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PREFACE

The Council on Forest Engineering (COFE) was formed in 1978 and is headquartered in Corvallis, Oregon. The basic objectives of COFE are to foster the development of forest engineering in industry, government, and in university teaching, research and extension programs in order to promote the best methods of management and operations in public and private forests; to service the Council and its members in such matters; to serve the forestry profession on matters of policy in the area of forest engineering; and to disseminate timely technical information on topics relative to forest engineering and forest operations. COFE membership is open to anyone with an interest in forest engineering. Members receive a quarterly newsletter and a membership directory.

Each year the activities of COFE are highlighted through an annual meeting which focuses on a timely theme. The theme for the 14th Annual Meeting of COFE was "Forestry Operations in the 1990's; Challenges and Solutions." Engineers and scientists from across Canada, the United States, Europe, and the Far East gathered in Nanaimo, British Columbia to discuss the challenges that will be faced in the next decade and to exchange ideas regarding possible solutions through advancements in forest engineering.

Special thanks go out to the following individuals: The secretaries of the Department of Harvesting and Wood Science at UBC; Laurie Dahlgren at MacMillian Bloedel Research; Kathi Hagan and Chris van Beusekom at FERIC - Western Division for their time and effort in planning the 1991 COFE Meeting. We would also like to thank our sponsors and hosts; Finning, Inc., Caterpillar Tractor Company, S. Madill, Inc., Fletcher Challenge Canada, and MacMillan Bloedel Limited. Recognition must also be given to the authors of the papers in these proceedings and to the organizations that have supported their efforts at the 1991 COFE Meeting. Finally, we'd like to recognize the support of the attendees, speakers, and other participants in making the 14th Annual COFE Meeting a success.

The papers in this Proceedings were presented at the COFE 1991 Meeting and printed directly from author-prepared copy without UBC Technical Review. The authors assume full responsibility for the contents of their papers. The proceedings are available for $25 from the Forest Engineering Research Institute of Canada, 2601 East Mall, Vancouver, B.C. V6T 1W5.

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SESSION I:

PLANNING CONSIDERATIONS FOR THE NEXT FOREST

MODELLING GROUP SELECTION AND CLEARCUTTING METHODS TO FORECAST HARVEST SCHEDULES AND ROAD NETWORK DEVELOPMENT

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ABSTRACT

Spatially constrained clearcutting is compared with group selection cuttings on a coastal watershed. Harvest levels, age class distributions, and road network development and maintenance are forecasted with computer models. Selection cuttings were able to capture incremental stand growth during the conversion to uneven-aged stands that was unavailable to the spatially constrained clearcutting method. Selection cuttings require that the road network be constructed early, and the length of active roads during any decade is higher than in the clearcutting case. Increasing the length of the cutting cycle reduces the high level of activity on the road network. Long-term research into uneven-aged management of coastal species is critically needed in order to quantify stand revenues and harvesting costs.

Keywords:
Uneven-aged management, western hemlock, coastal forests.

INTRODUCTION

Public concern for the protection of non-timber values in the forests of British Columbia is escalating. A considerable proportion of our society now supports heavily regulating clearcutting, and where possible, eliminating it altogether. While clearcutting is the most widely used silvicultural system in coastal British Columbia, the public is now demanding that partial cutting methods be used where possible to protect non-timber values. Many advantages are associated with a partial cutting system; minimal impact on visual aesthetics, reduced impact on animal habitat, increased soil stability in sensitive areas, avoidance of monocultures, and natural regeneration by some tree species (Smith, 1986). Partial cutting also avoids the problem of "green up" or exclusion periods required before adjacent blocks can be harvested after clearcutting. As clearcutting becomes increasingly constrained with smaller opening sizes and longer exclusion periods, selection methods may become viable alternatives.

There are, however, concerns about the use of selection cutting systems in coastal forests. While selection systems have been successfully used elsewhere in North America (Alexander and Edminster, 1977; Reynolds et al, 1984; Haight, 1987), there are very few examples of its use in western species. Regeneration of shade intolerant species is hampered by partial cutting, and residual trees may be more susceptible to wind damage. Experimentation with partial cutting in old-growth stands of the Douglas-fir region proved to be a dismal failure for these reasons (Munger, 1940; Munger, 1950; Isaac, 1956). Damage to residual trees during partial cutting can increase the incidence of disease, and the extra care in protecting residual stems will also increase harvesting costs (Alexander and Edminster, 1977). The major barrier to implementing a selection system is the initial high cost associated with developing a permanent road network. Given the high cost of road construction in the mountainous terrain of coastal B.C., and the desire to regenerate Douglas-fir, it is not surprising that uneven-aged stand management has not been practiced here.

However, as we enter the second timber rotation on the coast, there are areas with western hemlock stands that are candidates for selection methods. This shade tolerant, climax species has typically been managed with clearcutting, but the selection cutting system is also a viable regeneration method (Klinka and Carter, 1991). Candidate stands for uneven-aged management are located on gentle terrain (so they can be harvested with ground based equipment), and where at least part of the road network is already in place from the first rotation.

This paper uses a modelling approach to forecast harvest schedules and road network development for a forest managed under two silvicultural systems; clearcutting and group selection. It does not deal with the complexities of single-tree selection yields, forest level optimization of cutting compartments (Hann and Bare, 1979), and specific delivered wood costs. It does focus on harvest levels and the extent of the transportation system needed to support each alternative. Specifically, the objective is to quantify how harvest levels, forest inventories, and road construction and maintenance schedules are affected by each system. The assumptions and methodology used to model forest development under each system are presented, followed by a summary of the results obtained from a sample problem. Finally, extensions of this work that are needed prior to implementing uneven-aged management systems on coastal forests are identified and discussed.

METHODOLOGY

The Sample Problem

A spatial data set from a previous study that examined cut block sizes and exclusion periods (Nelson and Finn, 1991) was used in this study. A 3880-ha. coastal watershed was partitioned into 20-ha blocks, and the road network needed to access these units was proposed (see figure 1). The total length of the roads, excluding skid trails, was 114 kilometres, giving a road density of approximately 30 metres/ha. It was assumed that the watershed was forested with 120-year old western hemlock, and further, that the protection of non-timber resources requires either constrained clearcutting or partial cutting methods. Figure 2 shows the merchantable volume over age curve used in the analysis. To determine the long-term, "regulated state" of the forest under each silvicultural system, a planning horizon of 250-years was used. Under the selection cutting method, the initial, even-aged stands are converted to uneven-aged stands.

THE CLEARCUTTING METHOD

The maximum opening size was set at approximately 20-ha (average block size), and the exclusion period for adjacent units was set at 30-years. It was assumed that the forest would be managed on a 120-year rotation. This clearcutting policy was used because it is representative of the constraints proposed for forests with high non-timber values, which makes it a reasonable baseline for comparison with the group selection system. The objective of the clearcutting model was to maximize the total volume harvested over the planning horizon. In order to make a reasonable comparison with the selection cutting methods, area control was used to place an upper bound on the clearcut harvest. The maximum area that could be harvested in any decade was taken as the minimum of two values; 1) the total forested area divided by the rotation age (3880 ha/12 decades = 323 ha/decade), and 2) the maximum area that would not violate adjacency constraints. Therefore, the maximum area that could be cut is 323 ha/decade unless adjacency constraints become binding below this level. A lower bound of 220,000 cubic metres per decade was placed on the harvest to prevent very low volumes flows from occurring during the planning horizon. In the model, the most accessible blocks are cut first to prevent early harvests at the extremities of the road network.

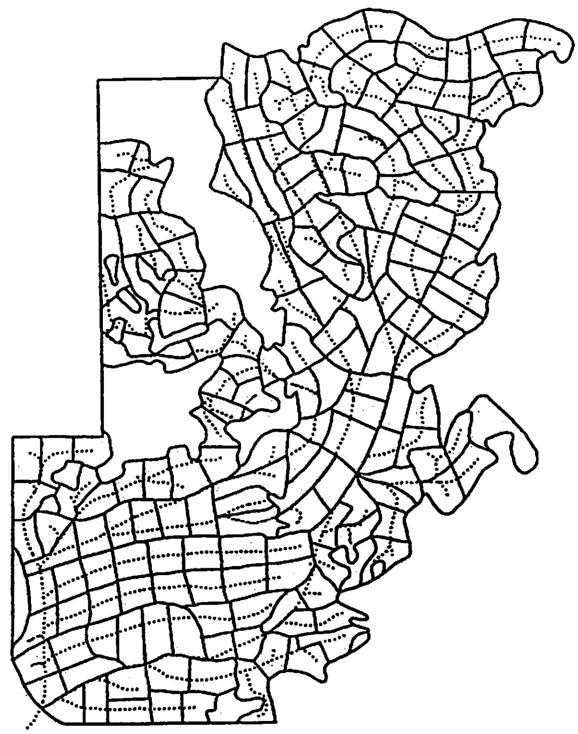

Figure 1. Map showing the 20-hectare block formation and road network.

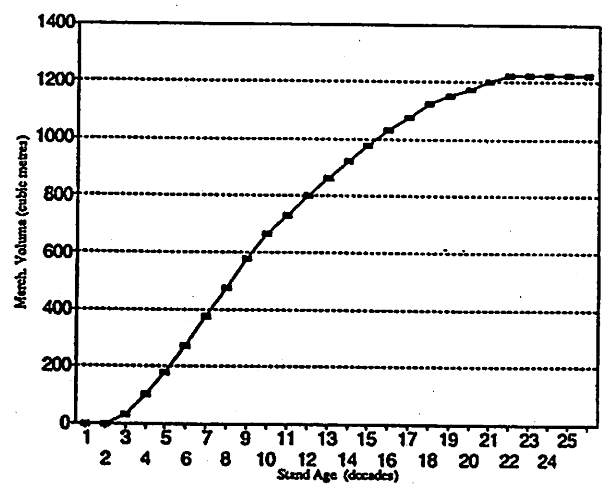

Figure 2. Volume-age curve used in the study (western hemlock).

The Group Selection Method

Due to the lack of information on uneven-aged management of western hemlock, it was impossible to design a single tree selection method for this species. Farr and Harris (1971) reported that after 17-years the height growth of natural regeneration was lower in partial cuts than in adjacent clearcuts, however, there are no long-term results to indicate the growth response in larger, older trees. In the absence of long-term data on residual growing stocks, in-growth, mortality, and diameter distributions, we chose a group selection method since this technique basically mimics clearcutting with very small openings. For the purpose of this analysis, it was assumed that the yield curve used in the clearcutting case (figure 2) will be identical for the group selection method. However, factors such as shading, residual stand damage, and productivity losses due to permanent skid trails will undoubtably challenge this assumption. Deviations from the equal yield assumption will be discussed in subsequent sections of this paper.

Under the group selection method, each hectare within the watershed is treated as a separate cutting unit, on which an uneven-aged stand must be maintained. Like the clearcutting case, it is assumed that the stand (eg 1-ha.) is managed on a 120-year rotation, and the age (or diameter) class distribution depends on the cutting cycle. In order to examine a range of options, three cutting cycles or entry periods (10-, 20-, and 30-years) are modelled. If a planning period of 1-decade is used, then under a rotation of 120 years, these cutting cycles require that 1/12-ha., 2/12-ha., and 3/12-ha. respectively, be harvested every time the stand is entered. Figure 3 illustrates how the forest is partitioned into 1-ha. cutting units, and how the choice of the cutting cycle affects the diameter (age) class distribution. In figure 3, note that there are multiple patterns in which the 1/12 -ha. sub-units can be harvested, and that those shown represent only one choice. Every small opening made in the group selection method is guaranteed a minimum exclusion period that equals the cutting cycle.

The road network (excluding skid trails) that provides access to landings within each 20-ha block (comprised of 20, 1-ha. cutting units) remains the same as in the clearcutting case. Under both silvicultural systems, the maximum skidding distance was set at approximately 200 metres. Ideally, local road and skidding costs should be used to determine the optimal road spacing for each system. In the clearcutting case, the skid trails are temporary, whereas in the selection case, these would become permanent access routes throughout the stand. Permanent skid trails would be spaced approximately 50 metres apart, resulting in a density of 200 metres/ha. If these trails are approximately 3.5 metres wide, then 7 % of the productive forested area will be lost to permanent skid trails.

