and moisture content measurements were taken for each site before and after harvest.

METHODS AND PROCEDURES

The two sites chosen for testing the primary transport machinery were in the northern and east central regions of Mississippi. The first site was in the central region in northern Winston County on the Mississippi State University, John Starr Memorial Forest. This site was less than two miles from the Oktibbeha County line which is the border between the northern and central regions. The second site chosen was in the

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northern region in eastern Carroll county within the Yazoo and Little Tallahatchie drainage system.

The MSU site consisted of a loblolly pine plantantion about twenty-two years old. Pre-harvest data included soil bulk density and soil moisture measurements. The slope of the ground surface on this site was 0-0.5%. The YLT site was a loblolly pine plantation about eighteen years old. This site, due to past erosion, had large gullies and the slope of the ground surface was 2-10%. The gullies were formed before and during the earlier years of tree growth. In certain areas on the site the gullies formed were anywhere from two feet to fifteen feet deep.

At each site one acre plots were established for each machine. The plots were adjacently positioned to keep the thinning operation in one location on the site. At each plot, DBH and merchantible height were recorded for each tree. At the YLT site, a prethinning cruise had already been conducted by the county forester. Thus, trees at the site were marked for commercial thinning. The production crew decided which trees to remove in the thinning at the MSU site.

The trees were felled, delimbed and topped by the production crew using chainsaws. Once a tree, was felled, delimbed, and topped, the DBH (diameter breast height) and the merchantible height were measured and recorded. The merchantible volume was estimated using an equation from Killcreas (1976). Tables 1 and 2 give the characteristics of the harvested trees and the stand summaries for each machine.

At each plot, decks were established as needed for the Farmi winch. From each deck the skid distance was recorded for each load. The tilt winch decks were established as it moved from one corridor to the next. Once again, the yarding distance for each load was recorded in reference to its particular deck.

The two machines observed in operation were time-studied only during primary transport. The time-study crew began observation when the machine left the deck for a load. When the machine returned to the deck with a load, unloaded, and prepared to make the next load, a cycle was completed. The primary transport function was time-studied continuously, observing the total time per cycle. Delay times observed included general maintenance, breakdowns, operator breaks, and operational caused delays. Delay times were subtracted from the productive time for a cycle. All time records were to the nearest one-hundredth of a minute.

There were 251 total observed cycles for both machines at both sites. There were 173 complete cycle observations of the Farmi winch and 78 of the tilt winch.

After thinning was completed on each plot, post-harvest data collection for each plot included:

1. soil bulk density and soil moisture measurements
2. residual stand characteristics (DBH, total height, and total number of trees remaining after thinning)

RESULTS

The independent variables considered for evaluation in all the models were the location indicator variable, (MSU or YLT) skid or yarding distance, volume per load, and number of trees per load. The dependent variable in the following models was time per cycle.

Farmi Winch Time Model

The following equation was found to be the best in predicting total time per cycle for the primary transport function using the Farmi winch:

Time/cycle = 0.735 + 0.00778 * skid distance + 0.0752 * volume/load + 1.76 * trees/load (1)

where: Time/cycle = total productive time in a cycle (min.)

skid distance = one-way skid distance between deck and where load was gathered (ft.)

volume/load = volume of wood in that load (cubic ft.)

trees/load = number of trees skidded in the load

The variables were significant at the 0.05 level with 46.6 percent of the variation being accounted for in the cycle time. The mean, standard deviation, and range of all variables are listed in table 3.

Farmi Winch Cost Analysis

An equipment cost analysis using the standard method of computing straight line depreciation and average annual investment was calculated for the Farmi winch (Sanders, 1985). There were several assumptions made when assigning a cost to the Farmi winch and its carrier. These were:

1. Farm tractor would be used only for primary transport during its lifetime.
2. Life = 3 years
3. Salvage value =10%
4. Labor hours per year =2000
5. Utilization = 60%

The cost per productive hour was estimated to be $29.56 which includes fixed, operating, and labor cost.

Tilt Winch Time Model

The following equation was the best equation developed to predict total time per cycle using the tilt winch:

Time/cycle = 0.315 + 0.0161 * yard distance + 0.0788 * volume/load + 0.517 * trees/load (2)

Where: Time/cycle = total productive time in a cycle (min.)

yard distance = one-way yarding distance between deck and where load was gathered (ft.)

volume/load = volume of wood in that load (cubic ft.)

trees/load = number of trees yarded in the load

The variables were significant at the .05 level with 39.5 percent of the variation being accounted for in the cycle time. The mean, standard deviation, and range of all variables are listed in table 4.

Tilt Winch Cost Analysis

An equipment cost analysis using the standard method of computing straight line depreciation and average annual investment was calculated for the tilt winch (Sanders, 1985). The assumptions associated with assigning a cost to the tilt winch and its carrier are as follows:

1. A used six year old skidder with a good engine and transmission was selected as the carrier.
2. Life = 6 years
3. Salvage value = 10%
4. Labor hours per year = 2000
5. Utilization = 50%

The cost per productive hour is estimated to be $62.09 which includes fixed, operating, and labor cost.

Production and Cost Tables

Equations 1 and 2 give estimates for the primary transport function in minutes per cycle. Using these equations and making certain unit transformations (1 cord = 85 cubic ft^3) production in cords per day can be obtained for the machine. Also, from the cost analysis for each machine, dollars per cord of production can be calculated. These production estimates were made for each machine using the variables proven to be significant. The estimates are shown in tables 5 and 6 for the Farmi and tilt winch respectively.

Soil compaction results

Soil bulk density and soil moisture measurements were taken on each plot before and after harvest. Bulk density measurements were taken at the 2 inch and 4 inch depths before and after harvest. The before harvest soil bulk density samples were taken at random throughout the one acre plots. However, after harvest measurements were taken in the log trail, in the tire tracks, and at random for the Farmi winch plots. After harvest measurements for the tilt winch plots were taken in the log trail and at random throughout the rest of the plot.

The average soil bulk densities for the various plots are shown in table 7 for both the before and after harvest samples at each site. One way analysis of variance tests were conducted on the bulk density measurements before and after harvest for each plot and each sampling depth separatively. Also, one way analysis of variance tests were conducted on the soil bulk density measurements with respect to where the sample was taken on the plot, i.e. in the skid trail or not.

The Farmi winch and its carrier (farm tractor) caused significant increase in bulk density before and after harvest at the 4 inch depth at the MSU site and at the 2 inch depth at the YLT site. These changes were significant regardless of where the samples were taken.

The tilt winch caused significant changes in bulk density before and after harvest at the 2 inch and 4 inch depths at the YLT site. However, this showed a significant reduction in bulk density after harvest than before harvest. Most samples taken after harvest for the tilt winch were in the log path itself. The log was observed to till the soil which might cause reduction in bulk density. There were no significant changes in bulk density in reference to where the measurements were taken.

CONCLUSIONS

In this study, the Farmi winch and Nordfor tilt winch have been observed performing the primary transport function involved with thinning of pine plantations. Of great importance to this study was the production of each machine and the examination of possible soil compaction caused by each machine. Each machine has been studied as an alternative means of primary transport on fragile soils like those encountered at the YLT site.

The Farmi winch and its carrier worked well on both sites. Although the Farmi winch takes only one operator, in general, it is a slow method of primary transport. Because of limitations on the load, which the Farmi can carry, acceptable levels of production become almost impossible. The Farmi winch, however, should be suitable to small landowners with pine plantations who wish to keep their stand at its most productive condition. This would enable the individual to perform the thinning at his own rate while picking up additional income for his efforts. The Farmi winch shows little promise in a commercial thinning operation. The Farmi and its carrier did indicate significant soil compaction.

The tilt winch and its carrier were originally thought to be better suited for commercial thinning. Evidence from this study indicates that the tilt winch did not cause any soil compaction on either site. However, the production of this machine and its high cost make it less appealing as an alternative machine for primary transport. The machine is very labor intensive and frequent repairs of the hydraulic and winch systems are required, thus a 50 percent utilization factor was used for the cost analysis of the tilt winch. There were times when the machine worked well and production was fairly consistent, but not high. However, when a break down occurred, much time was lost to lengthy repairs. The tilt winch could have applications on a fragile soil, however, in a commercial thinning operation it would have inconsistent production and would be very costly.

The gullies encountered on the YLT site caused many problems for both of these machines. The farm tractor could not move into these gullies to remove the trees and the tilt winch would have logs hang up at the lips of the gullies. Other small rubber-tired machines and high lead yarders would have similar problems in this situation. Self propelled machines which do not cause the compaction problems or possibly skyline yarders will be required to thin those sensitive stands.

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Table 1. Harvested tree characteristics and stand summary for the tilt winch at the MSU and YLT sites.

Harvested tree characteristics

Variable	Mean	Standard deviation	Range
DBH (in.)	6.96	1.91	4 - 14
Merchantible Height (ft.)	35.9	16.04	10 - 66
Volume per tree (cubic ft.)	6.74	5.257	.87 - 31.41

Stand Summary (trees/acre)

Species	Initial	Removed	Residual
		MSU Site	
loblolly pine	441	102	339
		YLT Site	
loblolly pine	217	71	146

Table 2. Harvested tree characteristics and stand summary for the Farmi winch at the MSU and YLT sites.

Harvested tree characteristics

Variable	Mean	Standard deviation	Range
DBH (in)	7.82	1.89	4 -14.7
Merchantible Height (ft)	47.79	12.87	15.5-72
Volume per feet (cubic ft)	10.25	6.04	1.42 - 38.2

Stand Summary (trees/acre)

Species	Initial	Removed	Residual
		MSU Site	
loblolly pine	280	120	160
		YLT Site	
loblolly pine	301	111	190

Table 3. Observed primary transport time summary for the Farmi winch.

Element Description	Mean	Standard deviation	Range
Skid distance (ft.)	196.73	69.23	66 - 429
Volume/load (cubic ft)	13.31	7.07	4.94 - 42.68
Trees/load	1.32	0.65	1 - 4
Travel time empty (min)	1.56	0.72	0.5 - 6.0
Time making load (min)	1.01	0.63	0.25 - 3.28
Travel time loaded (min)	1.85	1.07	0.41 - 7.85
Deck time (min)	1.18	1.09	0.25 - 6.83
Time/cycle (min)	5.60	2.42	2.21 - 18.10
Delay time (min)	1.03		

Table 4. Observed primary transport time summary for the tilt winch.

Element Description	Mean	Standard Deviation	Range
Skid distance (ft.)	142.02	60.22	49.5 - 346.5
Volume/load (cubic ft.)	9.07	5.35	2.18 - 31.41
Trees/load	1.35	0.62	1 - 3
Travel time empty (min.)	0.30	0.30	0.05 - 1.67
Time making load (min.)	1.13	0.66	0.19 - 3.16
Travel time loaded (min.)	1.32	1.08	0.22 - 5.53
Deck time (min.)	1.26	1.05	0.20 - 5.45
Time/cycle (min.)	4.01	1.69	1.55 - 8.89
Delay time (min.)	6.69		

Table 5. Estimated production and cost rates for primary transport function (Farmi winch).

Skidding distance	Trees per load	Volume per load	Time per cycle	Cords per day	Dollars per cord
Feet	No.	Cubic Feet	Min.	Cords	$
100	1	10	4.03	8.41	16.86
100	1	20	4.78	14.18	10.00
100	1	30	5.53	18.38	7.72
100	2	10	5.79	5.85	24.23
100	2	20	6.54	10.36	13.69
100	2	30	7.29	13.94	10.18
100	3	10	7.55	4.94	31.60
100	3	20	8.30	8.17	17.38
100	3	30	9.05	11.23	12.63
200	1	10	4.81	7.05	20.13
200	1	20	5.56	12.19	11.64
200	1	30	6.31	16.11	8.81
200	2	10	6.57	5.16	27.50
200	2	20	7.32	9.26	15.32
200	2	30	8.07	12.59	11.27
200	3	10	8.33	4.07	34.87
200	3	20	9.08	7.46	19.00
200	3	30	9.83	10.34	13.72
300	1	10	5.59	6.06	23.40
300	1	20	6.34	10.69	13.27
300	1	30	7.09	14.33	9.90
300	2	10	7.35	4.61	30.77
300	2	20	8.10	8.30	16.96
300	2	30	8.85	11.38	12.36
300	3	10	9.11	3.72	38.14
300	3	20	9.86	6.87	20.64
300	3	30	10.61	9.58	14.81
400	1	10	6.37	5.32	26.66
400	1	20	7.12	9.52	14.91
400	1	30	7.87	12.91	10.99
400	2	10	8.13	4.17	34.03
400	2	20	8.88	7.63	18.59
400	2	30	9.63	10.55	13.44
400	3	10	9.89	3.43	41.40
400	3	20	10.64	6.37	22.28
400	3	30	11.39	8.92	15.90

Table 6. Estimated production and cost rates for primary transport function (tilt winch).