The objective of the selection model was to harvest an equal area of the watershed every decade until the even-aged stands were converted into uneven-aged stands. As in the clearcutting model, the most accessible stands are harvested first to limit road construction in the early decades.

RESULTS AND DISCUSSION

Harvest Levels and Age Class Distributions

Areas and timber volumes harvested per decade for each cutting method are shown in figures 4 and 5, respectively. Under selection cuttings, the area harvested per decade remains constant (approximately 323 ha.), while in the clearcutting example there is considerable variation. Except in the first two decades, the area harvested by clearcutting is bound by adjacency constraints rather than the total area divided by the rotation age (323 ha). The area harvested is at its lowest point near the end of the first rotation, and subsequently fluctuates around 260 ha per decade. This general decline and subsequent increase is due to the growth of the forest. During the first rotation the volume per ha. increases, which under the minimum volume constraint (220,000 cubic metres) results in a downward trend in the area harvested. A considerable amount of variation in the area and volume harvested in the clearcutting example is due to the fact that cut blocks are 20-ha in size, and that they are either harvested in their entirety or not at all.

Selection volumes in figure 5 follow the same path because equal areas of the forest are being harvested every decade, and the same yield curve is being used in all examples. Volume flows for selection cuttings steadily increase during the first rotation (e.g. the conversion period) because of forest growth, at which point they stabilize at approximately 260,000 cubic metres. Clearcutting is unable to capture all of this additional volume during the conversion period because of adjacency constraints, and during the later part of the planning horizon the volume harvested per decade fluctuates around 250,000 cubic metres. This difference is also apparent in the age class distributions illustrated in figure 6. In the clearcutting example, adjacency constraints prevent the harvest of some blocks, which results in a higher percentage of the forest growing into the older age classes (120+ years). In the selection cuttings, the 120+ age class is liquidated at the end of the first rotation, resulting in a uniform age class distribution.

Clearcutting adjacency rules heavily constrain the area harvested per period, and under group selection cuttings, the area harvested per period is constant. Knowing that the area cut per period is essentially a binding constraint, and that it results in a particular age class distribution means that the opportunity to test yield sensitivity is readily available without re-working the entire problem. If it is felt that group selection yields are significantly different from the clearcutting yields, one could quickly assess the impacts on harvest levels through a sensitivity analysis. Assessing yields for a single tree selection system is considerably more complex, and research is needed to determine stocking levels, stand dynamics, and cutting cycles.

Road Network

Road construction schedules for each cutting method are

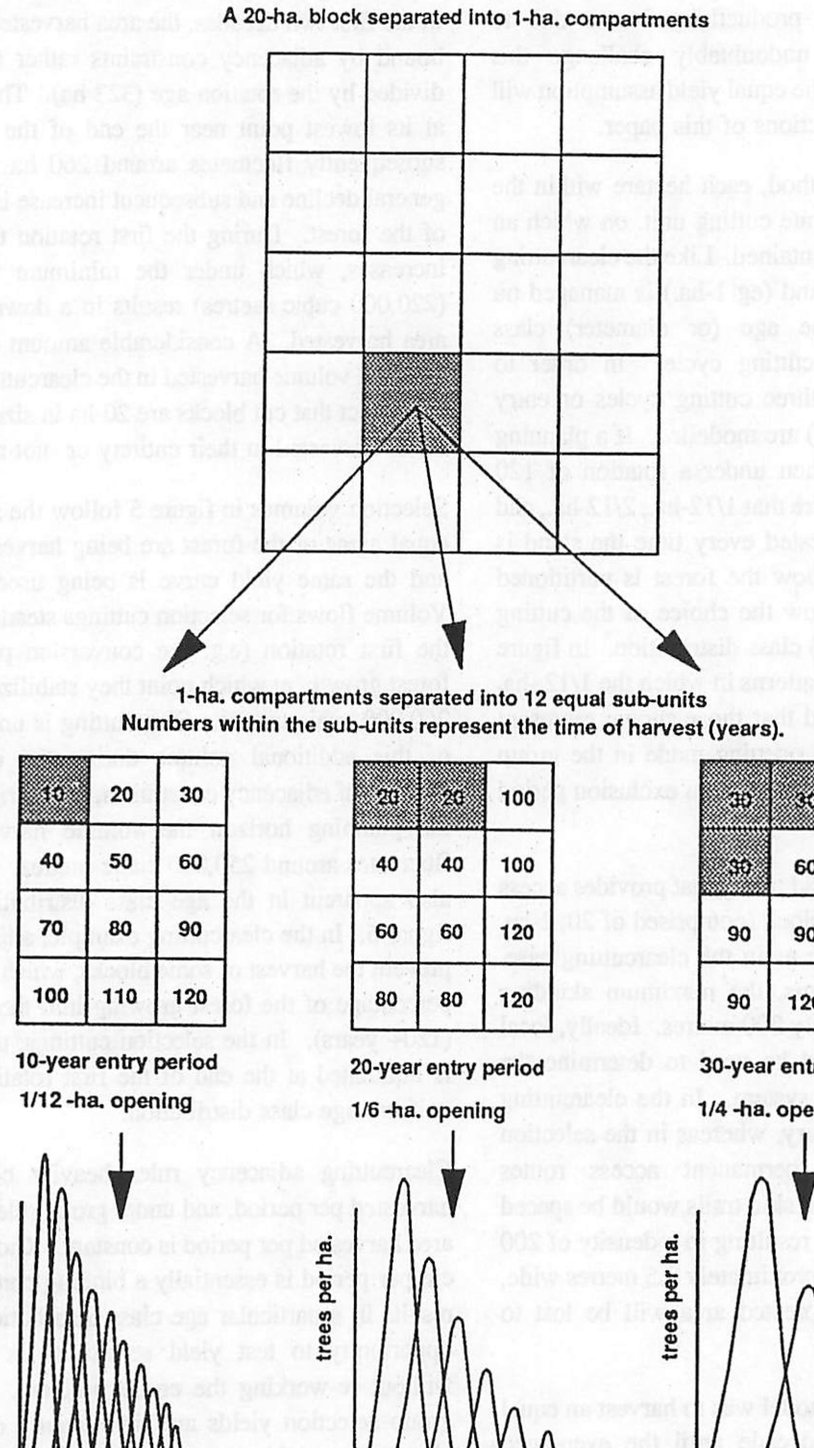

Figure 3. Illustration of how the forest is partitioned into 1-ha. cutting units and managed under group selection systems. Each 1-ha. unit is managed on a 120-year "rotation."

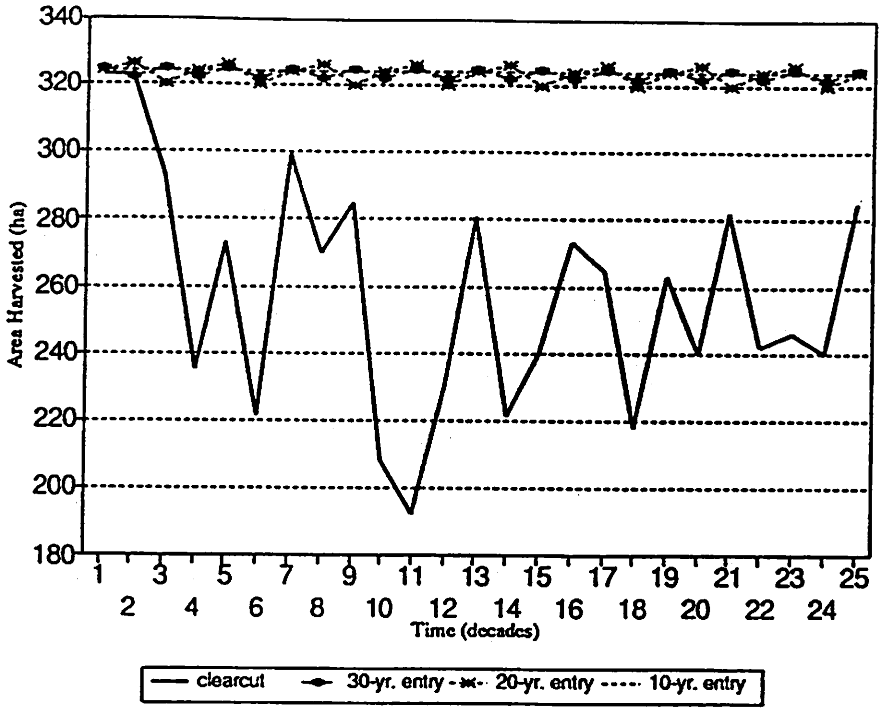

Figure 4. Area harvested per decade for each cutting method.

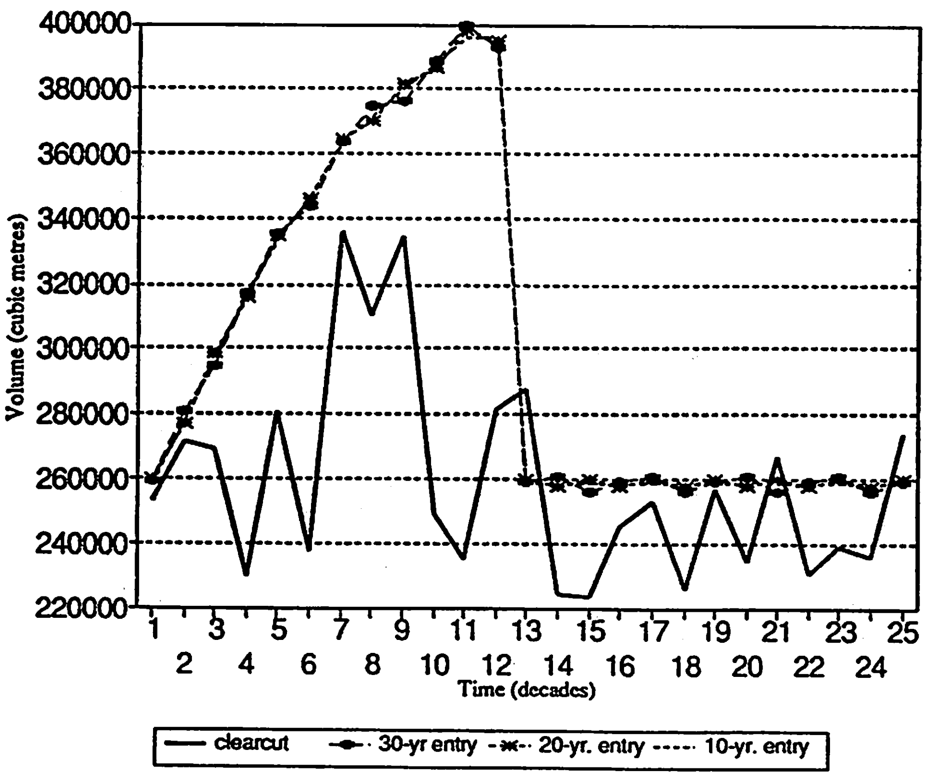

Figure 5. Timber volumes harvested per decade for each cutting method.

Figure 6. Age class distribution over time for the two silvicultural systems.

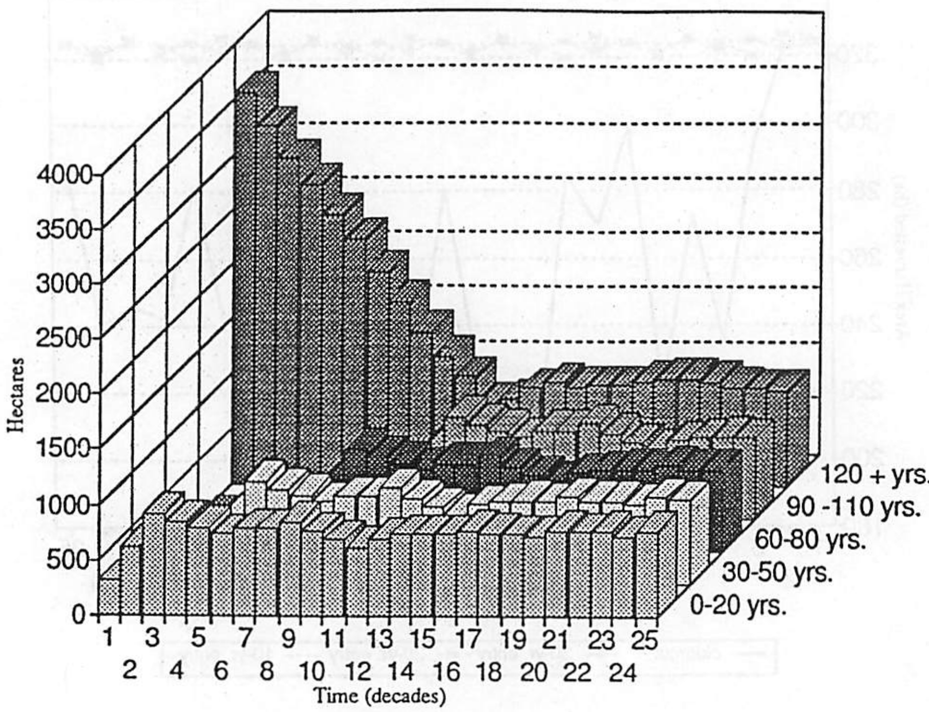

Figure 6.a. Age class distribution for the clearcutting example.

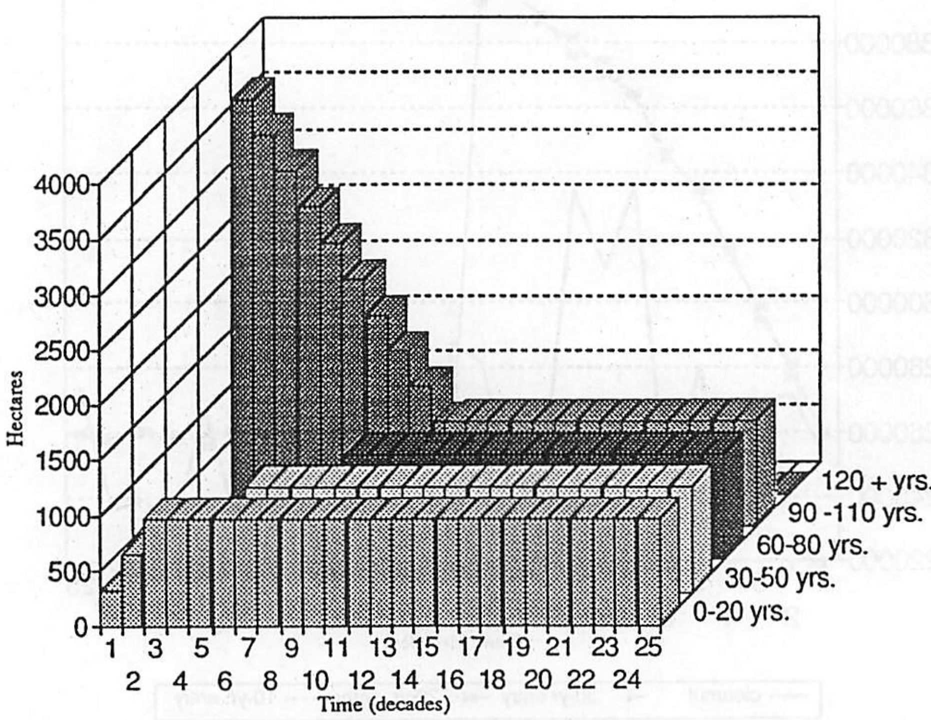

Figure 6.b. Age class distributions for the group selection cutting example.

shown in figure 7. With a 10-year entry period, the whole drainage must be accessed in the first decade, which means that the entire road network (114 km) must be constructed in decade 1. With 20- and 30-year entry periods, approximately one-half and one-third of the road network is constructed in the first decade, respectively. Slight variation from these target values is apparent in figure 7 because of the specific location of roads within the watershed. Accessing 1/2 of the watershed does not necessarily mean that only 1/2 of the road network must be constructed due to site specific factors such as terrain, timber boundaries, and road locations.

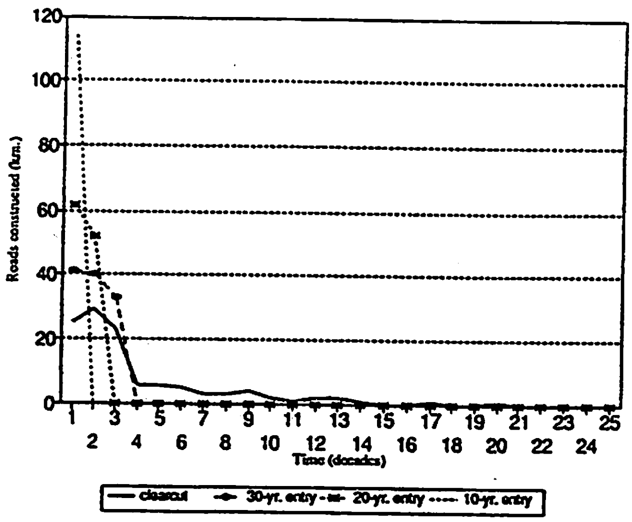

Figure 7. Road construction schedules for each cutting method.

Clearly, as the entry period decreases, there is a rapid increase in the amount of immediate road construction. Attempting to write-off high construction costs against current harvests could quickly result in deficits. If the road network was already in place, and required only re-construction to rehabilitate the roads, then from an economic perspective, shorter cutting cycles would become more attractive. Note that the clearcutting method and the 30-year selection cutting method have very similar road construction patterns. In the clearcutting case, small portions of the network are constructed in the latter decades, whereas in the 30-year selection cut, the entire network is constructed during the first three decades.

Figure 8 plots the amount of road that is active in each decade for each cutting method. A road is defined as being active if it is used, regardless of the volume hauled over its length. The amount of active road gives an indication of the level of routine maintenance that must be conducted (drainage structures, brushing, etc.). Variable maintenance that depends on the level of use (e.g. grading, surfacing) can be approximated by calculating the sum of the volume

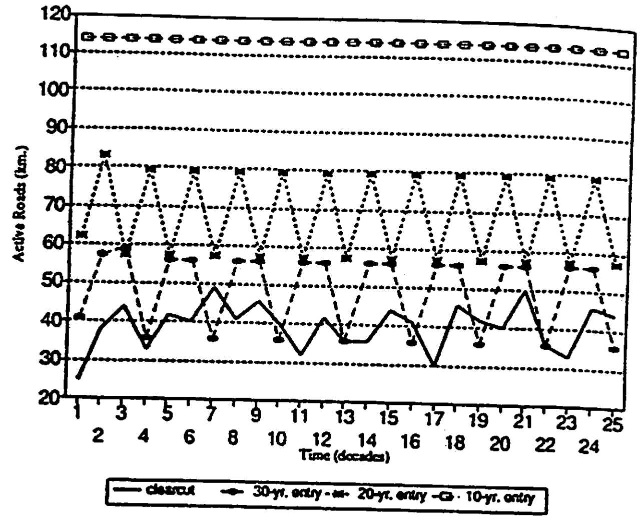

Figure 8. Kilometres of "active" road during each decade for the different cutting methods.

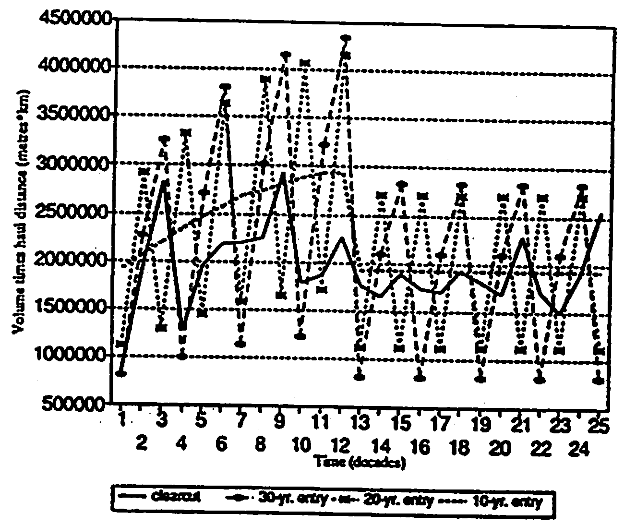

Figure 9. Graphs of the volume hauled multiplied by the haul distance (m^3 X km) for the different cutting methods.

hauled multiplied by the distance hauled (cubic metres X haul distance). Figure 9 plots these values for the different silvicultural systems.

Figure 8 clearly shows that the amount of active road increases as the entry period decreases. Further, it is apparent that the level of active road follows a pattern determined by the cutting cycle. This pattern corresponds to the harvest rule that specified that the most accessible blocks are cut first. For example, in the 20-year entry period, the most accessible half of the forest is cut in decade 1, and the least accessible half is harvested in the following period. Over time, this pattern could be altered to equalize the active roads during each decade, however, there are advantages to concentrating felling, skidding, and stand tending operations within the forest. The clearcutting example requires less active roads than the selection methods, and the decade-to-decade variation tends to be lower.

During the first 12 decades, there is considerable variation in the volume-times- haul-distance values shown in figure 9. In the subsequent decades, these values cycle according to the entry period. All systems appear quite similar in absolute terms, with the 10-year entry selection cut and the clearcutting method having less period-to-period variation.

Other road maintenance cost are associated with opening and closing roads, particularly the placement and removal of drainage structures. To determine the amount of road that was opened and closed each decade, the status of individual road links was tracked to determine when they were active and inactive. The opening and closing of roads, expressed as averages taken over all decades are found in table 1.

Under group selection methods, both the road construction and "active road" schedules derived here will not vary when different stand yields are used, because these schedules are determined by the area (ha) of forest that is harvested according to the cutting cycle. Local costs can be used to quantify the economics of these activities, and sensitivity analyses similar to those proposed for selection yields could be performed.

CONCLUSIONS

As the public's tolerance of current clearcutting practices dwindles, it is highly probable that some form of partial cutting will be required in suitable forest types where it is deemed essential to maintain a forest cover. As a first approximation of what the impacts of partial cutting will be on harvest levels and the transportation system, we have examined relatively simple group selection methods and compared them to a heavily constrained clearcutting method. Under the assumption of identical forest growth for each system, the selection methods were able to harvest more timber during the conversion period than in the clearcutting case. Selection cuttings require early establishment of the road network, and the kilometres of active road remain high over time.

Further research is needed to determine the stand dynamics of uneven-aged management in coastal species. Long-term yield analysis will broaden our understanding of stocking levels, cutting cycles, and the resulting merchantable log distributions. This information is critically needed in order to evaluate stand revenues and harvesting costs.

Whether the group selection method proposed here is more environmentally attractive than constrained clearcutting is debatable. Clearcutting has a large impact on a hectare of land, but these disturbances only occur once during the rotation. With group selections, large areas of the watershed are frequently disturbed, however, the level of disturbance on any hectare of land is less than in the clearcutting case. The resulting stand structure may or may not be suitable to all wildlife species. Animals such as deer that need a mix of forage and shelter types would benefit, but species that prefer old-growth timber (Spotted Owl) would not. The extensive and continual use of the road network could have detrimental effects on water quality due to erosion and sedimentation, particularly in coastal forests. Delivered wood costs will surely increase, resulting in reduced stumpage revenues to the provincial economy. Selecting a workable balance from these environmental and economical concerns is a major challenge for our society.

Table 1. The average kilometres of road that were opened and closed each decade for the different cutting methods.