Skidding distance	Trees per load	Volume per load	Time per load	Cords per day	Dollars per cord
Feet	No.	Cubic Feet	Min.	Cords	$
100	1	10	3.23	10.49	28.41
100	1	20	4.09	16.86	17.67
100	1	30	4.81	21.15	14.09
100	2	10	3.75	9.04	32.96
100	2	20	4.54	14.94	19.94
100	2	30	5.32	19.09	15.61
100	3	10	4.26	7.95	37.51
100	3	20	5.05	13.41	22.22
100	3	30	5.84	17.40	17.12
200	1	10	4.84	7.00	42.57
200	1	20	5.63	12.04	24.75
200	1	30	6.42	15.84	18.81
200	2	10	5.36	6.32	47.12
200	2	20	6.15	11.03	27.03
200	2	30	6.93	14.66	20.33
200	3	10	5.87	5.77	51.67
200	3	20	6.66	10.17	29.30
200	3	30	7.45	13.64	21.84
300	1	10	6.45	5.25	56.73
300	1	20	7.24	9.36	31.83
300	1	30	8.03	12.66	23.53
300	2	10	6.97	4.86	61.28
300	2	20	7.76	8.74	34.11
300	2	30	8.54	11.89	25.05
300	3	10	7.48	4.52	65.94
300	3	20	8.27	8.19	36.39
300	3	30	9.06	11.22	26.56

Table 7. Average values of soil bulk density before and after harvest.

	Tilt winch		Farmi winch	
2"	MSU	YLT	MSU	YLT
Before	1.14	1.31	1.00	1.21
After	1.11	1.21	1.06	1.31
4"				
Before	1.19	1.28	0.90	1.11
After	1.13	1.09	1.06	1.15

DIRECTIONAL FALLING BY TREE LINING IN OLD GROWTH DOUGLAS FIR[1]

Jack Gerstkemper[2]

Abstract: Falling large, old growth timber on steep, fragile soils in an area of high fisheries values presents several resource management problems. There is a high potential for soil erosion, stream degradation and excessive timber breakage. These unacceptable resource impacts have been avoided by utilizing a method of timber falling known as tree lining or tree pulling. This paper describes the successful implementation of tree lining on the Siskiyou National Forest in Southwest Oregon.

INTRODUCTION

The Siskiyou National Forest, located on the Southwest Oregon coast, has been a pioneer in the implementation of tree lining techniques in the Pacific Northwest Region of the Forest Service. Although the initial work in this area had been done in the 1950's and 1960's by private timber companies, it was not until 1974 that the Siskiyou National Forest sold its first timber sale requiring directional falling by tree lining. In the 11 years following that initial sale, tree lining has become a common and accepted technique in falling old growth timber on the steep and fragile soils of the Siskiyou National Forest. This paper is a discussion of the technique of tree lining, the areas of its applicability and the problems and successes that have been encountered in implementing the technique on National Forest land. For broad based research in directional falling by jacking or tree lining the reader should refer to a study conducted by Hunt and Henley, 1981.

SITE DESCRIPTION

The Siskiyou National Forest is characterized by steeply dissected terrain with shallow, skeletal soils (Amaranthus and McNabb, 1984). 80 to 90 percent of the annual timber harvest is logged with skyline systems requiring either one end suspension or full suspension. Timber is commonly harvested on slopes of 50 to 100 percent. The principal commercial species, Douglas Fir (Pseudatsuga menziesii), frequently reaches diameters of 150-200 cm (60-80 inches). Average stand diameters are typically 75 - 90 cm. Port Orford Cedar (Chamaecyparis lawsoniana), a species found only in the riparian areas of Southwest Oregon and Northwest California, is a rare and extremely valuable tree found in the riparian areas. It can attain diameters equal to those of the Douglas Fir. Falling these valuable old growth trees while minimizing breakage in the rough terrain is a challenge that frequently requires falling the trees uphill. In some cases this uphill directional falling can be accomplished by wedges or hydraulic jacks, but on very steep ground (65%+) or when falling trees with heavy lean, tree lining is often the only practical means of minimizing breakage.

The Siskiyou National Forest also has extremely high value anadromous fisheries. Streams on the Forest support large runs of steelhead (salmo, gairdweri), Coho (Oncorhynchus, kisutch) and Chinook (Oncorhynchus, tshawypscha). Maintaining or enhancing the spawning and rearing habitat of these streams is a primary reasource objective of all timber sales on the Siskiyou National Forest. Coniferous or hardwood buffer strips are maintained along all streams including streams with only intermittent flows. A basic logging systems requirement on all sales is that timber be felled away from all streamside management units (SMU's). Precipitation, mainly in the form of rainfall, is very high. Precipitation ranges from 115 cm (45 inches) on the dryer eastside of the forest to over 305 cm (120 inches) on the high elevation coastal areas. The numerous streams resulting from the heavy rainfall means that most of the harvest units have SMU's that need to be felled away from. In addition, the timber must be prevented from sliding or rolling back into the streams damaging both the soil and the protective vegetation in the streamside buffer zone. Tree lining provides a method whereby even the heavy leaning trees can be felled directly uphill away from the stream. There are numerous advantages to tree lining around steep SMU's.

1. The tree has a high possibility of catching on the stump rather than sliding back down the slope into the stream (see figure 1).

2. In cases where the tree does not catch on the stump the tree can often be restrained by the tree pulling line.

3. If the tree does not catch on the stump and cannot be restrained by the tree pulling line, it will slide into the stream butt end first, doing minimal damage to the stream.

4. The individual bucked logs will not roll into the stream but will "bind in the buck". That is, each bucked log will be held in place by the log below it.

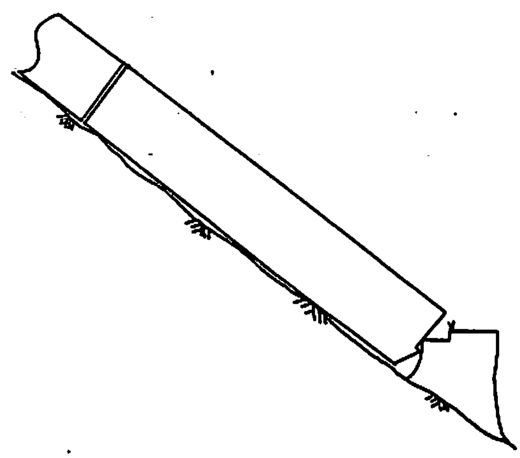

Figure 1 -- Tree fallen uphill caught on stump.

[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

[2]Forest Logging Engineer, Siskiyou National Forest, Forest Service, U.S. Department of Agriculture, Gold Beach, Oregon.

TECHNIQUE OF TREE LINING

Tree lining requires a 4 or 5 man falling crew including an operator for the mobile tree pulling machine, a high climber, a faller, and one or two buckers. The tree pulling machine usually consists of a single drum or double drum winch, mounted on either a flat bed truck or a sled. The pulling machine should be equipped with 615 m (2000 ft) of 14 mm (9/16 inch) diameter pulling line, compatible brakes, clutches and a torque converter or automatic transmission to allow variable inhaul speeds sufficient to keep up with the falling tree and to assure a steady, even pull (Oregon Occupational Safety and Health Code, 1982). A choker one size smaller than the pulling line is attached to the tree at approximately 18 meters (60 feet) above ground level. The exact height will vary with the size of tree and the amount of lean. The pulling line with the attached choker is then tensioned slightly while the under cut and back cut are made. The fallers move to a safe place away from the tree and signal the lining machine operator to pull the tree over.

Direct, verbal radio communication between the fallers and the lining machine operator is strongly recommended. Tensions on the pulling line may be varied throughout the operation on any one tree and the lining machine operator usually cannot see the falling crew or the tree being felled. The operator often has no way of knowing how much restraining force may be needed on the felled tree. Whistle signals cannot convey this information very well.

The tree pulling machine is usually placed at the top of the unit so that the pulling line can be pulled directly off the drum by the fallers (figure 2). If a road is located at the top of the unit, a truck mounted machine is used. If there is no road, a sled mounted machine is either flown in with a helicopter, flown in on a skyline, or winched into position under its own power. Reverse tree lining, that is, pulling trees uphill away from the machine rather than towards the machine requires a haulback line to pull the main pulling line off the drum (see figure 3). Although this practice has been used successfully in other locations[3], it has not been used on the Siskiyou N.F. because of the anticipated problems with the haulback and/or mainline getting trapped under the fallen tree.

As with all safe timber falling operations on sideslopes, the cutting starts at the bottom of the slope and progresses up the slope. This necessitates falling the trees uphill through standing timber which creates additional difficulties and danger.

Figure 2 -- Conventional Tree Lining

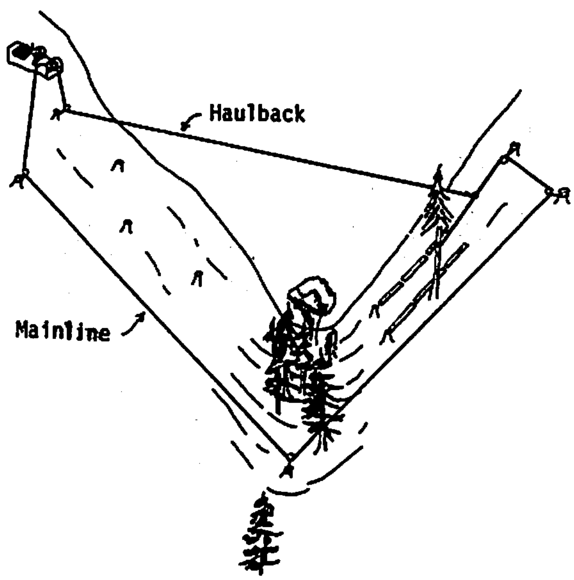

Figure 3 -- Reverse Tree Lining

AREA OF APPLICABILITY

The Siskiyou National Forest has been requiring tree lining in areas where uphill falling is required to protect resources or minimize breakage and where such uphill falling cannot be accomplished with wedges or jacks. The following general guidelines have been established for determining which areas or individual trees should be lined.

1. Use on sideslopes in excess of 65 percent. Trees judged likely to run downhill will have restraining action applied.

2. Use on poor falling ground on sideslopes less than 65 percent if jacking appears unable to direct trees to the best "lay".

[3]Gene Muir, Western Timber Cutting Inc., Springfield, Oregon, reports having successfully reverse lined old growth timber around the Eugene, Oregon area.

3. Use on areas where stand defect predicts trees cannot be safely jacked.

4. Use in areas of blowdown where safe bucking is essential, and logs must be turned to prevent excessive falling and yarding breakage.

5. Use on old growth cedar with more than 15 feet of back lean or equivalent side and back lean; and trees not readily jackable because of obvious defect in the butt.

6. Use on trees other than cedar with more than 20 feet of back lean or equivalent side and back lean.

The guidelines are not indisputable limits but they are used as an indication of when tree lining will probably be necessary. Exact requirements vary between different trees and between different stands of timber.

PROBLEMS ENCOUNTERED

The primary problem encountered in promoting and implementing tree lining has been resistance by the timber sale purchasers and the fallers. Although this resistance has decreased or disappeared as the advantages of tree lining have become more apparent, the initial objections centered around faller safety and the high cost of tree lining.

Experience has shown that properly executed tree lining is actually safer than conventional falling or falling with hydraulic jacks. Because the fallers can move far away from the tree before the tree is pulled over, they are in a safer position than with any other method of falling. Moving far away from the tree before the pulling operation begins is necessary because of the likelihood of the tree "jumping the stump" and running downhill after the tree is felled. Also, the necessity of falling the trees through standing timber means that there is a greater likelihood of tops and branches coming back towards the faller. Standing away from the stump offers greater safety from this flying or rolling material. A safety problem can also occur if too much tension is applied to the pulling line while making the backcut. This can cause the tree to "barber chair" with disasterous results. Since tree lining is typically used on slopes over 65 percent, it is reasonable to assume that the steep ground will be a hazard both for manuverability and the potential of rolling rocks and logs. Standing clear of the danger is the only means of avoiding accidents. Finally, a tree with a rotten butt usually cannot be jacked or wedged away from its natural lean, but if it can be climbed, it can often be safely lined uphill.