Cutting Method	Roads Opened (km/decade)	Roads Closed (km/decade)
Selection: 10-year entry	0	0
Selection: 20-year entry	39.4	39.4
Selection: 30-year entry	32.6	33.0
Clearcutting	16.4	15.8

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RECOGNITION AND INVESTIGATION OF LANDSLIDE RISK DUE TO TIMBER HARVESTING ACTIVITIES IN OREGON

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ABSTRACT

Landslides are recognized as the dominant form of erosion on the steep, landslide prone forest lands of Oregon. Timber harvesting activities, especially road construction, can cause accelerated erosion due to increased landsliding rates. Preventing management induced landslides and/or minimizing the effects of timber harvesting on the stability of landslide-prone terrain, the high risk sites that are susceptible to management induced landslides must first be identified and then these sites can either be avoided or alternative practices can be used to mitigate landslide risk. Over the years, numerous methods have been developed to identify site specific high risk sites. The two predominant methods used in Oregon are either a checklist type of approach which results in a landslide hazard rating or LISA (Level I Stability Analysis) which is implemented using a slope stability computer program.

Slope stability investigations as a part of activities in forested environments have long been the domain of earth scientists, especially soil scientists and geologists. Landslide hazard rating checklists, such as the Siuslaw National Forest headwall check list, have resulted from correlative research at a regional scale, such as landslide inventories, and are used by just about anyone with some earth science training or background. LISA, either the two-or three-dimensional model (3DLISA), is implemented as a slope stability analysis using the infinite slope method as a computer model. However, given the way the program is used and the manner in which the input parameters are collected, the full potential of LISA has never been realized and consequently, its results are quite similar to a landslide hazard rating checklist. Likewise, in its contemporary form. LISA can be used by anyone with some earth science training or background.

This paper describes a third, alternative approach for identifying and evaluating the effect of management practices on sites with high landslide risk. The approach involves site-specific investigations using traditional engineering geology and geotechnical engineering techniques that have been adapted for use with the geology and soils of steep, landslide-prone forested environments. In this approach, high risk sites are investigated on an individual, site-specific basis at the mechanistic level. The approach involves, first of all, a geologic interpretation of the site which results in a geologic model of it. The geologic interpretation is developed using information from existing sources and a site reconnaissance which investigates on-site features such as land form, drainage pattern, road cuts, rock outcrops, seeps, springs, and streams. The geologic model of the site may then be further developed and either confirmed or modified by information form formal subsurface investigations using hand augers or core drills.

Finally, the effect of land management objectives is evaluated by means of a formal slope stability analysis and the results of the analysis are used to help formulate management recommendations. This approach currently is used widely in Oregon by the Geotechnical Specialists employed by the Oregon Department of Forestry.

Two case studies are presented to illustrate this alternative approach. In the first case study, a gently sloping midslope bench in the marine sediments of the central Oregon Coast Range was designated to be a disposal areas for waste generated by end-haul road construction. A site reconnaissance was carried out and a geologic model of the bench was developed. Slope stability analysis was carried out and a geologic model of the bench was developed. Slope stability analysis was carried out to determine the amount of material that could be wasted on the site. In the second case study, evidence of existing and potential future slope movement was identified within the boundary of a harvest unit in volcanic rock of the northern Oregon Coast Range. A geologic model of the existing feature was developed based on aerial photo interpretation and field reconnaissance of the site. Slope stability analysis was carried out using a cross-section from the geologic model and based on the analysis, alternative timber harvesting strategies were recommended. This investigation resulted in relocating the boundaries of the harvest unit to minimize the risk of harvest-related slope movement.

THIS PAPER WAS NOT AVAIABLE AT THE TIME OF PUBLICATION.

GRADEABILITY ON FOREST ROADS - FIELD OBSERVATIONS COMPARED TO AN ANALYTICAL MODEL

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ABSTRACT

A survey was conducted to identify logging truck performance on steep roads in the western National Forests. Survey results indicated that log trucks had successfully road grades of 16% to 25%. A regression line was developed to express road gradeability as a function of curve radius. The shape and range of gradeability values compared favorably with the results of an analytical model.

Keywords:
Gradeability, truck performance on steep grades, forest road design.

INTRODUCTION

During the last decade, many roads in western forests have been built on grades exceeding 12 percent to minimize environmental damage caused by sidehill roads. In 1989 a study was conducted to find out more about truck and trailer performance on steep roads. The reasons for doing a study were to develop a data base about what had worked and what had not worked in the design and operation of steep roads. Also, we wanted to compare field observations to results from an analytical model we had developed to predict the performance of stinger-steered log trucks on steep curves. This paper will summarize the results of that survey and compare the survey to the analytical model.

ABOUT THE SURVEY

The survey asked for basically one thing, specific cases of vehicle performance on steep curves. More than 80 questionnaires were sent out --one to every USDA Forest Service unit in the western United States. Thirty-five responses were received with 107 individual field observations.

The questionnaire asked for specific information: location of road, road name or number, length, surface type, truck type, centerline road grade, curve radius and curve superelevation. The questionnaire also asked if the log haul had been accomplished without assistance or vehicle damage (Figure 1).

DATA SHEET FOR STEEP ROADS INFORMATION

DATA POINT #____

ROAD LOCATION (#, TIMBER SALE, NATIONAL FOREST)

APPROX. LENGTH OF SEGMENT________

SURFACE TYPE (E.G. DENSE GRADED CRUSHED ROCK) ________

TRUCK TYPE (LONG LOG, SHORT LOG, ETC.)________

CENTERLINE GRADE (+,-)______ CENTERLINE CURVE RADIUS______

SUCCESS OR FAILURE______

REASON________

SUPERELEVATION (+,-) %______

SPECIAL CIRCUMSTANCES

Figure 1. Survey form.

Although the survey asked for specific case study data not how road managers perceived steep roads, people responded in two ways. First they told what had be done; second they told what they were willing to put up with on a long term basis. Both types of responses were valuable even though the original intent of the survey was only to find out "what had been done".

The data showed that log trucks are physically capable of climbing 16% to 25% grades unassisted. However, many managers said they would limit road grades to 6% to 15% citing soil erosion, safety, maintenance costs to repair the road surface.

We summarized the grade data, successes and failures, by curve radius, superelevation, and centerline grade (Figure 2). There are quite a few successes at grades of 18% and 19% at curve radii of less than 100 feet. Failures at lower gradients were usually caused by non-uniform road conditions. Although the road may have generally been in good shape, the gradeability is limited by the poorest surface conditions.

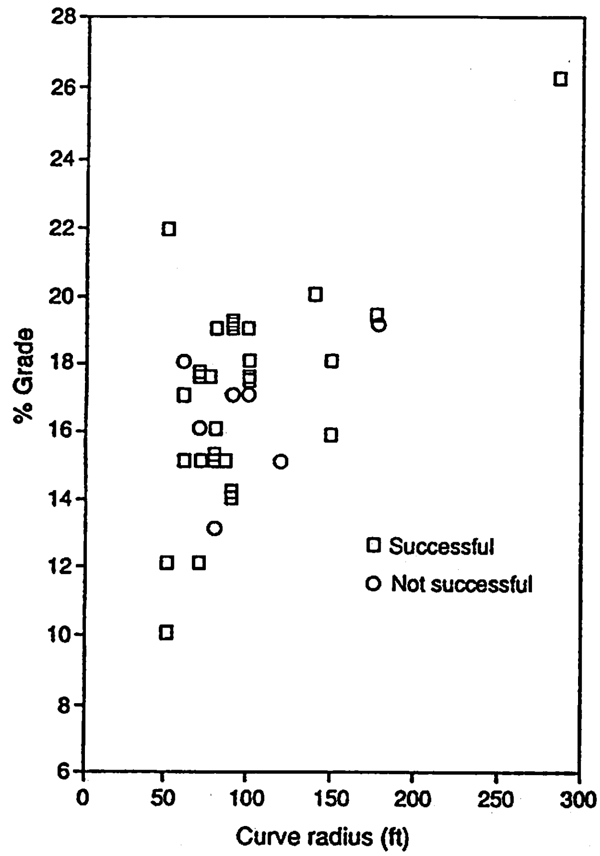

Figure 2. Survey responses for adverse haul native and gravel-surfaced roads with no superelevation.

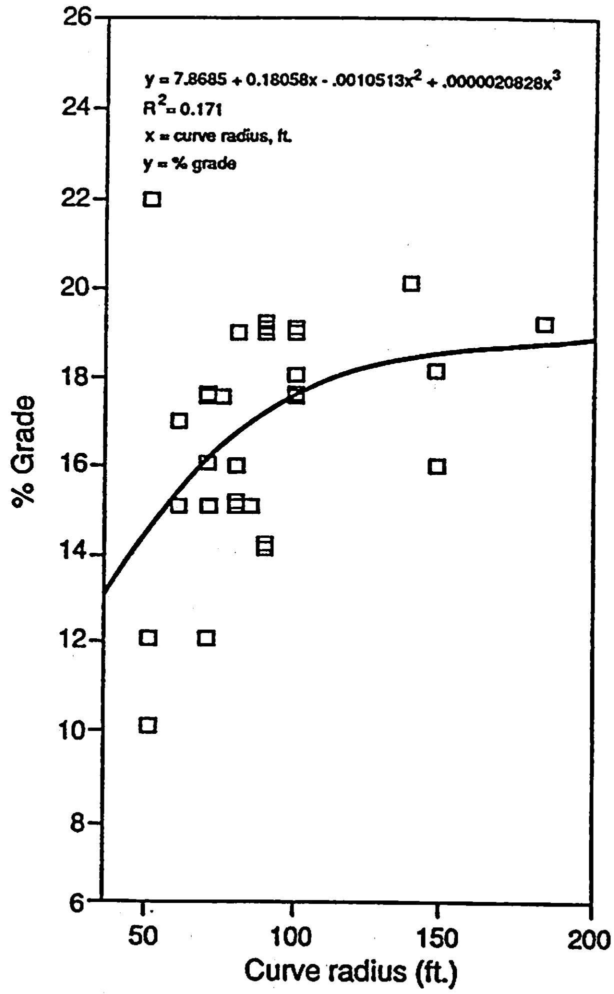

Figure 3. Regression equation developed using survey responses for successful operations on steep adverse native and gravel-surfaced roads with no superelevation.

A multiple regression equation was developed using the survey data for reported successes on native and gravel-surfaced roads with no superelevation. Centerline curve radius was used as the independent variable and gradeability as the dependent variable (Figure 3). The regression equation is a composite for all surface types. The maximum gradeability in a specific situation will depend upon surface type.

ANALYTICAL MODEL

The field observations were compared to an analytical model that was developed to predict the maximum gradeability of stinger-steered log trucks on steep adverse curves with and without superelevation. The analytical model balances the resisting forces acting on the log truck with the tractive forces that are available from the drive wheels. The resisting forces include rolling resistance, grade resistance, and tandem resistance. Tandem resistance is created when tandem axles are forced around a corner.

The tractive force available to the log truck depends upon the loading of the drive wheels and the coefficient of traction between the tires and road surface. Wheel loading is important due to the action of the differential which divides torque between the inside and outside wheels. When the differential is not locked out, all other things equal, the maximum tractive force that a log truck can put on the road surface is limited to twice the traction which can be developed on the most lightly loaded side. Wheel loading is dependent upon distribution of the log load, the relative positions of the truck tractor and trailer as they travel around a curve, superelevation and vehicle speed.

When a log truck travels around a curve the trailer does not follow the tractor (Figure 4). As the radius of the curve decreases, the angle between the tractor and the trailer increases. Grade resistance and rolling resistance of the trailer and load act along the axis of the trailer unloading the outside drive wheels. Positive superelevation adds to this unloading effect on the outside wheels. Centrifugal force created by vehicle speed around the curve acts in an offsetting way, loading the outside wheels. The maximum grade climbing conditions around a curve occur when the combination of superelevation, vehicle speed, and off-tracking produce a truck loading which produces equal force on the drive tires.

Survey results were compared to results using the analytical model for a stinger-steered log truck with specifications typical of operations of on-highway trucks in the western National Forests (Figure 5). There were only two failures below the predicted maximum gradeability line developed using a 0.45 coefficient of traction. Both of these were on native material. The regression equation compared favorably with the analytical model, both in shape and in the range of values between radii of 50 to 200 feet (Figure 5).