The high cost of tree lining represents a very real problem to the purchaser because the benefits do not occur until the yarding or milling stage of the log processing operation. The benefits are not easily quantified while the high cost of tree lining must be paid "up front". The cost of a four or five man crew plus a lining machine will greatly exceed the cost of a two man crew for conventional falling. In addition, production rates are lower than conventional falling. Falling costs vary with timber size and type of terrain but appraised costs for a timber sale sold in June of 1985 included the following cost allowances:

Conventionally felled timber including some jacking = $ 11.02/mbf
Tree lining = $ 28.26/mbf
Cost difference = $ 17.24/mbf

Costs for tree lining are typically 2-3 times the cost of conventional falling. This increased cost must be off-set by the following factors:

1. Reduced breakage. A 5 to 15 percent increase in the amount of timber going to the mill with a virtual elimination of breakage in the high value butt log.

2. Purchaser gets preferred log lengths.

3. Average yarding distance reduced by tree length.

4. Yarding cost reduction due to elimination of the need to yard small, broken pieces.

5. Stream clean-out costs reduced.

6. Slash burning costs in clearcut units may be reduced or eliminated.

Savings in stream cleanout costs and slash burning costs are difficult to quantify, however, savings in overall yarding costs due to uphill yarding were determined to be 11.1 percent. (Hunt and Henley, 1981.) The dollar value of preferred log lengths due to reduced breakage is also difficult to quantify, however, estimates in Forest Products Utilization by the U.S. Forest Service indicate that a 3 percent increase in value is a reasonable estimate.[4] Volume savings in reduced breakage due to directional falling has been conservatively estimated at 4 percent. (Hunt and Henley, 1981.)

Using June, 1983 costs for a Skagit 739 yarder with a 100' tower and 1-3/8 skyline with an estimated stumpage value of $150/mbf for old growth Douglas Fir the following savings can be estimated:

Yarding:		
$83/mbf x 11 percent	=	$ 9.13/mbf
Preferred log lengths:		
$150/mbf x 3 percent	=	$ 4.50/mbf
Breakage:		
$150/mbf x 4 percent	=	$ 6.00/mbf
Total Savings	=	$19.63/mbf

Figure 4

Figure 4 shows that the savings from yarding, preferred log lengths, and breakage ($19.63/mbf) is greater than the additional cost of lining ($17.24/mbf). If the less easily defined savings in slash burning, stream clean-out, and damage to fisheries were included, the economics would be even more strongly in favor of tree lining.

[4]Vern Clapp, Improved Cutting Practices Workshop, U.S.D.A. Forest Service, 1985.

CONCLUSION

Perhaps the best justification for tree lining is that it has enabled the Siskiyou National Forest to harvest timber on ground that could not be harvested using conventional falling techniques. Falling with wedges or hydraulic jacks simply would not meet the environmental objectives on some of the steeper ground above sensitive stream courses. Rather than suffering the environmental degradation that would have resulted from these more conventional falling techniques, the Siskiyou would have been forced to forego harvesting in these areas.

Experience has shown that a combination of several factors are at work on sideslopes greater than 65% that often preclude falling with jacks or wedges:

1. The amount of lean is often too great for jacking uphill.

2. Trees felled in a contour pattern will either slide into the streams or the logs will roll into the streams after they are bucked.

3. Even where most trees can be felled uphill, the occasional tree that must be felled sidehill, across the lead of the other trees, will slide into the creek on the "skids" created by the uphill felled trees.

4. Safety of the fallers becomes a major problem on steep slopes. Quite justifiably, the fallers will dump a difficult tree downhill or sidehill rather than risk their lives falling it uphill with conventional methods. Tree lining offers a safe way to fall these trees.

5. A restraining force is sometimes needed to hold trees on steep slopes. If a tree can be restrained before it starts to slide downhill it will sometimes settle into its bed or come to rest against a smaller tree or stump. The pulling line can provide this restraint.

The Siskiyou N.F. is using tree lining as a falling method for 10-15 percent of the volume harvested each year. It is being used on entire units, on portions of units, and for falling incidental trees in units that have been conventionally felled. After a difficult period of introduction, the technique has become accepted as a safe means of falling dangerous timber, as a means to increase the amount of wood recovered from a stand of timber, and as a means to protect valuable stream resources.

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Harvesting Hardwoods with a Feller-Buncher[1]

Cleveland J. Biller and Penn A. Peters[2]

Abstract: A National Hydro-Ax 511 with a Morbark 20-inch accumulating head felled and bunched 8-inch-diameter hardwoods for $0.40 per green ton. The average number of trees per cycle was 1.6, with a felling rate of 118 trees per scheduled hour. The harvest unit was a 6-acre clearcut bounded by property lines that could not be crossed. Boundary restrictions and oversize trees that could not be felled by the Hydro-Ax 511 resulted in an unusual felling pattern that reduced the potential efficiency of the felling operation.

The logging industry has used feller-bunchers to fell softwoods for a long time, but in the past few years, these machines have gained acceptance in shearing hardwoods. In whole-tree chipping operations, the economics of felling small trees with chainsaws are unfavorable because small trees are left scattered over the hillside and economic recovery to the landing is a problem. However, if these small trees can be felled and bunched, they may be transported more efficiently to a landing by a grapple skidder or cable system.

Probably the most important reason for changing to feller-bunchers, other than the increase in productivity per man-hour over the chainsaw, is the increased safety aspects for the operator. Also, the heated or air-conditioned cab of the feller-buncher is an improvement in operator comfort in adverse weather conditions.

A feller-buncher, the National Hydro-Ax 511 with a Morbark 20-inch shear[3] and accumulator head, was studied on relatively level land in Ohio harvesting Appalachian hardwood for a whole-tree chipping operation (Ward et al. 1984).

This article presents the results on the operation and performance of the Hydro-Ax 511 shearing hardwoods. The reader is cautioned that the data presented are from a limited testing period. The detailed results are presented for the purpose of establishing baseline data, and may not be typical of the capability of this machine in other types of stands. Such information is needed to determine machine improvements and proper application of the feller-buncher in hardwood harvesting systems.

EQUIPMENT

The National Hydro-Ax 511 with a Morbark 20-inch shear and accumulator is a fully hydraulic machine, mounted on four 23.1 X 26 tires. The machine is hinged in the middle with an oscillating front axle for steering and traversing obstacles. It is powered by a 4-53N Detroit diesel (130 hp at 2,800 rpm). The hydrostatic transmission allows the machine to move with infinitely variable speeds for ease of movement through the stand. The machine is equipped with a no-spin differential in the front and rear axle for better traction on rough terrain.

SITE DESCRIPTION

The study was conducted in June 1983 near Jackson, Ohio, on a 6-acre clearcut that was to be strip mined. The size and shape of the harvesting plot are illustrated in Figure 1. The cross-hatched area was cleared for a powerline right-of-way; thus, no trees were growing in this area. The area was nearly level, and the feller-buncher did not have any trouble moving over the entire area.

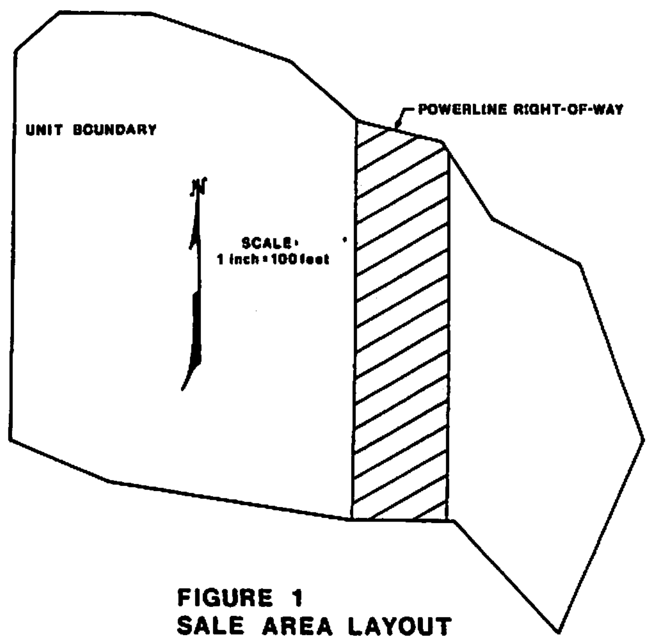

FIGURE 1
SALE AREA LAYOUT

[1]Presented at the 8th Annual Council on Forest Engineering Meeting. Tahoe City, California, August 18-22, 1985.

[2]Mechanical Engineer and Project Leader, Forest Engineering Research, Northeastern Forest Experiment Station, Morgantown, West Virginia.

[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 and official endorsement of 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.

Data were collected prior to harvesting on 1/10-acre circular plots to identify species composition, diameter at breast height (dbh), tree height, and butt diameters. Forty-seven percent of the trees were hickory, 20 percent sassafras, 19 percent oak, and the other 14 percent consisted of dogwood, gum, poplar, maple, cherry, elm, and locust (Ward et al. 1984).

Figure 2 shows the distribution of dbh with an average 8-inch dbh and a range of 4.5 to 16 inches. Roughly 60 percent of the trees were 8 inches or less with a stand density of approximately 220 trees per acre. The average tree height was 57 feet with a minimum of 21 feet and a maximum of 80 feet (Ward et al. 1984).

TIME STUDY AND PRODUCTION DATA COLLECTION

Time study data were collectd by observing the Hydro-Ax 511 in operation and recording the complete cycle with a stopwatch. The elements of a complete cycle are:

1. Unloaded move - begins following the dropping of trees of the previous cycle and ends when the machine is positioned for a cut.

2. Cut - begins when machine is in position to cut, and ends when the machine starts to move.

3. Loaded move - follows cut and ends when the machine is in position to cut or drop the trees that are accumulated.

4. Drop - begins when machine has stopped from the loaded move, and ends when machine begins the unloaded move to cut the next tree.

Some cycles could have more than one cut element because the machine could accumulate stems before dropping them. After a "drop" was made, the machine would back away from the pile; this would be the start of a new cycle. The distance that the feller-buncher traveled was obtained by mounting a revolution counter on one wheel and counting the revolutions, then multiplying the revolutions times the circumference of the tire. This counter accumulated in both forward and reverse, and the total distance the machine traveled was recorded. This method of obtaining distance traveled does not take into account any wheel slippage; it is based on the revolutions the wheel turned.

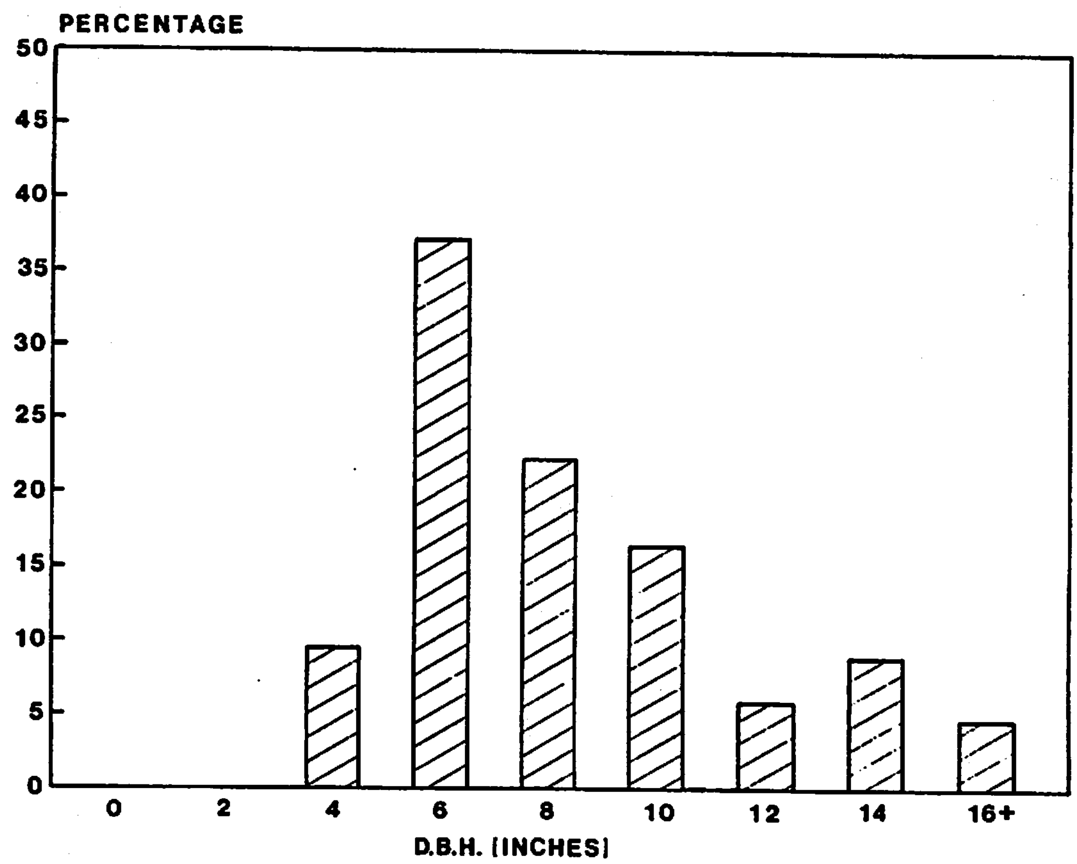

FIGURE 2. DISTRIBUTION OF DIAMETER AT BREAST HEIGHT

In addition to collecting the time study data on the machine, the following data were collected on each pile of cut trees:

1. Number of trees in pile.

2. Butt diameter of trees in a pile. (Not all trees could be measured because some were buried deep in the pile.)

3. Orientation of the pile with respect to magnetic north. Reading from the butt to the top of the tree.

4. Distance and bearing to another pile (for pile location on map).

5. Piles and windrows were numbered allowing the machine to be tracked through the stand.

DISCUSSION OF CUTTING PATTERN

This 6-acre unit was small to be harvested with a feller-buncher. The small unit created problems that would not happen on a large tract. The operator had to be very careful and not drop a tree past the property line. Figure 3 shows the felling pattern that the operator took to harvest the area on one side of the right-of-way. The operator felled and piled most of the timber in windrows as shown in Figure 3: pile numbers from 1-6, 13-15, 21, 25, 27, and 28. The windrows were created because the operation used four cable skidders. The windrows made it easier to set the chokers on the felled trees. These four cable skidders were used to bring trees from the stump to within 40 yards of the chipper. Then a grapple skidder was used to transport the trees to the chipper as needed, which reduced congestion near the chipper as one skidder did not have to wait until another could unhook its load. Operating in this manner keeps trees at the chipper within reach of the loader. The owner of the operation intends to replace the cable skidders with grapple skidders as they wear out.

Figure 3 shows an erratic travel pattern when the machine is followed through the numbered sequence, such as the move from pile 8 to pile 9. Some of the movement can be explained by felling areas and creating space to pile trees that are along the property-boundary line. There were several trees in the area that were too large for the machine; thus, they were left standing. These standing trees created obstacles where piles could not be made. The travel sequence was probably the best the operator could do given the boundary conditions and the large trees that were left standing.

PRODUCTIVITY AND RESULTS

The elemental times for 185 complete cycles are summarized in Table 1. The rest of the 675 cycles were measured as complete cycles; elemental times were not recorded. The number of observations differs for each element because of the feller-buncher's ability to accumulate several trees per cycle. The range was from 1 to 6 trees per

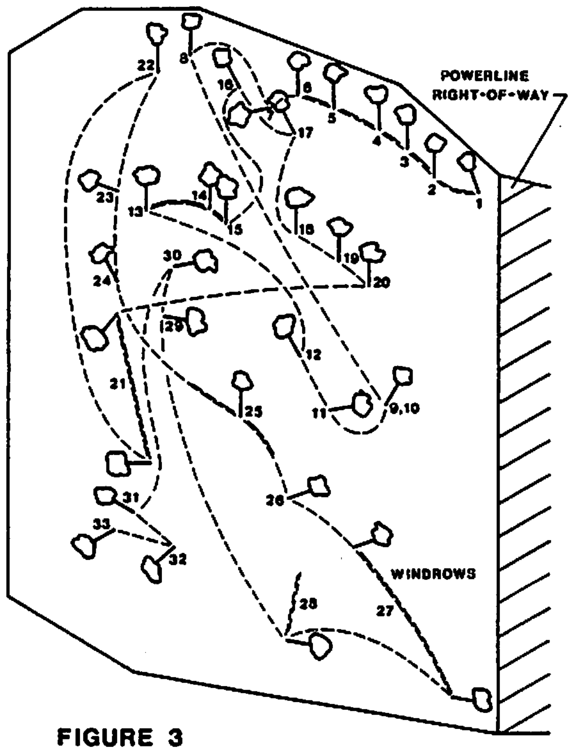

FIGURE 3
PLOT OF CUTTING PATTERN

cycle with an average of 1.6. Thus, three trees sheared in a given cycle will require three cuts, two loaded moves, one unloaded move, and one drop. Some unloaded moves were considerably longer than others because of the cutting pattern the operator chose to follow, e.g., from pile 8 to pile 9. The unloaded move times ranged from 0.05 to 3.8 minutes with an average of 0.37 minutes. There were several long-distance unloaded moves as shown in Figure 3. Some of these were to ensure that the operator did not drop a tree outside the property line (Ward et al. 1984).

In Table 1, the delay element was introduced to represent all delays in a cycle. These delays were for personal time, property-boundary checks, mechanical breakdowns, removing debris from the machine, and determination of cutting patterns. Since this area was harvested in about 9 hours, the delays for mechanical breakdowns are not representative of long-term experience. Over the long run, delay time per cycle is expected to be greater because major mechanical breakdowns are not recorded in this study.

The feller-buncher traveled 13 miles and harvested 1,059 trees in 675 cycles. It took about 9 hours to harvest these trees which totaled 780 tons of wood based on mill receipts. The average cycle time was 0.79 minute and average dbh was 8 inches. The operation yielded 1.6 trees per cycle with 75 cycles per hour or 118 trees per hour which was 87 tons per hour. The weight per tree was 1,480 pounds, and the feller-buncher traveled (forward and reverse) an average of 65 feet for each tree harvested (Ward et al. 1984).

Table 1

Elemental cycle-time summary

Element	Observations	Mean	Standard deviation	Minumum	Maximum
	No.			- - - Minutes - - -	
Unloaded Move	191	0.34	0.37	0.05	3.80
Cut	256	0.12	0.07	0.04	0.54
Loaded Move	61	0.11	0.07	0.05	0.40
Drop	185	0.17	0.13	0.05	1.07
Delay	17	3.91	4.19	0.45	16.00

Table 2

Cycle-time summary

Variable standard	Mean	Standard deviation	Minimum time	Maximum time
			- - - Minutes - - -	
Cycle time	0.79	0.44	0.06	2.8
1 tree cut per cycle	0.64	0.37	0.06	2.0
2 trees cut per cycle	0.90	0.40	0.25	2.8
3 trees cut per cycle	1.14	0.41	0.55	1.96
4 trees cut per cycle	1.58	0.51	0.96	2.05
5 trees cut per cycle	2.01	0.54	1.67	2.04

fell the 6 acres was $316.00. This yields a cost of $53.00 per acre to fell and bunch the timber: a cost of $0.40 per ton of green chips or $0.50 per tree for felling and bunching.

A summary of feller-buncher time and production studies conducted in the Eastern United States is presented in Table 4. Some of the machines harvest trees differently from the Hydro-Ax 511, but we want to look at the numbers in general to see how it compares.

The average cycle time ranged from 0.79 to 2.2 minutes. The Hydro-Ax 511 and the 411 had the same cycle time, but the 411 harvested 4.4 trees per cycle and the 511 harvested 1.6 trees per cycle. The 411 was moving down a row of trees in a plantation and, therefore, would require very little movement on the part of the machine other than straight-ahead moves. The 511 moved about a natural growth stand and harvested 1.6 trees per cycle. These two completely different methods of harvesting and growing timber resulted in one method harvesting 2.8 times as fast as the other method (Ashmore et al. 1983).

In comparing the 511 with the Menzi-Muck (Table 4), keep in mind that the Menzi-Muck operated on steep slopes; the 511 could not begin to operate on such steep slopes; and the Menzi-Muck operated with a swinging boom from

Regression analysis was applied to the data to develop a cycle time equation for the feller-buncher. The model developed was:

Cycle time = 0.3658 + 0.2756 (No. of trees per cycle)

R^2 = 0.22, STD = 0.44 minutes, n = 675

Therefore 22 percent of the variation in the observed cycle times was explained by the model.

Table 2 presents a cycle-time summary of the cycles with different number of stems per cycle. The average cycle time was 0.64 minute for a single stem and increased to 2.01 minutes for a cycle with five stems. Table 2 shows that it would be cheaper to harvest five trees before dropping the load. For example, five trees per cycle are faster than 4 + 1, 2 + 3, or 1 + 1 + 3 trees per cycle. The more productive techniques tend to maximize the payload.

COST ANALYSIS

The hourly operating cost was estimated from manufacturer's cost and information supplied by the operator. The cost analysis is shown in Table 3. The hourly operating cost was $35.15 per productive hour. For the 9 hours to harvest the stand, the total cost to

Table 3

Cost analysis of feller-buncher

Description	Abbreviation	Cost	Basis
**Purchase price	P	$70,000	
Salvage value	S	$28,000	40%
Estimated life	N	5 years	
*Working days/year		250 days	
*Scheduled hours	SH	2,500 hrs.	
*Utilization	U	75%	
Productive hours	PH	1,875 hrs.	SH/U
Average value of investment	AVI	$53,200	$\frac{(P-S)(N+1)}{2N}$ +S
Depreciation	D	$ 8,400	(P-S)/N
Interest/insurance/taxes	IIT	$12,768	(24%AVI)
Yearly fixed costs	YFC	$21,168	D + IIT
Hourly fixed costs	HFC	$11.29/hr.	YFC/PH
Maintainence/repair	MR	$4.48/hr	100% D/PH
**Fuel costs	F	$4.80/hr.	
Tires	T	$0.71/hr.	$\frac{\$1000/tire}{PH}$
*Oil/fluids/lubricant	O	$3.20/hr	
Hourly operating cost	HOC	$13.19/hr.	MR + F + O
Hourly machine cost	HMC	$11.29/hr.	HFC
*Labor cost	LC	$10.07/hr.	Wage*SH/PH
Hourly cost		$35.15/hr.	

*Information obtained from the feller-buncher operator.
**Information obtained from manufacturer.

Table 4

Production capability of feller-buncher

	Hydro-Ax 511 clearcut hardwoods	Hydro-Ax 411 pine plantation row thinning[a/]	Menzi-Muck pole stand clearcut hardwoods[b/]	JD-544 selective-cut hardwoods[c/]	Franklin 105 row and corridor thinning pine plantation[d/]
Avg. cycle	0.79	0.79	1.27	2.2	1.12
Time, mins/tree	0.50	0.18	1.21	0.75	0.28
Trees/cycle	1.6	4.4	1.1	3.0	4.0
Cyles/sched. hour	75	75	47	27	53
Avg. dbh, inches	8	6	7	N/A	6

[a/] Ashmore et al. 1983.
[b/] Arola et al. 1981.
[c/] Biltonen et al. 1976.
[d/] Schroering et al. 1985.

a set position to fell trees within its reach. The Menzi-Muck cycle time was 1.21 minutes with an average of 1.05 trees per cycle. This machine tended to be a little slower than the 511, but it could operate in the most difficult site conditions.

The JD-544 operated in a selective-cut hardwood stand (Table 4). The average cycle time was 2.2 minutes with an average of 3.0 trees per cycle. This yields 0.75 minute per tree, which was a little slower than the 511. But, we do not know the average distance this machine traveled between cuts and drops. It could have moved farther than the 511, or numerous other factors could have effected its time (i.e., selective cut).

The Franklin 105 (Table 4) operated in a row and corridor thinning planation. This machine had an average cycle time of 1.12 minutes with 4 trees per cycle for an average load. This yielded about 0.28 minute per tree to fell and bunch. Compared to the 411, with 0.18 minute per tree, the Franklin 105 is a little slower. These two machines were the fastest machines. They were both operating in the best conditions, row thinning a plantation (Schroering et al. 1985).

The average minutes per tree for these five machines is 0.58. Compared to the Hydro-Ax 511's 0.50 minute per tree, this shows that the 511 was comparable.