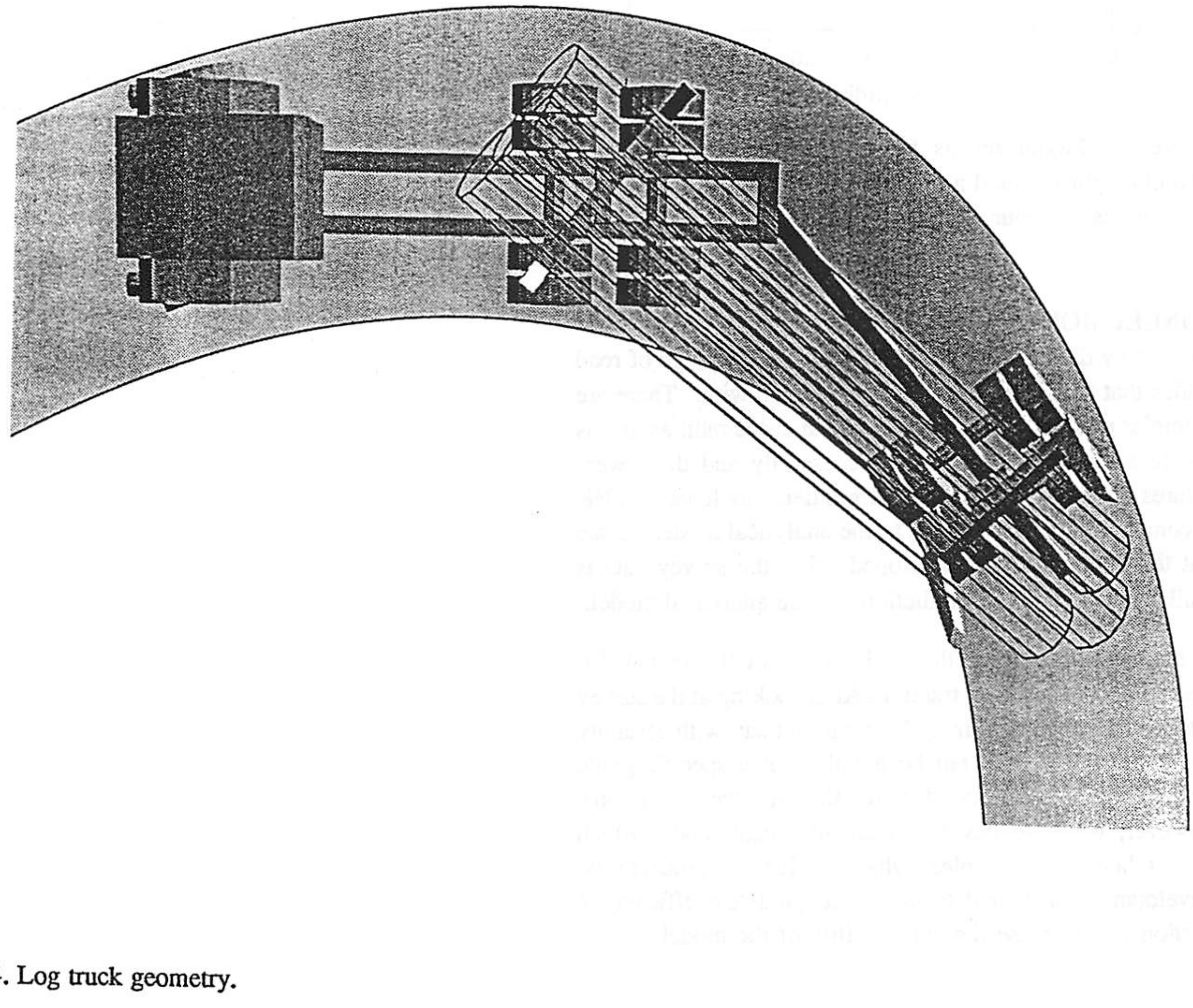

Figure 4. Log truck geometry.

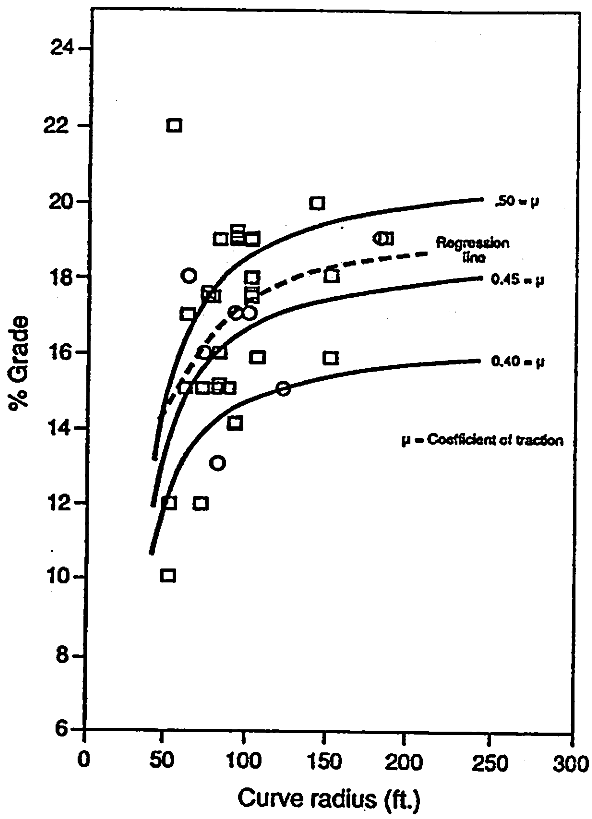

Figure 5. Model results for a stinger-steered log truck traveling uphill around a switchback with no superelevation at 3.5 miles per hour compared with survey data.

CONCLUSION

The survey data that we have shows the wide range of road grades that managers have had experience with. There are examples of 18% and 19% grades with curve radii as low as 100 feet that were negotiated successfully and there were failures occurring on roads with gradients as lows as 13%. In comparing the survey data to the analytical model we see that the regression line developed using the survey data is similar in shape to the predictions of the analytical model.

A major difficulty is the lack of a field method for predicting coefficient of traction. After looking at the survey data and the analytical model we can not say with certainty that there will or will not be a failure at a specific grade because of uncertainty due to the surface conditions. However, we have developed an analytical model which does relate the variables which influence gradeability. Development of a field technique to predict coefficient of traction will increase the applicability of the model.

TACTICAL FOREST PLANNING USING SNAP-II

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ABSTRACT

SNAP II is a spatial forest planning model developed to address complex forest planning requirements on public lands as well as those requirements rapidly approaching on private lands in the Pacific Northwest. These concerns include size of openings, habitat connections, and various cover-to-forage ratios for wildlife. SNAP attempts to determine the best harvest schedule in combination with the best choice of harvest systems, road locations, haul routes and mill destinations over a planning horizon of up to four time periods. Stands can be grown using even or uneven-aged management. Current capacity of the program on 386 microcomputers is 1000 parcels and 3000 road segments.

Keywords:
Harvest planning, tactical planning, spatial analysis.

INTRODUCTION

Over one-half of the sawtimber in the western United States is on public lands, predominantly lands administered by the USDA Forest Service. Strategic plans defining timber outputs over many decades have been prepared. These strategic plans have some spatial resolution, but due to their broad scope leave many of the spatial details to be resolved during implementation of the plan. The objective of this paper is to describe a current software development project funded by the USDA Forest Service to assist land managers in implementing strategic plans. The Scheduling and Network Analysis Program is referred to as SNAP II.

PROBLEM DESCRIPTION

Often, as part of a larger overall forest management plan, land managers must determine the sequence of units to be harvested and the transportation plan which will be needed to harvest subareas of the forest. The harvest plans for the subareas are usually short term, 10 to 30 years, and are referred to as tactical plans. A specific requirement of these plans is that they contain sufficient spatial detail to define where the units are located with respect to one another and with respect to the transportation system. This is because:

- multiple use considerations on many public lands often result in the requirement that harvest units cannot be adjacent to one another during the same harvest period and,
- accurate transportation costing requires explicit spatial definition of the transportation plan.

Two other important considerations for forest managers are that the planning procedures must
- be simple enough to be used by forest and district personnel on a production basis, and
- solution time is rapid enough to permit plan modification, alternative evaluation and frequent updating.

The size of the tactical problem varies, but it is not unreasonable to consider forest areas as large as 20,000 acres consisting of 500 to 1000 units of 10 to 60 acres to be scheduled over one to four time periods. The units are linked to a transportation system of 1000 to 3000 road segments. Often more than one way exists to harvest each unit so that harvest system selection and road location must be considered simultaneously.

SOLUTION METHOD

Exact solution procedures for the tactical plan can be time consuming and costly, requiring a special type of mathematical programming procedure known as mixed integer linear programming. The term integer refers to the requirement that (1) if a unit is eligible for harvest, you must take all of it or none of it and (2) if a road is to be built, you must either build it or not build it. A 1000 unit, 3000 road segment plan over 4 time periods may require more than 10,000 integer variables to represent the problem. Covington et al. (1988) report time to an exact solution for a 300 integer forest planning problem to be 8 hours on a mini-computer. On the other hand feasible solutions for this size integer problem can be obtained in seconds.

The approach used in this paper is to rapidly develop many feasible solutions and to select the best among those feasible solutions. The computer does this in five steps by:
(1) evaluating the optimal harvest plan in the absence of multiple use constraints as a way of evaluating each parcel's intrinsic potential for timber production considering mill values, existing inventory, candidate harvesting systems and road development opportunities.
(2) stochastically generating many feasible patterns of harvest considering multiple use objectives as well as the information learned in (1). Patterns are generated period by period with growth and seral stages of each parcel being updated each period.
(3) evaluating the harvest and road system network using methodology from Sessions (1987) for each pattern which meets the spatial constraints,
(4) calculating the costs for each feasible alternative, and

(5) preparing graphical and tabular reports of the analysis for each feasible solution.

RESOURCE DATA

Good data and the ability to modify data easily is paramount. SNAP requires resource data of two types, (a) resource data within a parcel and (b) resource relationships between parcels.

Resource data within parcels includes:
-Species composition
-Existing seral stage
-Species volume and defect
-Candidate silvicultural treatment
-Other parcel attributes
-(X,Y) coordinates (Z optional)

SNAP permits a maximum of three timber species for the planning area and each parcel may contain one or more species. Species are user-defined and can represent individual species, species groups, or special products. For example, in eastern Oregon, species may be divided between ponderosa pine, lodgepole pine and mixed conifers. In other situations, the species may represent products such as sawtimber, pulp, and energy wood. As many as 100 timber destinations can be considered with individual price trends per species. Although only three species are permitted within SNAP, quality differences within species (or products) can be recognized by assigning quality premiums by species from specific parcels. In this way diameter, piece size, or surface quality can be recognized.

Most resource controls in SNAP are by the seral stage of the parcel. Each parcel must have a beginning seral stage. Depending upon how the parcel is treated over time, stands are grown, change seral stage and move through successional stages. Habitat controls such as desired cover-forage ratios and habitat connections are implemented through finding feasible combinations of seral stages across the landscape.

In addition to timber and seral stage data, you are permitted to define up to 15 parcel attributes for each parcel. These attributes can identify such characteristics as elk winter range, erosive soils, aspect, slope or elevation. Within limits, SNAP solutions can be guided by user-specified maximum acreages by seral stage or attribute.

Parcel coordinates (X,Y) are important since SNAP automatically generates harvest patterns which satisfy non-adjacency requirements. SNAP also uses the coordinate geometry to determine the spatial relationships of the parcels and their connection to transportation system (Figure 1). The coordinate geometry input is of two types, "points" data and "stick" data. Depending upon the digitizing method that was used to collect unit coordinates, a harvest unit may be composed of hundreds of vertices. To facilitate scheduling, SNAP requires that a harvest unit be described by a maximum of 25 sides for determining adjacency. The "points" data are the actual digitized points. The "stick" data are the thinned set of points to reduce harvest units to a set of 25 sides maximum. During file building and display of results, the planning area can be shown in either "points" or "stick" format. The choice of display format is often decided by the speed of your computer.