CONCLUSIONS

The Hydro-Ax 511 feller-buncher is a very capable machine to use in harvesting hardwood Appalachian harvesting timber for processing through a chipper. It averaged 1.6 trees per cycle with an average cycle time of 0.79 minute, or an average of 87 tons per scheduled hour of operation.

It was $0.50 per tree to fell and bunch the trees. The production times of the Hydro-Ax 511 compared very favorably with other types of feller-bunchers operating in different types of harvesting situations. The range was 0.18 to 1.21 minutes per tree for the five felling machines with 0.50 minute per tree for the Hydro-Ax 511. This type of felling timber is much safer compared to manual chainsaw felling. The operator rides in an air-conditioned or heated cab, which generates less operator fatigue.

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Guidelines for Minimizing Shear Damage to Southern Pine Sawlogs[1]

Robert M. Shaffer[2]

Abstract: Types of shear damage to southern pine sawlogs are described. Guidelines are discussed for minimizing shear damage through proper shear selection, operating technique, and maintenance.

Hydraulic tree felling shears are common on many logging operations in the southern pine region today. Shears can increase production over chainsaw felling through faster felling and moving times. Skidder productivity can be increased by adding an accumulator to the shear or by using a feller-buncher head. Recovery can be increased by the shear's reduced stump heights. Shear felling is also safer than chainsaw felling. The shear operator works off the ground in an enclosed, protected cab. In addition, the shear operator has direct mechanical control over the direction that the tree will fall.

Along with the advantages gained with the shear, there are some potential problems. Shears can cause damage to the tree at the point of severance. This damage may result in reduced yield and/or grade product recovery from the butt log. Until recently, many loggers and forest products companies tended to accept this damage as a tradeoff for the increased recovery and production gains generated by the use of shears. Today's economic climate, however, dictates maximum volume and grade recovery from every log. In addition, emerging alternatives to shearing, such as circular saw felling heads, are causing many forest industry firms in the South to take a hard look at the economic loss due to shear damage.

Two types of shears are commonly used in southern timber harvesting. The double-acting, or "scissor" shear (figure 1) uses two blades of the same size, with each blade cutting toward the center of the tree. Scissor shears are often used in feller-buncher heads because of their relatively light weight, where the addition of an accumulator allows for the collection of several trees at one time. Because they must pass only halfway through the tree and have greater peripheral support at the base of the shear, the blades for a scissor shear may be relatively small and thin. Scissor shears also enjoy a fast cycle time, since two blades are moving through the tree simultaneously. Smaller hydraulic cylinders can be used since the force is divided between the two blades. Scissor shears are typically used on smaller diameter timber, where bunching of stems is desired.

The second type of shear, the single-acting or "directional" shear (figure 2), consists of one blade that passes completely through the tree and closes on a stationary anvil. Directional shears are heavier but less complex, since only one cylinder and blade are involved. They are often used on larger diameter timber, since the inherent strength of the design minimizes mechanical failures.

Figure 1--Scissor shear.

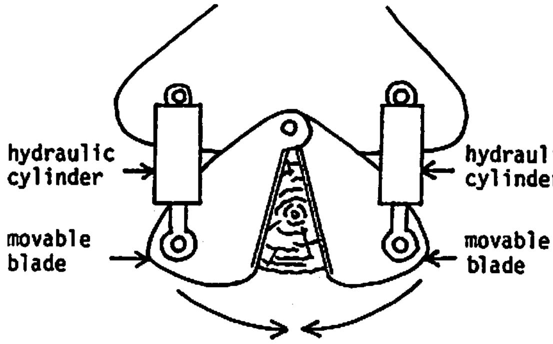
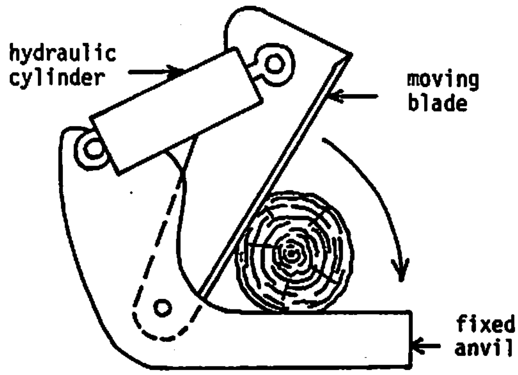


Figure 2--Directional shear.



TYPES OF SHEAR DAMAGE

A recent study at Virginia Tech (Gallagher and others, 1985) identified three major types of shear damage commonly found in the South. These are:

1. stump pull
2. split
3. butt shatter

Stump pull (figure 3) occurs when the tree is lifted from the stump or is allowed to fall before the shearing process is completed. With scissor shears, the pull occurs in the center of the log and may travel down into the stump or up into the butt log. A pull that travels into the log is the most common and will cause the underlength lumber produced from this part of the log to be trimmed back 2 feet, resulting in a major volume loss. If the pull extends out from the log into the stump, another problem arises. When the damaged stem is merchandized at the slasher saw on a tree-length deck, the protruding stump pull will cause a miss-cut log length, and subsequent green lumber trim will be required, resulting in a volume loss.

Stump pull associated with a directional shear is often called a barberchair. Barberchairs result when a tree falls before the cut is completed and the tree splits at the face of the uncut portion. Barberchairs can be reduced by increasing the cutting rate of the shear as the tree starts to fall. The tendency to barberchair increases if the tree has natural lean in

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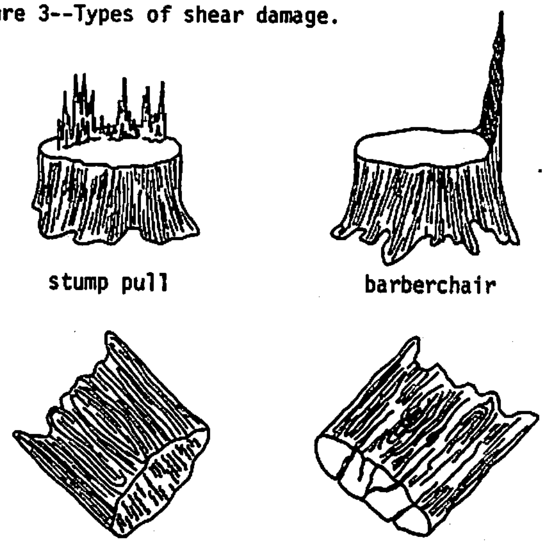
Figure 3--Types of shear damage.



the direction of felling. Barberchair usually results in a somewhat less significant loss of lumber than center stump pull since it occurs at the outer portion of the tree that often goes into chips.

The second type of shear damage, split, describes a massive failure that occurs as the shear blade is being forced through the wood. Splits may extend well into the butt log, averaging 8 to 20 inches in depth. Splits can occur when the tree is tipped on the stump or forced sideways before the cut is complete. A dull shear blade can also cause a split. With a sharp blade, wood fibers are cut ahead of the shear as it penetrates the tree, but a dull blade will force the wood fibers to pack in front of the shear, causing failure along the grain before it is severed. A split will also occur when inadequate force is applied to the shear and the cut is not completed, requiring the blade to be backed up to make a second cutting attempt. Wood fibers grip the shear as it reopens, and a massive split will result.

Butt shatter, the third type of shear damage, results from the crushing of wood fibers as the shear passes through the tree. Some degree of shatter seems to be inherent to the shearing process. It is often difficult to identify immediately after shearing but becomes obvious when the lumber is sawn and dried. Shatter is characterized by multiple, shallow splits and separation of the annual rings, with the damage usually occurring parallel to the direction of shear movement, and may extend up to 6 inches into the log. Butt shatter can result in a significant amount of lumber degrade.

The Virginia Tech shear damage study examined 1,557 shear-felled trees in five southern states. The occurrence of damage by type is shown in table 1. Stump pull was found to be the most frequent type of shear damage, occurring on 60 percent of the trees felled with directional shears and 47 percent of the trees felled with scissor shears. Splits were observed on 20 and 9 percent of the sample, respectively. Visible butt shatter, while only reported on 8 percent of the trees observed, was probably underestimated because of the difficulty of identifying this type of damage on freshly sheared trees. While it appears from this survey that directional shears cause more damage than scissor shears, it should be noted that the directional shears were used in larger timber, and damage tends to increase with tree diameter.

REDUCING SHEAR DAMAGE

Most shear damage can be traced to either improper operator technique, poor operating condition of the shear or carrier, or improper shear selection. Choosing the right shear for the job is critical--blade thickness and diameter must be matched to the size and species of timber to be harvested. Continually operating a shear in timber at or near its maximum rated capacity will result in increased fiber damage. Blades must be heavy (thick) enough to avoid any deflection due to normal cutting stress. Poor initial shear selection will compound future maintenance and operating problems.

Proper operating technique is vital to minimizing shear damage. Stopping the shear prematurely during the cutting cycle, or lifting and/or backing away before the tree is completely severed are common operator errors. Stressing the tree by improperly placing the shear head into position will often cause damage during the cut. The operator should never attempt to fell a tree larger than the shear's rated capacity or try to force too many trees into the accumulator when using a feller-buncher head. Shear operators should receive adequate professional training in the correct operating procedures prior to commencing actual production work.

Implementing a program of proper shear and carrier maintenance offers perhaps the greatest potential to the logging contractor for reducing shear damage. Much of the damage observed in the Virginia Tech study was reported as being due to the poor operating condition of the shear. Key areas of recommended shear and carrier maintenance include the following:

1. Shear blades must be properly aligned and must close completely. This is a common problem that was frequently reported in the survey. Stump pull will result from misaligned blades on nearly every cut. The situation is correctable by inserting the proper size shim between the blade and the backing strip on the knife holders to position the blade so that it closes completely.

Table 1--Occurrence of shear damage by type from survey of 1,557 shear-felled trees (Gallagher and others, 1985).

	Percentage of trees that incurred:[1]			
Type of shear	stump pull	split	butt shatter[2]	no visual damage
directional	60 pct.	20 pct.	8 pct.	35 pct.
scissor	47 pct.	9 pct.	8 pct.	54 pct.

[1]Some trees incurred multiple types of shear damage; therefore, percentages do not equal 100.

[2]Butt shatter is difficult to identify in the field immediately after felling. It is highly probable that many trees with butt shatter were recorded as having no apparent visual damage.

2. Shear blades must be adequately torqued with the proper grade bolts. A great deal of stress is placed on the shear blades during the cutting cycle. Inferior-quality bolts may stretch, causing the blade to deflect during the cut. Grade 12 or better bolts are recommended, torqued to 245 pounds, to properly capture the blades to the shear. In addition, lock washers should never be used under these bolts, since they will often break under this kind of stress.

3. The shear must be kept clean and free of wood, bark, or material that may wedge between the blade and the knife holder. If this occurs, drop the blade out, remove the material, reshim, and retorque the blade. Foreign material can actually wedge between the blade and knife holder hard enough to break or deflect the shear blade.

4. Shear blades must be sharp. A dull blade will cause excessive butt shatter (or splits) on every cut. When resharpening blades, it is critical to achieve the proper cutting angle. If this is not done, the blade will deflect during the cut and cause unnecessary damage to the tree. It is extremely difficult, if not impossible, to achieve the proper cutting angle by sharpening a shear blade with a hand grinder in the field. Dull shear blades should be removed, resharpened on a bench knife grinder in the shop, reshimmed, and retorqued.

5. The hydraulic system of the shear carrier must be adequate to power the shear. Reduced hydraulic pump delivery, loss of engine power, or bent hydraulic cylinders may cause the shear to operate ineffectively. This may result in both a loss of production as well as increased fiber damage, particularly if the shear lacks sufficient power to pass cleanly through the tree in one smooth cut.

These and other guidelines for proper shear operation and maintenance have been incorporated into a 20-minute videotape produced by the Cooperative Extension Service at Virginia Tech. Copies are available for $20 by writing the author at the Department of Forestry, Virginia Tech, Blacksburg, Virginia 24061.

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Reduced Vibration With Twin-Cylinder Chainsaw[1]

Bryce J. Stokes[2]

Abstract: Lowering of the amount of vibration transmitted to chainsaw operators is important to reduce occupational risk and to improve production. A twin-cylinder chainsaw was evaluated to determine if there were reductions in vibration levels transmitted to the operator. The saw was tested along with two different types of single-cylinder saws in a static bench test and in a dynamic bucking test. The tests showed a significant reduction in vibration at the handles of the twin-cylinder saw model as compared to the single-cylinder saws.

Long-term exposure of chainsaw operators to vibration may result in occupational hazards. One such hazard, known as Raynaud's disease, is numb, cold fingers and a loss of sensation in the hand (Davis, 1978). The risk of injury depends on the intensity, duration, and aggregate exposure (Axelsson, 1968). Vibration injury has been shown to be related to prolonged daily use of chainsaws in repetitive tasks. Operators must take frequent breaks to recover from fatigue and restricted circulation in their fingers caused by the physical exertion and saw vibration. Excessive vibration can result in loss of productivity when frequent rest periods are required.

Studies have been completed to determine the sources of and remedies to reduce vibration in chainsaws. Vibration occurs in a chainsaw for several reasons, but the major sources are the forces and moments on the engine due to combustion, unbalanced inertia of internal moving parts, and contact between the chain and wood. Past work on reducing the vibration of single-cylinder chainsaws involved better-balanced rotating parts and improved designs for handles and suspensions. Most modern single-cylinder chainsaws utilize improved vibration isolation devices; however, because of the inherent design of the engine, there are still high levels of vibration. Past research has concluded that a possible alternative for reducing vibration is a design with opposed cylinders in a twin-cylinder chainsaw (Axelson, 1968 and Davis, 1978). Modern engineering technology has now made this design feasible.

A new twin-cylinder chainsaw with opposed cylinders has been developed by Kioritz Corporation of Japan and is currently being marketed in the U.S. by a subsidiary, Echo Incorporated[3]. The new design uses two horizontally opposed cylinders and pistons that fire simultaneously to counterbalance each other. The simultaneous combustion is ensured by a single electronic ignition system. Since vibration mainly results from a piston changing direction at the end of its stroke in the operation of a single-cylinder saw, there is potential for reducing vibration using an opposed-cylinder concept.

The twin-cylinder model and two single-cylinder models were tested to determine if there is a difference in vibration levels among the saw types. The test included evaluation of the vibration in a static bench test and in a dynamic bucking (cross-cutting) mode under laboratory conditions.

DESCRIPTION OF SAWS

The twin-cylinder saw model (fig. 1) has a two-stroke engine with two opposed cylinders that are oriented 9° from horizontal. The displacement is 61.0 cc (3.72 in^3) divided equally between the two cylinders. Weight, with a 51-cm (20-in) guide bar and chain, is 9.03 kg (19.9 lbs) when full of gas and oil. The saw has a floating engine suspension system with eight cushioned connector points.

Two single-cylinder saw models were used in the study. One has a two-stroke engine with a horizontal cylinder. The displacement is 64.2 cc (3.92 in^3). With a 51-cm (20-in) guide bar and chain, the saw weighs 8.99 kg (19.8 lbs) when full of gas and oil. It also has a floating suspension system with seven cushioned connector points.

The other single-cylinder chainsaw model has a two-stroke, vertical-cylinder engine. The displacement is 66.7 cc (4.07 in^3). The saw weighs 8.59 kg (18.9 lbs), full of gas and oil, with a 51-cm (20-in) guide bar and chain. The engine is mounted with six cushioned connector points.

The isolation and suspension design differences among the saws made comparison of the vibration levels on the saw bodies impossible without removal of the recoil starter covers. One model isolates the engine from the handles and recoil starter assembly and the other models have suspension designs that isolate the engine and recoil starter from the handles. Therefore, only the vibration measured at the handles is discussed.

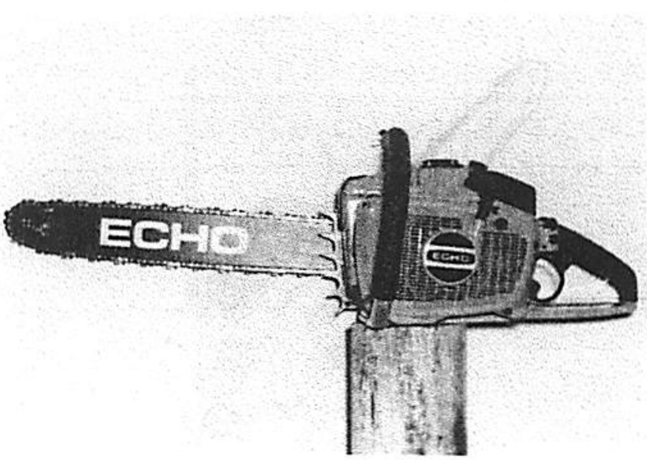

Figure 1--Twin-cylinder chainsaw.

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[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

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[3]The use of brand names is for the convenience of the reader and is not an endorsement by the USDA Forest Service.

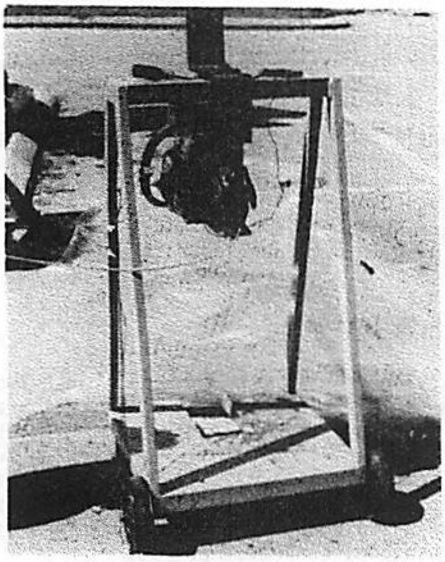

Figure 2--Chainsaw testing-stand.

The twin-cylinder and horizontal, single-cylinder saw models had low-kick asymmetrical bars with roller noses. A regular bar was used on the vertical, single-cylinder model because it had a chain brake. These guide bars and chains were suggested by the manufacturers.

DATA COLLECTION

Vibration in the Testing Stand

Levels of vibration were measured for the saws in a static position using a testing stand designed by Abrams and Suggs (1977). The stand (fig. 2) simulates the holding characteristics of a human operator and reduces the measurement variation that results when operators are used.

A three-axial accelerometer, MB Electronics model no. 310, which can measure accelerations at frequencies up to 10,000 Hz, was attached to the saw handles using a hose clamp with a short protruding stud. The accelerometer was connected via three coaxial cables to an ENDEVCO charge amplifier (model 2735). Three axial accelerations were recorded simultaneously on a RACAL tape recorder (model 14D5). The sampling rate was 12,800 samples per second to a maximum frequency of 5,000 Hz. An NCS dual channel FFT analyzer and x-y plotter were used to analyze and plot the data. The vibration was analyzed at intervals of one-third of an octave.

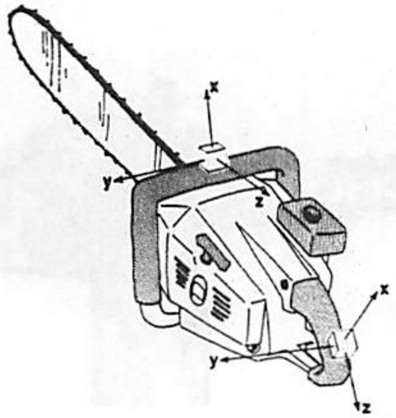

Figure 3--Diagram of axial directions.

Vibration measurements were taken at the top and rear handles in three orthogonal directions (fig. 3). The Y-axis was parallel with the crankshaft. Different Z- and X-axes were used for each handle. On the top handle, the Z-axis was parallel to the chainsaw bar and perpendicular to the crankshaft. On the rear handle, the reference axis, Z, was parallel to the throttle handle (hand grip). The X-axis was orthogonal to the corresponding Y- and Z-axes.

Two chainsaws of each model were used. Saws were placed into the testing stand in random order. The handle mounting blocks were adjusted to snugly fit each saw with a resilient material insulator between the metal blocks of the testing stand and the chainsaw handles.

External throttle controls were connected to each saw to insure a steady operating speed. A digital tachometer was used to determine and monitor the speed in rpm's (revolutions per minute). Vibration levels for no-load running in the testing stand were measured at an approximate speed of 10,500 rpm's for the saw models with horizontal cylinders. The vertical-cylinder saws were operated at approximately 14,000 rpm's because of the shorter piston stroke that enables higher speeds. These speeds are recommended by the manufacturers as the maximum no-load values. The engine speeds were maintained at these rpm levels for approximately 5 seconds while the accelerations were recorded.

After a saw was placed into the testing stand, the accelerometer was mounted on either the top or rear handle. The saw was started and engine speed increased to the prescribed rpm using the tachometer. The vibration levels were recorded for all three axes simultaneously. Then the saw was idled down and the accelerometer was moved to the other handle location. This procedure was replicated once for each saw.

Vibration During Bucking Test

Each saw was used to cut a disk off a pine log in a cross-buck. The test procedures generally followed those outlined for the testing stand. In the cutting test, the chainsaws were operated in a random order by one person. The accelerometer was attached to each handle in random order. Measurements were taken on both handles of a particular saw before testing another saw.

Cutting speed was monitored and maintained with a digital tachometer. An assistant held the tachometer so the operator could watch and maintain a relatively stable speed. All saws were run at approximately 8,600 rpm's in the bucking tests.

The operator cut off the disk in the conventional manner of bucking a log. The cut was made from the top of the log to the bottom. During the cutting process, vibrational measurements were taken and recorded in all three directions simultaneously at one handle location. After the disk was cut, the saw was stopped and the accelerometer location was changed to the next handle. Then the operator would cut another disk for the measurements to be taken. Tests were not replicated during this phase of the study.

ANALYSES

Vibration in the Testing Stand

Maximum rms (root-mean-square) accelerations were derived from the recorded data by using a location

Table 1--Average peak accelerations for testing stand.

Saw Type	Handle Location	No. of Obs.	X-Direction Frequency Hz	X-Direction Acceleration g's-rms[1]	Z-Direction Frequency Hz	Z-Direction Acceleration g's-rms	Y-Direction Frequency Hz	Y-Direction Acceleration g's-rms
Twin cylinder	Rear	4	132.8	0.8 a[2]	168.8	1.3 a	296.9	2.3 a
	Top	4	179.7	2.7 a	178.1	3.3 a	275.0	0.6 a
Single cylinder								
Horizontal	Rear	4	160.9	2.1 a	164.1	0.6 a	181.3	3.4 a
	Top	4	157.8	4.7 a	178.1	4.1 a	179.7	2.5 ab
Vertical	Rear	4	239.1	9.4 b	268.8	7.2 b	237.5	6.4 b
	Top	4	239.1	8.7 b	189.1	3.0 a	518.8	4.2 b

[1]rms = root-mean-square.

[2]Means at the same handle location and direction followed by the same letter are not significantly different among saw types at the 90 pct. level of significance.

curser on the oscilloscope of an FFT analyzer. The replicated tests resulted in four observations for each saw type in each of the three axial directions. The highest acceleration (g's-rms) for the entire frequency range became the observation. The means with the corresponding frequency are shown in table 1. Highest average maximum acceleration, 9.4 g's, was recorded in the X-direction of the vertical, single-cylinder model. Lower maximum accelerations were measured for the twin-cylinder and horizontal, single-cylinder chainsaws. The Duncan multiple range test was used for testing for significant differences among the chainsaw models (Montgomery, 1976). There proved to be no significant differences between twin-cylinder and horizontal, single-cylinder saw models. There were significant differences between the twin-cylinder and vertical, single-cylinder saw models.

The acceleration (g's-rms) means of one-third octave band frequencies were determined for each test run from the tape recorder using the FFT analyzer. The bands ranged from 40 to 1000 Hz (cycles per second). The one-third octave acceleration values were plotted and the actual acceleration level for each octave band was read directly from the analyzer using the oscilloscope cursor. Statistical analyses were completed on these numerical data.

Means and significant differences of vibration levels for all the one-third ocatve bands for each saw type, axial direction, and measurement location are shown in table 2. Generally, the vertical single-cylinder saw model had higher vibration levels. There were significant differences between the twin-cylinder and the vertical, single-cylinder saw models, except in the Z-direction at the top

Table 2--Test stand mean acceleration of octave band frequencies.

Handle Location	Direction	No. of Obs.	Twin cylinder	Single cylinder horizontal	Single cylinder vertical
			g's-rms[1]		
Rear	X	60	0.25 a[2]	0.40 a	1.50 b
	Z	60	0.36 a	0.19 a	1.31 b
	Y	60	0.82 a	0.79 a	1.51 b
Top	X	60	0.82 a	0.72 ab	1.37 b
	Z	60	0.81 a	0.72 a	0.68 a
	Y	60	0.45 a	0.67 ab	0.86 b

[1]rms = root mean square.

[2]Means across rows followed by the same letters are not significantly different at the 90 pct. level of significance.