Z-coordinates are optional in SNAP. If Z-coordinates are available for the perimeter of the parcels, the harvest patterns identified by SNAP can be later viewed in three dimensional perspective from a user-selected location outside of the planning area. Although the perspective view only includes data from the perimeter of the unit, it gives an idea of the "seen" area from a viewing point.

SNAP II is designed to tap GIS for most of the data input including resource and coordinate data. Currently SNAP users use the Forest Service software LT-Plus as the bridge between GIS and SNAP although output from any GIS output file meeting SNAP input format could be used.

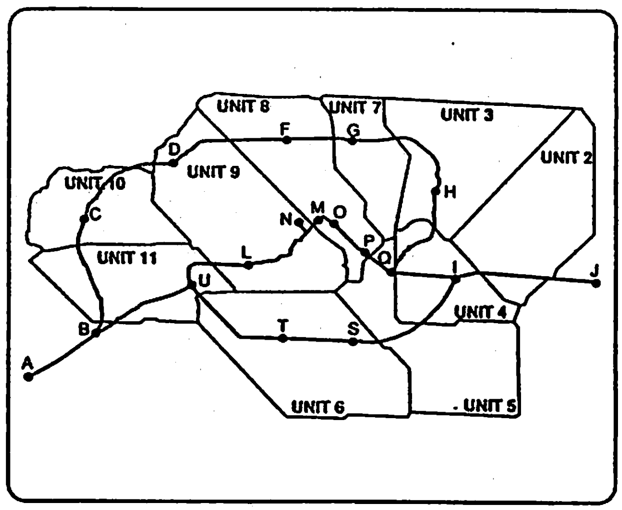

Figure 1. A planning area showing parcels, existing and proposed roads.

Resource relationships across parcels includes:
- non-adjacency requirements
- size of openings
- critical parcels for habitat connections and seral stage requirements.

Non-Adjacency

Non-adjacency requirements can be either (1) that no harvested parcel can share a common vertex (point) with another harvested parcel during the same period, or (2) that no harvested parcel can share a common side with another harvested parcel during the same harvest period. If non-adjacency is by sides, you can specify the minimum side that is to be considered a true side for scheduling.

Size of Opening

Depending upon the size of parcel, non-adjacency rules may be more appropriately applied to groups of parcels. Within SNAP, you can specify a maximum size of opening. SNAP will group parcels during analysis while maintaining non-adjacency between groups of harvested parcels if it is efficient to do so. You are also permitted to define the maximum existing timber volume which can be removed from a parcel during a selective cut before it is considered an opening.

Habitat Connections

Sometimes the ability to maintain habitat connections across the landscape may be useful to prevent isolation, provide migration routes, or limit maximum distances to cover. SNAP permits identification of a maximum of five groups of critical parcels and the definition of the seral stage eligibility requirements for the habitat connection. During analysis, SNAP will identify the most efficient set of parcels to satisfy the habitat connections according to your criteria. You can also specify the minimum length side that a parcel in a habitat connection must share with another parcel in the habitat connection. This capability may be useful in guiding SNAP to solutions which provide a sufficient width of hiding cover.

TRANSPORTATION DATA

Transportation data for SNAP consists of information about existing and proposed roads. Information for roads are entered by road segment and includes the following:

- Node names
- Road status (available, requires reconstruction, does not exist)
- (X,Y) coordinates (Z optional)
- Other segment attributes

Road segment attributes include information on alignment, road maintenance, topography, grade, and miscellaneous optional management classifications. SNAP will use this information to estimate transport, maintenance, and construction costs for each road segment. SNAP will create two-way road segments and estimate roundtrip log truck travel time by one of several methods. The default method is from a travel time matrix using road grade and alignment as the independent variables. Construction cost for each segment can be calculated from either simple cost coefficients per mile or from an estimate of construction quantities based upon segment attributes.

ANALYSIS

SNAP is harvest-volume driven. SNAP, using a heuristic procedure, tries to find feasible spatial solutions to the planning problem in such a way as to reach your timber harvest goals as closely as possible in such a way as to maximize present net worth. This is done by attempting to find the best harvest schedule, combination of timber destinations, road locations, harvest systems, and transport routes. However, other multiple use objectives have priority in the sense that for any solution to be feasible, it must meet non-adjacency, habitat connection, and other requirements such as cover-forage ratios. As part of this heuristic procedure, SNAP initially will identify the best overall long-term strategy for harvesting the entire area including choice of harvesting systems and pattern of road development assuming no multiple use constraints. This information is used later to guide SNAP to an efficient solution while meeting multiple use constraints. Often, there are many feasible solutions for the planning problem. SNAP will attempt to identify as many feasible solutions as you request.

REPORTS

Unlike broad strategic plans which define management direction, tactical plans must contain more detailed information. SNAP provides information on the distribution of parcels each period by seral stage and silvicultural treatment and identifies harvest systems and roads used and habitat connections. The mill destination, transport route, harvest system, stump-to-mill cost, and volume transported is provided for each species from each parcel harvested.

Visual displays of solution results are essential to both verify input and communicate results easily to managers. A number of graphic reports are available including displays of seral stages by period (Figure 2), harvest units and roads by period (Figure 3), silvicultural treatments (Figure 4), and habitat connections (Figure 5). A visual display of the planning area in terms of the relative value of each parcel for timber production is also available to help planners evaluate tradeoffs (Figure 6). Transport routes and destinations can be visually checked by highlighting specific parcels on the display which activates the display of the haul route(s) to the destination(s) for the timber harvested from a parcel. To aid landscape planners, the planning area can viewed from a user defined point at the end of each period (Figure 7).

You can also generate your own report format by exporting the SNAP solution in ASCII files which can be imported into spreadsheets or a GIS.

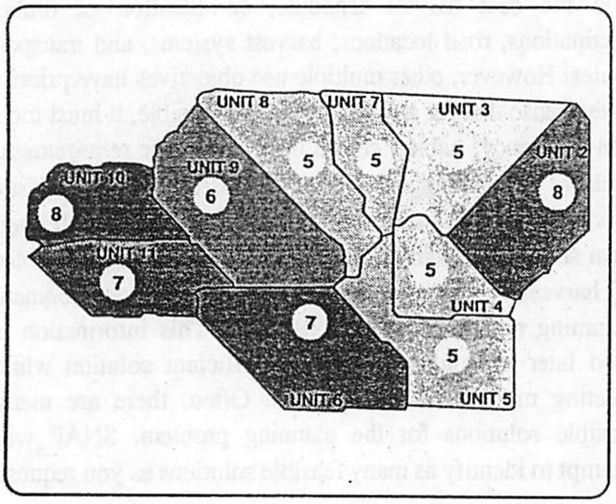

Figure 2. Seral stages of each parcel during a period. A maximum of 10 seral stages can be identified.

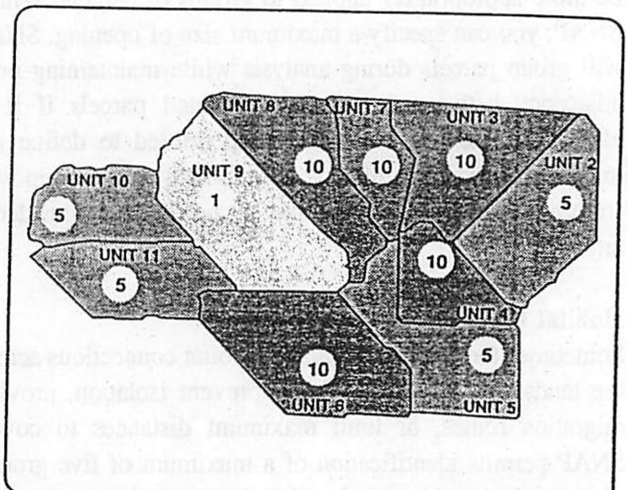

Figure 4. Silvicultural treatments by period. Nine types of treatments can be defined. Treatment 10 is the "no cut" treatment. In this example, treatment 1 is a selective cut, treatment 5 is a clearcut.

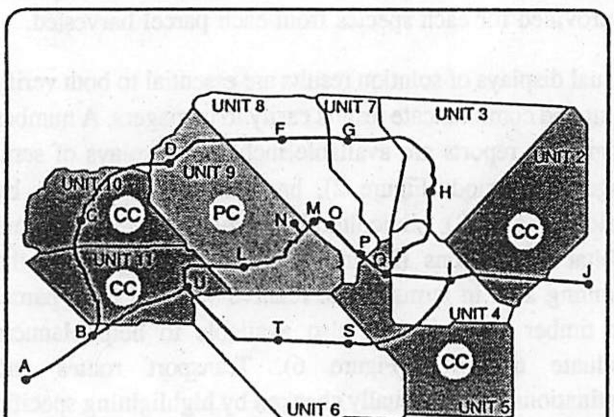

Figure 3. A harvesting pattern where Unit 10 and Unit 11 have been grouped together and cannot share a common vertex with either Unit 2 or Unit 5. CC is clearcut, PC is partial cut.

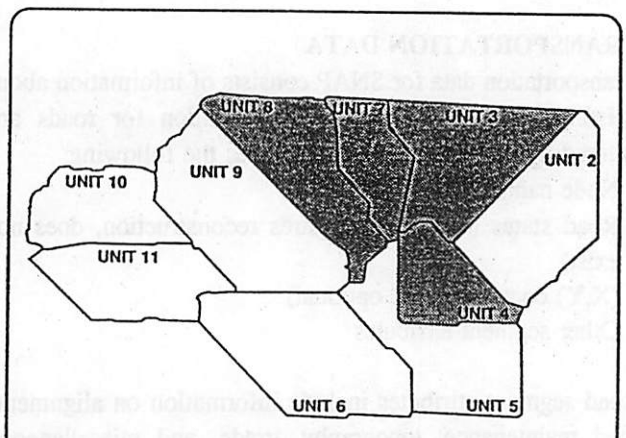

Figure 5. Unit 8 and Unit 4 have been designated critical parcels for a habitat connection with seral stage 5 being the only eligible seral stage for connecting parcels. During solution SNAP identified that these parcels should be connected by Unit 3 and Unit 7.

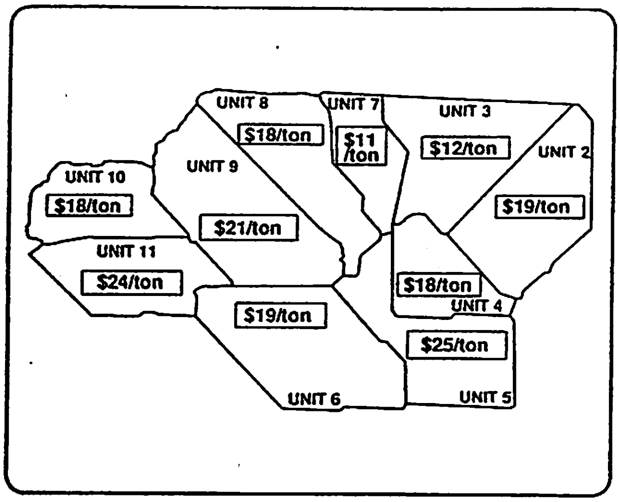

Figure 6. Relative value of parcels for timber production determined by considering alternative harvesting systems, road systems, and mill destinations.

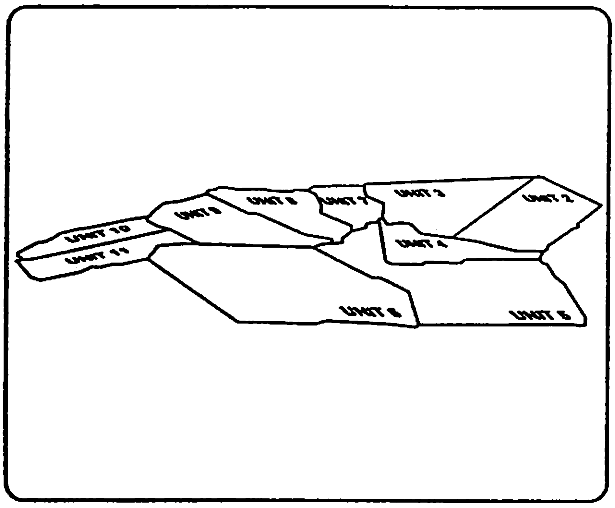

Figure 7. Perspective view of the planning area (treatments not shown).