Table 3--Average peak acceleration for bucking test.

Saw Type	Handle Location	No. of Obs.	X-Direction Frequency	X-Direction Acceleration	Z-Direction Frequency	Z-Direction Acceleration	Y-Direction Frequency	Y-Direction Acceleration
			Hz	g's-rms[1]	Hz	g's-rms	Hz	g's-rms
Twin cylinder	Rear	2	116.3	0.4 a[2]	139.4	0.3 a	111.3	0.9 a
	Top	2	145.0	0.5 a	156.3	0.3 a	133.8	0.1 a
Single cylinder								
Horizontal	Rear	2	139.4	2.8 a	113.1	1.0 a	138.8	2.8 b
	Top	2	134.4	3.0 a	175.6	1.4 b	196.3	2.2 b
Vertical	Rear	2	143.3	4.0 a	136.3	2.1 a	139.6	4.6 c
	Top	2	131.7	5.5 a	74.2	1.9 b	142.9	3.4 c

[1]rms = root mean square.

[2]Means at the same handle location and direction followed by the same letter are not significantly different among saw types at the 90 pct. level of significance.

handle. There were no significant differences among any of the three saw models in the Z-direction at the top handle. The twin-cylinder saw type was not significantly different from the horizontal, single-cylinder saw type. The horizontal, single-cylinder saw model vibration levels significantly lower than the vibration levels of the vertical, single-cylinder model at the rear handle only.

Vibration During Bucking Test

Only one observation was used at each location and direction for each chainsaw. Maximum accelerations were taken from continuous data using the curser on the analyzer.

The highest maximum acceleration (5.5 g's-rms) averaged by saw type occurred with the vertical, single-cylinder saw type in the X-direction at the top handle (table 3). The lowest maximum acceleration was produced by the twin-cylinder model in the Y-direction at the top handle. In most cases, the maximum acceleration averages were lower for the twin-cylinder model than the horizontal, single-cylinder model, and the horizontal-cylinder models had lower maximum acceleration averages than the vertical-cylinder model. The Duncan multiple range test was used to test for significant differences among the models. There were no significant differences among chainsaw types in the X-direction. Means were significantly different among saw types in the Y-direction.

One-third octave acceleration levels were taken from the taped test runs after processing with the FFT analyzer. Acceleration for each one-third octave band was read directly from the analyzer using the oscilloscope cursor. This information was recorded and placed into computer files for analysis.

In the bucking vibration test there proved to be significant differences among the chainsaw types for acceleration (g's-rms) means of the one-third octave band frequencies in the tests (table 4). The bands

Table 4--Bucking mean acceleration of octave band frequencies.

Handle Location	Direction	No. of Obs.	Twin cylinder	Single cylinder horizontal	Single cylinder vertical
			g's-rms[1]		
Rear	X	30	0.22 a[2]	1.09 b	1.47 b
	Z	30	0.55 a	1.10 ab	1.49 b
	Y	30	0.19 a	0.43 a	0.74 b
Top	X	30	0.19 a	0.96 ab	1.45 b
	Z	30	0.17 a	0.96 b	1.04 b
	Y	30	0.19 a	0.69 b	0.76 b

[1]rms = root mean square.

[2]Means across rows followed by the same letters are not significantly different at the 90 pct. level of significance.

Figure 4--Vibration levels at the top handle during bucking.

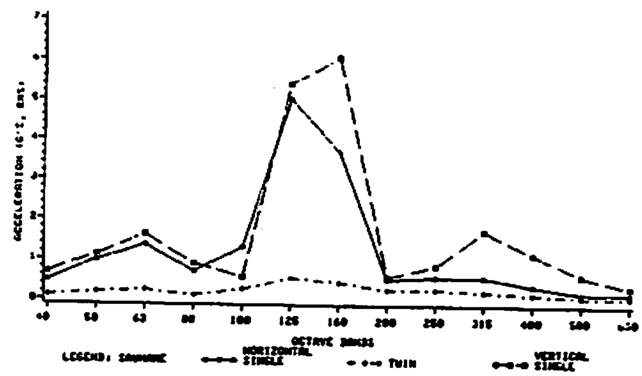

Figure 5--Vibration levels at the rear handle during bucking.

used in the tests ranged from 40 to 1000 Hz. The twin-cylinder model usually exhibited lower levels of vibration across the whole frequency range than the two single-cylinder models. There was a significant reduction in vibration at the handles in most directions. At the top handle, the reduction was 81.3 percent for the twin-cylinder saw over the single-cylinder models. There was a 69.3 percent reduction in vibration of the twin-cylinder saw at the rear handle location. The acceleration levels for the octave bands are graphically shown for the top and rear handles in figures 4 and 5, respectively. The twin-cylinder had the lowest level of vibration over the octave bands. There were no significant differences between the two single-cylinder saw models in the octave analysis. For octave bands greater than 200 Hz, there were no significant differences among all the saw models. The magnitudes of the accelerations were greater at the rear handle than at the top handle.

SUMMARY

In the analysis of the data taken using the testing stand, the peak acceleration levels were generally lower for the twin-cylinder model than for the horizontal, single-cylinder model. Both of these saws generally had significantly lower maximum accelerations than the vertical, single-cylinder model. There were significant differences between the twin-cylinder model and the vertical, single-cylinder model in the one-third octave band analysis. The twin cylinder usually had lower vibration levels in all directions at both handles than the other saw models.

In summary, the study showed the twin-cylinder chainsaw to have less overall vibration with signicantly lower levels of vibration at both locations (top and rear handles) and in all axial directions in the bucking test.

SIGNIFICANCE TO FOREST WORKERS

Reduction in vibration levels transmitted to the operator results in a lower risk of occupational hazards. A related study of the twin-cylinder chainsaw model has shown that it takes far greater exposure periods (from 9 to 26 years) to produce the same risk of developing vibration-induced vascular disorders as compared with the single-cylinder models (Rummer and others, 1985). Lower vibration levels permit a healthier working environment.

Even the development of this twin-cylinder concept is not the final solution. Hartsough and others (1984) developed an engine-suspension-handle-operator model to predict relative vibration levels for the twin-cylinder saw model and a single-cylinder saw model. The model can be used to refine the saws' operation for minimizing vibration levels and making comparisons between the two saw models. Hopefully, further reductions in vibration transmitted to the operator, even for the twin-cylinder concept, can be achieved through more research and advanced technology.

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Teaching Logging Cost Analysis with Spreadsheets[1]

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Abstract: Spreadsheets on microcomputers have been successfully used for two years to help teach topics in timber harvesting classes at Auburn University. The same approach was recently used in equivalent courses at two other land-grant universities with similar success.

Most forestry schools in the United States include a course in timber harvesting as an undergraduate degree requirement. Due to the wide variety of harvesting equipment and systems, basic evaluation techniques, and current harvesting problems, students are often only exposed to the rudiments of estimating logging costs. This typically includes discussions of such fundamentals as machine rates and considerations in "balancing" a harvesting system.

Such exercises are necessary to provide students with an appreciation of the factors which can affect logging costs. While the mathematics of the method is simple, the procedure quickly becomes tedious and prone to computational error. Consequently, cost estimation calculations are well suited for implementation within an electronic spreadsheet for use on a microcomputer. Students quickly gain an awareness of the important factors affecting logging cost while being exposed to a powerful use of microcomputers.

SPREADSHEETS IN THE CLASSROOM

At Auburn University, students use spreadsheets in the advanced harvesting course. This senior-level course is required for forest engineering majors and is optional for forest management majors. Students earn 3 quarter hours of credit for the course. Spreadsheets are used to analyze logging systems and equipment replacement decisions which are the major topics covered during the course.

Analysis of Logging Systems

Students become acquainted with cost analysis of logging systems using machine rate costs and production equations in the preequisite basic timber harvesting course. To allow study of factors affecting logging systems in the advanced course, a spreadsheet which is easily adapted to represent many systems is used.

This spreadsheet (Figure 1) is organized into four sections, each with a specific purpose. The first section, found at the top, contains most of the necessary inputs. Major inputs include: (1) a stand and stock table; (2) mileage and per mile costs of roads to be built; (3) support items and their costs; and (4) information on scheduled work time. The information in this section is used throughout the spreadsheet.

Immediately below the top section, productivity estimates of each harvesting function in the system are calculated. Appropriate production equations which rely upon information found in the input section along with additional specific inputs are provided in this section. When using this spreadsheet for different logging systems, this section requies the greatest number of changes. The format of inputs and production equations will often require changes to adequately represent new systems. The remainder of the spreadsheet requires that the productivity of each function in cords per productive machine hour (PMH) be stored on the bottom line of the section.

The third section contains user-provided information on machine and operator costs. As shown in Figure 1, these costs are not machine rate costs but estimates of actual out-of-pocket expenses. This format can be easily changed for classroom purposes. In practice, cost manipulations are common exercises for students to perform. Machine and operator costs are combined with the production estimates in the section that follows.

The fourth section of the spreadsheet combines each harvesting function into a system. First, the actual utilization of each function is determined from the number of each type of machine and its production rate. The system production rate is limited to the least productive function. Actual utilization rates are calculated based upon system productivity. Once determined, actual utilization is used to accurately estimate costs on a a scheduled machine hour (SMH) basis. Cost/SMH for each function is divided by system productivity to give a cost per cord estimate. Function cost rates are summed, along with estimates of moving, road building, and support costs per cord, to give total cost per cord for the harvesting system.

With such a tool at their disposal and a short introduction to the use of the particular spreadsheet software, students can quickly become adept at playing "what-if" games with system performance and cost. Assigned work encourages use of spreadsheets and requires the students to perform sensitivity analyses by changing the type of stand harvested, haul distances, and other controlling factors.

One question which always generates student interest is the effect of a wood quota. Quotas are commonly imposed upon a logger during periods of excess supply or weak demand at the mill. By playing "what-if" games with the quota level, students quickly see the need to work fewer hours and the marked effect of the quota on the logger's cost of producing wood.

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[1]Presented at the 8th Annual Council on Forest Engineering Meeting, Tahoe City, California, August 18-22, 1985.