FUTURE DEVELOPMENT

It is anticipated that by the end of the year, SNAP II will be extended to permit:

(1) calculation of the elk habitat effectiveness for a harvest pattern using the method outlined by Wisdom et al. (1986),

(2) habitat connections to float over time,

(3) individual habitat connection to have different seral stage eligibility requirements,

(4) definition of at least three separate zones where size of opening, "green up" time, and timber harvest goals can be specified separately for each zone,

(5) increased flexibility for choice of silvicultural treatments.

(6) permit perspective views from within the planning area, with or without vegetative screens.

HARDWARE

SNAP II is designed for 32-bit 386 compatible microcomputers with INTEL math coprocessors running under DOS. An EGA or better graphics adaptor, color monitor and mouse is required. Using a program option, SNAP will run smaller problems (less than 200 parcels) successfully on 286 computers with 640 k and a math coprocessor. Larger problems will require use of a 386 microcomputer with extended memory. Hard disks should have at least 4 megabytes of available space to store the SNAP code and reports from SNAP. Performance can be enhanced by using a memory cache and/or a large RAM disk if 4 megabytes or more of extended memory are available.

SOFTWARE AVAILABILITY

SNAP II is public domain software. Questions regarding availability of the software and documentation should be directed to Don Nearhood, Division of Timber Management, USDA Forest Service, POB 3623, Portland, Oregon 97208. For information on SNAP Workshops and on-the-job program support, contact John Sessions, Department of Forest Engineering, Oregon State University, Corvallis, OR 97331.

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EVALUATING TIMBER HARVESTING AND UTILIZATION OPTIONS TO MAXIMIZE HARVESTING REVENUE

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ABSTRACT
Environmental concerns and resulting timber harvesting restrictions along with rising costs and changing roundwood markets make it increasingly important to maximize value recovery from harvesting operations. Methods presented perform economic analyses of multiproduct harvesting and wood-utilization alternatives by estimating harvesting cost and revenue as a function of timber-stand attributes, product markets, and wood-utilization levels. Results show that the minimum tree dbh harvested to maximize net revenue ranged from 7 to 13 inches depending on roundwood markets and utilization practices. Revenue gains attributed to multiproduct harvesting also were dependent on market conditions: $122/acre with low prices, and $789/acre with high prices. While the results are applicable to the upland oak stand analyzed, the methodology has widespread applications for increasing value recovery from timber harvesting operations.

Keywords:
Timber harvesting, wood utilization, simulation, cost revenue.

INTRODUCTION
The need to increase the volume and value of wood harvested from a tract of timber can result from the reduced availability of harvestable timber or the increased cost of harvesting operations. Changing landowner attitudes, with increased emphasis on nontimber resources, have reduced the availability of eastern hardwood timber (Dennis and Sendak 1991). Concerns over the plight of endangered wildlife species also have constrained timber harvests. With the cost of harvesting equipment and supplies increasing faster than roundwood prices (Cubbage et al. 1988), loggers are forced to increase revenues through increased production and improved utilization practices.

Although multiproduct harvesting is used to increase both the value and volume of wood harvested (Dennis and Remington 1987), net revenue is most important to loggers and landowners. Net revenue is determined by the timber harvesting system, timber-stand attributes, and harvesting practices that influence cost; as well as products markets and wood-utilization practices that determine gross revenue. Maximizing net revenue for a variety of harvesting and market conditions requires a relatively complex and detailed analysis that estimates costs and revenues as a function of the tree-harvesting and utilization alternatives to be evaluated.

Because tree harvesting and wood-utilization practices can affect harvesting system production and resultant harvesting costs, it is important that production and costs reflect the tree diameters and the stem component harvested. Computer simulation of harvesting operations is a versatile method that is well suited to this task. System simulation has been applied to estimate harvesting costs as a function of timber-stand attributes and system configuration (Cubbage and Granskog 1982), and to evaluate harvesting systems and utilization practices (Hypes 1979).

In this paper we demonstrate the application of harvesting-system simulation for the economic analyses of harvesting and utilization alternatives, and illustrate the nature of the relationships among these alternatives, product prices, and net revenue.

METHODS
A simulation model was used to estimate harvesting-system production rates and product volumes for a series of simulated harvests of an upland oak timber stand. Each simulation applied a unique set of tree-harvesting constraints that are defined by the minimum tree diameter at breast height (dbh) to be harvested and the minimum stem top diameter inside bark (dib) to be utilized. The subsequent economic analysis was applied to the estimated production rates and product volumes to calculate net revenue per acre for each of five wood-utilization options and several combinations of roundwood product prices. Utilization options were defined by the types of products used and the method of allocating roundwood to product markets.

The harvesting simulation model was developed to simulate conventional ground-based harvesting systems. In this case, the system simulated consisted of two chainsaw operators felling timber, a 90 hp rubber-tired skidder, and a hydraulic loader/slasher combination to buck, sort, and deck roundwood products. This stochastic discrete event model is written in FORTRAN 77 and applies the next-event method of controlling simulation time (Baumgras 1990). Machine cycle times are estimated from equations and delay-time distributions developed from West Virginia harvesting operations. The cycle time and volume estimates are sensitive to timber-stand and tract attributes as well as the tree harvesting options that determined the attributes of trees harvested. The estimated system production rate reflects the productivity of the system components and the interactions between components.

To simplify presentation of results, the same harvest-tract attributes were used for all simulations. This 50-acre unit represented a 110-year-old stand of even-aged upland oaks on site index 60. The stand table representing trees available for harvesting was obtained using the OAKSIM growth model (Hilt 1985), assuming an even-age regeneration cut at age 110. The diameter class distribution is summarized in Figure 1.

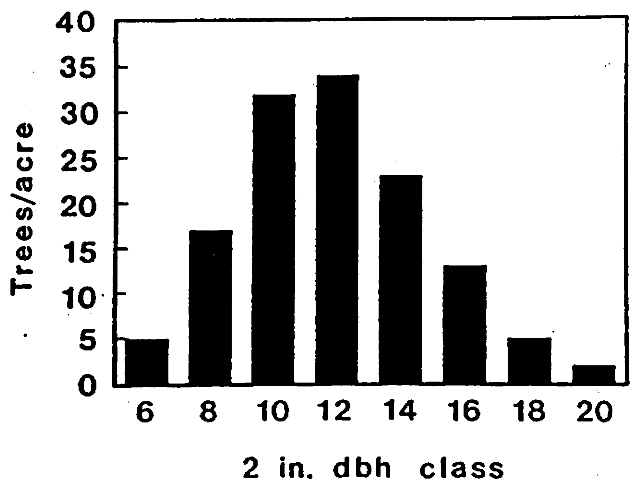

Figure 1. Diameter distribution of trees available for harvesting.

The harvesting and wood-utilization options evaluated are defined in Table 1. Several minimum tree diameters were tested for each utilization option. The smallest dbh tested equaled the minimum diameter that would yield the lowest quality product utilized. The largest dbh limit was 16 inches. In each simulation, only trees greater than or equal to the specified minimum dbh were considered merchantable. To meet silvicultural objectives all trees were felled but only merchantable trees were skidded and used. The merchantable top dib equaled the minimum dib of the lowest quality product used: 10 inches for sawlogs, 6 inches for sawbolts, and 4 inches for pulpwood.

Products used include factory grade sawlogs, sawbolts, and pulpwood. Sawlogs have a minimum scaling diameter of 10 inches and meet or exceed the quality requirements for USDA Forest Service factory grade 3 (Rast et al. 1973). Sawlog volumes were estimated by tree species and USDA Forest Service hardwood log grades 1, 2, and 3. Sawbolts are sawable bole sections with a minimum scaling diameter of 6 inches that lack the quality or dimensions to make a sawlog. Pulpwood is bolewood greater than 4 inches dib and 8 feet or longer that would not make sawlogs or sawbolts. Product volumes were estimated by a subroutine in the simulation program that applies tree-taper functions (Martin 1981), tree-grade distribution estimators (Dale and Brisbin 1985), and equations for estimating sawlog volume by log grade (Yaussey et al. 1988).

Table 1. Definition of wood-utilization and tree-harvesting options tested.

Utilization option	Products harvested[a]	Harvesting options: Minimum merchantable dbh[b]	Minimum top dib
		------------ inches	---------
1	SL	12 to 16	10
2	SL-SB	8 to 16	6
3	SL-PW	6 to 16	4
4	SL-SB-PW	6 to 16	4
5	SL-SB-PW[c]	6 to 16	4

[a]SL = sawlogs, SB = sawbolts, PW = pulpwood.
[b]Range of minimum tree diameters tested.
[c]Wood allocated to highest value market within diameter and quality constrains.

Utilization options 1 through 4 allocate the total volume estimated for each product to that product market regardless of product prices. Option 5 allocates all roundwood to the highest value market consistent with quality and dimensional constraints. This allows low-value sawlogs to be allocated to the sawbolt or pulpwood market, or sawbolts to be allocated to the pulpwood market, when the equivalent unit value of the lower quality product exceeds that of the higher quality product. While delivered prices generally reflect log size and quality, market fluctuations and differences in haul cost can favor allocating higher quality roundwood to lower quality markets.

The product prices used in the economic analysis include three price levels for each product to represent varying market conditions with respect to delivered prices and haul costs (Table 2). Because the simulations estimate only stump-to-truck costs, estimated haul costs were deducted from surveyed prices of roundwood delivered to mills (Ohio Agric. Stat. Serv. 1989; Pa. State Univ. 1989) to develop net prices that reflect different haul distances. With three tree species groups each with three log grades, together with sawbolts and pulpwood, the economic analysis included 11 distinct roundwood products. To constrain the numbers of price combinations evaluated, the price level of sawlogs pertained to all tree species and log grades.

Table 2. Net product prices by price level, product, species group, and log grade.

Product and species	Log Grade[a]	Net price levels[b] High	Medium	Low
		----Dollars/Mbf---		
Sawlogs				
White oaks				
	1	374	300	205
	2	194	173	132
	3	105	82	39
Red oaks				
	1	550	418	265
	2	298	242	164
	3	124	98	51
Other[c]				
	1	182	150	97
	2	134	107	60
	3	92	71	29
		-- Dollars/100 ft^3 --		
Sawbolts		66	46	18
Pulpwood		56	42	18

[a]USDA Forest Service hardwood factory log grade.

[b]High = maximum delivered price and 15-mile haul; Medium = median delivered price and 30-mile haul; Low = minimum delivered price and 100-mile haul.

[c]Red maple and yellow-poplar.

RESULTS

Harvesting Simulation

Harvesting options and stand attributes greatly influence harvesting costs as shown in Table 3 for utilization options that apply to a 4 inch top dib limit. Harvesting successively smaller trees increases the number of merchantable trees per acre and total volume per acre, but reduces average volume per tree. Total harvesting costs increase with volume per acre, but unit costs decrease from $41/100 ft^3 with a 16-inch dbh limit to $19.23/100 ft^3 with a 12-inch dbh limit, and then increase to $23.13/100 ft^3 at 6 inches. Because estimated harvesting costs reflect only dbh and dib limits,estimated harvesting costs were equal for all wood-utilization options sharing the same dbh and dib constraints. For the system analyzed, the tree bucking and product sorting process generally was underutilized so that product sorting and number of products harvested did not constrain system production.

Table 3. Tree merchantability limits, cut stand attributes, and estimated harvesting costs.