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SYSTEM:  HYDROAX 511, TIMBERJACK 380, GATE, PRENTICE 210
=========================================================================
--STAND & STOCK TABLE-- ----------------GENERAL INFO----------------
 DBH  T/AC CD./T CD./AC HOURS/DAY=     9  TRACT SIZE=  250  ACRES
----------------------- DAYS/WEEK=     5   MOVE TIME=    5  HOURS
  6     32 0.035   1.12 WEEKS/YR =    48  HOME DIST.=   35  MILES
  8     23 0.082   1.89
 10     15 0.156   2.34 SUPPORT--                ROADS TO BE BUILT--
 12     10 0.196   1.96     2 PKUP:   0.18  $/MI.    TYPE    MILES  $/MI.
 14      5 0.340   1.70   FOREMAN:   1500  $/MO. MAIN HAUL:  0.00 10000
 16      2 0.450   0.90  OVERHEAD:    500  $/MO. SECONDARY:  0.00  3000
 18      1 0.600   0.60    2 SAWS:    600  $/EA.  PUSH-OUT:  1.25  1050
 20      1 0.900   0.90
----------------------- ARTH. MEAN DBH=  8.83  TRUCK HRS/DAY=   12.00
 TOTAL  89        11.41 QUAD. MEAN DBH=  9.35  QUOTA (CD/WK)=     N/A
=========================================================================
------FELLING----- ----SKIDDING----- -----LOADING----- -----HAULING-----
-----------------------MACHINE PRODUCTIVITY-----------------------------
 BA/ACCUM=  0.56  DECK-WOODS=  300  TIDWN TIME= 3.87         MILES SPEED
------------------  GATE-DECK=  150   TRIM TIME= 2.31   2NDRY  0.5   3.2
 DBH  MIN/T HR/AC SKIDDER WT=17140   DBH  MIN/T HR/AC   MAIN  1.1   6.8
 ---  ----- ----- SKIDDER HP=  136   ---  ----- -----  GRVEL  2.5  19.0
   6  0.37  0.20  TREE/CYCLE=  4.0     6  0.31  0.17  PAVED 40.0  40.0
   8  0.44  0.17  BNCH/CYCLE=  1.1     8  0.47  0.18   ------------
  10  0.50  0.12   -----------        10  0.61  0.15   LOAD SIZE= 9.80
  12  0.56  0.09  CYCLES/AC.=22.25    12  0.74  0.12  UNLOAD TIM=   30
  14  0.63  0.05  CORDS/CYCL= 0.51    14  0.84  0.07   LOAD TIME=45.06
  16  0.69  0.02    PMM/CYCLE= 3.49   16  0.92  0.03   TRIP TIME= 4.15
  18  2.51  0.04                      18  0.97  0.02
  20  2.88  0.05                      20  0.99  0.02
------------------                 ------------------
TOTAL    --- 0.75                 TOTAL ----  0.75
CORDS/PMH= 15.22   CORDS/PMH= 8.82  CORDS/PMH= 13.05   CORDS/PMH= 2.36
-------------------------MACHINE COST-----------------------------------
PMT ($/MO)= 2049             1742          1230              1332
I&T ($/MO)=  239              204           144               134
F&L ($/HR)= 5.95             4.84          4.08              5.36
M&R ($/HR)= 4.34             4.43          2.60              1.97
LABR($/HR)= 6.50             6.50          7.50              7.00
FRINGE (%)=   30               30            30                30
MAX UT(%) =   65               70            85                90
NUMBER    =    1                2             1                 4
=========================================================================
            CORDS   MAX   CORDS/SMH    NEW -----COST PER SMH------  COST
FUNCTION     /PMH  % UT   ONE   ALL   % UT FIXED  OPER LABOR TOTAL  $/CD
-------------------------------------------------------------------------
FELLING     15.22    65  9.89  9.89    65 12.71  6.69  8.45 27.85  2.82
SKIDDING     8.82    70  6.17 12.35    56 21.62 10.40 16.90 48.92  4.95
LOADING     13.05    85 11.09 11.09    76  7.63  5.06  9.75 22.45  2.27
HAULING      2.36   120  2.83 11.33   105 32.58 30.71 42.36 105.6 10.68
            -----------------------------------------------------
SUPPORT     PICKUPS, CHAINSAWS, FOREMAN, AND OVERHEAD              1.46
ROAD WORK                                                          0.46
MOVING      5.00 HOURS SPENT MOVING MEN & EQUIPMENT TO TRACT       0.27
-------------------------------------------------------------------------
                 SYSTEM RATE = 9.89        SYSTEM COST/SMH:  204.8
    WEEKLY PRODUCTION (CORDS) =  445
   DAYS REQUIRED TO CUT TRACT =   33            SYSTEM COST/CORD: 22.90
=========================================================================
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FIGURE 1. CLASSROOM SPREADSHEET FOR LOGGING COST EXERCISES.

Equipment Replacement Decisions

Another topic discussed during the advanced harvesting class concerns the equipment replacement decision. This is examined by an after-tax, discounted cash flow analysis (Tufts and Mills, 1982). Annual equivalent costs for each alternative machine and each alternative life are computed to determine the economic life of a machine, compare investment alternatives, or calculate the cost of a single machine. The procedure is time-consuming by hand and prone to error. This greatly limits the work which can reasonable be assigned to students.

For this exercise, students use a spreadsheet which contains a cash flow analysis framework to examine alternative replacement policies during the class (Tufts, 1985). A major assignment requires that this spreadsheet be used extensively to select the best life for several machines. Sensitivity analysis is also easily accomplished with the spreadsheet, allowing students to quickly determine the effects of changes in taxes, salvage values, and interest rates on the desirability of their decisions.

Other Past Experiences

Over the last two years, the use of spreadsheets in the class has changed substantially. The first year spreadsheets were used, students were required to build their spreadsheets from scratch. This proved too large of a task in addition to other class projects for students unfamiliar with microcomputers and specific spreadsheet software. Now, spreadsheet instructions are copied to a student's diskette, and the student is required to make major changes during some assignments. This approach provides students with a general understanding of spreadsheets without consuming an undue proportion of their time.

Any spreadsheet package and microcomputer is acceptable. In the past, software used has included SuperCalc by Sorcim [3/] and PeachCalc by Peachtree Software. Presently 1-2-3 by Lotus Development Corporation is used in class due to its availability at campus microcomputer facilities and its widespread use by industry. The IBM-PC has served as the microcomputer for all class related work, although several models are adequate.

EXPERIENCE AT OTHER SCHOOLS

Copies of the spreadsheet and a brief oral and written description of the underlying logic and assumptions were provided to instructors of timber harvesting courses at Purdue University and Louisiana State University. According to the professors responsible for the classes, student response to the use of the spreadsheet was generally favorable at both institutions.

At Purdue University[4], the spreadsheet was used in a three semester credit senior-level course which covered a wide range of harvesting topics. This course appears rougly equivalent to the advanced harvesting course being taught at Auburn. Students were required to use the spreadsheet for sensitivity analysis as well as make minor modifications to the spreadsheet such as changing the underlying production equations. Response was very positive, even though most students were unfamiliar with Lotus 1-2-3 prior to the beginning of the class. To compensate for this, more time for familiarization with the software is planned for next year's class prior to the spreadsheet assignment. Comments from Purdue also indicate that the documentation provided with the spreadsheet could be improved.

At Louisiana State University[5], the spreadsheet was also used in a three-semester hour senior-level course to introduce students to cost analysis of logging operations. Students were required to use the spreadsheet for sensitivity analysis and determination of system balance. Student reaction was positive and students benefited from prior use of Lotus 1-2-3 before the harvesting class. Again, additional documentation of the spreadsheet and its underlying equations was suggested as a possible improvement.

CONCLUSION

A wide range of everyday problems concerning harvesting and raw material supply can be solved with the aid of spreadsheets which are relatively simple to create. Spreadsheets have greatly improved the teaching of harvesting topics which require many repetitive computions such as cost estimation and equipment replacment decisions. In addition, their use exposes students to real world applications of microcomputers, better preparing them to make decisions in jobs after graduation.

NOTE TO READERS

A copy of the spreadsheets mentioned in this paper are available on request from the authors.

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[3]Mention of product names is for the reader's convenience and does not constitute an endorsement by Auburn University or the Alabama Agricultural Experiment Station.

[4]Personal communication from Dr. T.W. Reisinger, Purdue University, West Lafayette, Ind., June 15, 1985.

[5]Personal communication from Dr. B.D. Jackson, Louisiana State University, Baton Rouge, La., June 15, 1985.

Regional COFEs - a Sharing of Protocol and Experiences from New England, USA[1]

Thomas J. Corcoran[2]

The New England Regional Council on Forest Engineering (NER.COFE), as its name implies, is a regional subdivision of the parent international organization, Council on Forest Engineering (COFE). NER.COFE had its initiation in November 1984, by action of a three-person ad-hoc committee of New England-based COFE members. Their action was in accordance with the vote of the COFE membership in attendance at the Seventh Annual Meeting[3] in Orono, Maine on August 12, 1984. This vote authorized regional COFEs. The establishment of NER.COFE is understood to be the first regional appearance of a COFE subdivision. Its initial year of existence has been judged a success, worthy of being documented; hence this treatise.[4]

The New England membership at the beginning of NER.COFE numbered about 42 persons. This figure grew to 58 members, an increase of 38 percent, with the announcement and fruition of a workshop[5] held in March, 1985. There were over 100 participants in the workshop which was open to non-COFE members. Further growth potential is evident. It should also be noted that COFE members from areas outside New England, particularly New York, Pennsylvania, Illinois and Canada attended the workshop.

Three workshop manuals[6] and a proceedings[7] permanently record the workshop presentations. These presentations were made by corporate forest engineers, private contractors, commercial vendors, government officials, research scientists and university educators. They provided indepth treatment of three basic themes:

1) road and structure establishment and maintenance
2) culvert sizing and selection
3) soils engineering

The manuals and proceedings have been made available at modest cost to the public.

During the business meeting at the workshop the NER.COFE members ratified a set of guidelines which is a constitution-like documentation, or a specific set of by-laws, that governs NER.COFE and includes provisions for its officers. An actual version of the guidelines follows:

Guidelines for the Conduct of
The New England Council on Forest Engineering

As adopted in August, 1984 by the international Council on Forest Engineering (COFE), subdivisions of COFE may be activated on a regional basis by the membership located within a membership-defined region. With the objectives of promoting the recognition and of enhancing the practice of forest engineering in New England, let it be known that the New England Regional Council on Forest Engineering (NER.COFE) had its origin on November 15, 1984.

Actions:

1) Define a NER.COFE as a member in good standing in COFE and whose COFE mailing address is within the New England region.
2) Establish the year for NER.COFE deliberations as from April 1 to March 31.
3) Declare that NER.COFE membership shall never be assessed NER.COFE membership dues, annually or otherwise. It is intended that the financing of activities in NER.COFE shall normally be by revenues collected as registration fees at NER.COFE meetings and by donations.
4) Appoint Thomas J. Corcoran as Executive Chairperson of NER.COFE for a three-year term ending on March 31, 1987 with duties to conduct the day-to-day business of NER.COFE.
5) Elect A. Allen Murphy as Chairperson Elect of NER.COFE for a two-year term ending on March 31, 1986 with duties of scheduling and chairing the activities of temporary committees of NER.COFE.
6) Declare that temporary committees of NER.COFE may be constituted by the Chairperson Elect and the Executive Chairperson with their joint agreement or by a majority vote of:
   a) the NER.COFE membership as a whole, or
   b) the NER.COFE membership in attendance at a NER.COFE conference/workshop.
7) Designate Nutting Hall, College of Forest Resources, University of Maine at Orono as the location of NER.COFE information and documentation.
8) Direct the Executive Chairperson to establish a bank account in the name of NER.COFE and authorize the Executive Chairperson and the Chairperson Elect to make the necessary deposits and withdrawals from said account that are consistent with the objectives of NER.COFE.
9) Direct the Executive Chairperson to report the financial status and the activities of NER.COFE on an annual basis to the COFE membership of record whose COFE mailing address is within the New England region on January 1 of that year. The reporting shall normally be completed not later than March 31 of that year.

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[3]COFE/IUFRO 1984 hosted by the Univ. of Maine at Orono (USA) and the Univ. of New Brunswick at Fredericton (Canada) during 11-18 August, 1984.

[4]Maine Agricultural Experiment Station External Publication Register #1021.

[5]NER.COFE Roads and Structures Workshop. 21-22 March, 1985, College of Forest Resources, 100 Nutting Hall, University of Maine at Orono.

[6]NER.COFE Roads and Structures Manual (55 pages) by Allen Murphy
NER.COFE Culvert Selection/Installation (75 pages) by Warren Hedstrom
NER.COFE Forest Soils Engineering (55 pages) by Warren Hedstrom

[7]A Proceedings of Selected Presentations, NER.COFE Roads and Structures Workshop, University of Maine at Orono. (March 21-22). 42 pp,

10) Establish a goal of conducting at least one NER.COFE conference/workshop each year. Furthermore, any NER.COFE conference/workshop is considered a committee meeting open to all NER.COFE members and invited non-members. Invited non-members, while they have neither the right to vote nor to hold office, can participate fully in all other deliberations.

The financial integrity of NER.COFE is supported by the following accounting for the 9-month period ending July 31, 1985:

NER.COFE Financial Statement
(11/15/84 - 7/31/85)

Receipts:	
Workshop Registration Fees	$6913.00
COFE Memberships Collected	170.00
Interest on Bank Account	132.24
Workshop Manuals and Proceedings	413.00
Total Receipts (7/31/85)	$7628.24
Expenses:	
Workshop Banquet, Luncheon, Coffee	$2231.00
Printing Costs	1785.60
Supplies and Materials	750.00
Postage	279.49
Speaker Fees	200.00
COFE Memberships Transmitted	160.00
Total Expenses (7/31/85)	$5406.09
Balance-on-hand (7/31/85)	$2222.15

The printing expenditure included the cost of printing the 1985 COFE membership directory - a courtesy extended by the membership of NER.COFE to the entire membership of the parent COFE. NER.COFE logo appears below.

We in NER.COFE believe that our successes can be easily replicated in other areas with the formation of new regional COFEs. You need only to state your existence, stake out your territory, let parent COFE bless you, and begin those activities needed in the new region. You might be called SWR.COFE (Southwest Regional), CSR.COFE (Central States Regional), WCR.COFE (Western Canada Regional), APR.COFE (Atlantic Provinces Regional), or whatever. You are welcome to pattern yourself after NER.COFE or go at it in your own way, by your own means...best wishes and good fortune to you. By the way, in the unlikelihood that NER.COFE ever goes defunct, its cash balance-on-hand will be directed to COFE's treasury.

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