Minimum dbh (inches)	No. Merch. trees/acre	Volume per acre	Average vol./tree	Harvesting cost	
		--------- ft^3	-----	Dollars/ acre	Dollars/ 100 ft^3
16	14	740	53	304	41.00
15	26	1210	46	320	26.47
14	36	1240	43	337	21.90
13	50	1940	39	377	19.43
12	67	2340	35	450	19.23
11	87	2730	31	557	20.39
10	102	2960	29	626	21.11
9	115	3110	27	682	21.89
8	122	3170	26	718	22.62
7	129	3210	25	738	22.96
6	131	3220	25	744	23.13

By looking at the effects of tree harvesting options on several key aspects of simulated system performance (Table 4), we can explain the cost variations shown in Table 3. When only trees 14 to 16 inches dbh were used, but fellers cut all trees, the skidder often was delayed waiting for merchantable trees. This resulted in a low utilization rate for the skidder, 37 to 78 percent (Table 4). Reducing the dbh limit increased skidder utilization but reduced the utilization rate for the felling crew. To avoid excessive inventories of felled merchantable trees, tree fallers were forced to wait on the skidder when lower dbh limits were used. For this analysis, utilization rates represent the percent of scheduled time that each system component is in productive cycles. This includes normal operating delays and minor mechanical delays but excludes time lost waiting on other system components.

By increasing the number of merchantable trees per acre, lower merchantable limits also increased the average of number of trees hooked per skidder turn from 3.5 trees/turn with a 16-inch dbh limit to 5.2 trees/turn with a 6 inch dbh limit. However, the corresponding decrease in average tree volume reduced average turn volume from 193 ft^3 at 15 inches to 128 ft^3 at 6 inches. The net result was system production rates that ranged from 187 ft^3/hr at 16 inches to 359 ft^3/hr at 6 inches, with a maximum of 443 ft^3/hr at 12 inches (Table 4). For merchantable tree dbh limits of 14 to 16 inches, skidder utilization rates constrained system production. With lower dbh limits, skidder turn volume constrained skidder and system production.

Table 4. Harvesting system simulation results by minimum merchantable tree dbh.

Minimum dbh (inches)	Utilization rate		Skidder turns		Average system production
	Felling	Skidding	Average no. trees	Average volume	
	-- percent --			ft^3	ft^3/hr
16	92	37	3.5	185	187
15	92	61	4.2	193	304
14	90	78	4.4	191	380
13	82	94	4.7	183	438
12	69	98	4.9	172	443
11	55	98	5.0	155	413
10	49	98	5.1	148	397
9	45	98	5.1	138	381
8	42	98	5.1	133	368
7	42	98	5.2	130	362
6	42	98	5.2	128	359

Economic Analysis

Maximum net revenue and the tree-harvesting options that maximized revenue for each wood-utilization option and six price cases that represent combinations of product price levels are shown in Table 5. These price cases were selected to demonstrate the effects of varying market conditions. Results show that the minimum tree dbh harvested to maximize net revenue for a specific utilization option was increased by 1 to 5 inches with decreasing prices. For example, with price case 1, net revenue is maximized for utilization options 4 and 5 by harvesting to a 7-inch dbh limit. With price case 6, net revenue for these utilization options is maximized with a 12-inch dbh limit.

To maximize net revenue requires the marginal revenue resulting from each reduction in minimum merchantable dbh to equal or exceed the marginal cost of harvesting additional volume from smaller trees. Lowering prices reduces marginal revenue as well as the volume of wood that can be harvested to maximize revenue. These results also indicate that increased utilization does not necessarily increase net revenue. However, merchantable dbh generally was minimized with utilization option 5.

Table 5. Maximum net revenue per acre and minimum merchantable dbh required to maximize net revenue, by wood-utilization option and product price levels.

Price Case	Net price levels by product[a]	Net Revenue: Option 1 (SL)	Option 2 (SL-SB)	Option 3 (SL-PW)	Option 4 (SL-SB-PW)	Option 5 (SL-SB-PW)
		Dollars/acre				
1	H-H-H	1390 (12)[b]	1901 (9)	2059 (9)	2176 (7)	2179 (7)
2	H-L-L	1393 (12)	1480 (12)	1535 (12)	1535 (12)	1535 (12)
3	M-M-M	1024 (12)	1315 (10)	1456 (10)	1508 (9)	1508 (9)
4	L-H-H	473 (13)	961 (9)	1119 (9)	1236 (7)	1587 (7)
5	L-L-H	473 (13)	540 (12)	1119 (9)	714 (12)	1375 (9)
6	L-L-L	473 (13)	540 (12)	595 (12)	595 (12)	595 (12)

[a]Price levels for each of three roundwood products; sawlogs (SL), sawbolts (SB), and pulpwood (PW) representing levels and prices in Table 2; H= high, M= medium, L= low.

[b]Minimum merchantable dbh (inches) in parentheses.

For price case 1 with high prices for all products, using two or more products increased net revenue by $511 to $789/acre compared to sawlog-only harvests (Table 5). Gains attributed to having and using the sawbolt market are $120/acre (option 5 vs. option 3). Gains created by the pulpwood market are $278/acre (option 5 vs. option 2).

Price case 2 represents the worst-case scenario for multi-product harvesting in a mature stand, with high sawlog prices and low prices for sawbolts and pulpwood. Nonetheless, options 4 and 5 increase net revenue by $142/acre. Since the lowest price for sawbolts equaled the lowest price for pulpwood, options 3, 4, and 5 yield equivalent revenue estimates.

Price cases 4 and 5 represent combinations of net prices that favor the flexible product allocation process employed by utilization option 5. Comparing revenue estimates from options 4 and 5 reveals revenue gains attributed to flexible wood allocation based on net prices. In price case 4 with high prices for sawbolts and low price levels for all sawlogs, low-quality sawlogs can be allocated to the sawbolt market to increase revenue by $351/acre (Table 5). In case 5 with low net prices for sawlogs and sawbolts and a high net prices for pulpwood, allocating low quality sawlogs and sawbolts to the pulpwood market increased net revenue by $661/acre over option 4, and $902/acre over the sawlog-only harvest represented by option 1.

To demonstrate differences in the wood-allocation process between utilization options 4 and 5, volumes allocated to each market are shown for price cases 4 and 5 (Table 6). With high prices for sawbolts and low prices for sawlogs, both utilization options harvest to a 7-inch dbh limit. To maximize revenue, option 5 allocates 160 board feet/acre of grade 2 logs and all grade 3 logs to the sawbolt market, increasing sawbolt volume from 1,174 to 2,129 ft^3/acre. With low prices for both sawlogs and sawbolts, low quality sawlogs and sawbolts increase the volume of pulpwood marketed from 312 to 2,574 ft^3/acre. In price case 5, adopting utilization option 5 also reduced the minimum merchantable dbh from 12 to 9 inches, and increased total volume harvested by 773 ft^3/acre (Table 6).

Table 6. Volumes of wood allocated to each market by utilization options 4 and 5, with price cases 4 and 5.

Variable	Price case 4 (SL Low, SB High, PW High)		Price case 5 (SL Low, SB Low, PW High)	
Wood utilization option	4	5	4	5
Min. merch. dbh (inches)	7	7	12	9
Sawlogs (Mbf/acre)				
Grade 1	740	740	740	740
Grade 2	2,930	2,770	2,930	2,770
Grade 3	6,010	0	6,010	0
Sawbolts (ft^3/acre)	1,174	2,129	537	0
Pulpwood (ft^3/acre)	547	547	312	2,574
Total volume (ft^3/acre)	3,213	3,213	2,341	3,114

Table 5 does not show differences in net revenue between the tree-harvesting options tested for each utilization option. The difference between the best and worst harvesting options tested for each utilization option ranged from $750 to $1423/acre with high prices for all products, and $297 to $391/acre with low prices for all products.

CONCLUSIONS

The results indicate that timber harvesting costs and revenues are highly dependent on the tree-harvesting and wood-utilization practices that are used. The minimum tree dbh and total volume harvested to maximize net revenue per acre can be extremely variable depending on product prices and wood-utilization practices. Whereas multiproduct harvesting consistently maximized revenue, the revenue gains attributed to wood utilization and allocation methods also were dependent on product prices. The effects of prices on revenue maximizing tree-harvesting options makes it difficult to generalize regarding preferred harvesting practices. Further, the effect of roundwood prices on harvesting practices demonstrates the importance of making a clear distinction between maximizing harvested volume and harvesting revenue, since maximum revenue was not always coincident with maximum volume.

The direct application of the results presented is limited to the specific timber stand and harvesting system evaluated. These results also reflect the assumption that all trees were felled during harvesting but that only the designated merchantable trees were used. However, the methods used define a procedure for estimating harvesting costs, product yields, and harvesting revenue as a function of timber stand attributes, timber-harvesting and wood-utilization practices, and roundwood product markets. The procedure demonstrated estimates the marginal cost and revenue associated with incremental reductions in merchantable tree diameter for specific wood- utilization options, information that is essential for maximizing net revenue. With growing concern for increasing the volume and value of wood harvested, the continued development of similar analytical tools for alternative harvesting systems and timber types is increasingly important. Addressing this concern requires the application of these advanced tools to the cost and revenue analyses of site-specific harvesting opportunities and prevailing market conditions.

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HOW TO IMPROVE VALUE RECOVERY FROM PLANTATION FORESTS: RESEARCH AND PRACTICAL EXPERIENCE IN NEW ZEALAND

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ABSTRACT

For over a decade the New Zealand Forest Research Institute (FRI) has been carrying out research to improve the value recovered from New Zealand's plantation forests. Studies have examined felling, extraction and log-making practices, and new methods recommended to industry. Early studies indicated that as much as 40% of the value of the forests were being sacrificed through poor harvesting practices. Computer products are being developed at FRI which allow the auditing and improvement in value recovery performance and log quality control of logging crews by the forest owners.

Many forest companies in New Zealand now recognise the importance that increased value recovery has on their profitability and that it is easier to improve value than reduce costs. Substantial gains have been made in improving value recovery over the last five years. Regular auditing of logging crew performance, evaluation of changes in cutting strategies, and specialist training and recognition of log-makers will be important features of plantation harvesting in the 1990's.

Keywords:
Harvesting, value recovery, log-making, felling, computers.

INTRODUCTION

The predominately radiata pine (*Pinus radiata*, D.Don) plantation forests established in New Zealand before 1940 were largely unmanaged. Harvesting practices used in these stands were mainly aimed at minimising costs while maximising productivity. The stands planted subsequently have received a wide variety of silvicultural practice incorporating various pruning and thinning regimes. Thus a new tree crop has been produced, which is now being harvested and has a potentially greater product value.

The tree sizes commonly produced on a 30 year rotation have an average volume of about 2 to 3 m^3 and are 40 to 45 metres tall. The tree size and the labour-to-capital cost ratios in New Zealand, have lead to the predominant use of motor-manual harvesting systems incorporating chainsaw felling. Extraction occurs to a central landing by either skidder, tractor or yarder where a number of log grades are cut and sorted.

New Zealand log grades stress diameter, length, branch size, sweep and surface defects. As many as fifteen log grades are cut at one site. Most log lengths are cut at fixed intervals with preferred lengths often also being included. Thus, because of the range in log prices (e.g., for some companies veneer logs are worth 25 times the value of pulp logs), and the demand for various log dimensions and qualities the potential to lose value through stem damage and log mis-allocation, can escalate through the harvesting chain.

VALUE RECOVERY: A SAGA OF OPPORTUNITIES LOST BY INDUSTRY

A high priority research effort has been maintained over the last decade within the FRI Harvest Planning Group to quantify the magnitude of losses through the handling chain during harvesting of short rotation plantation forests (Murphy, 1983). With information on the relative importance of various sources of losses, priorities can be set to devise means to reduce these losses.

The causes of value losses during harvesting fall into two main categories: handling damage and log misallocation.

Handling damage may occur between the tree standing in the forest and some final processing destination. These include:

- felling breakage and damage, as a result of the tree being severed and placed horizontally. Breakage reduces the number of length options available and is particularly important if long logs receive a value premium. Felling damage is particularly important at the high-valued butt end of the log where poor felling technique can result in major losses from slabbing and splitting.

- extraction breakage, where the stem is broken while being transferred in long length to a processing landing. Again this reduces the number of log options available.

- bucking damage, the end of the log is split or slabbed through poor cross-cutting technique if the logs are under tension. This effects the scaled value of exported logs.

- loading/unloading breakage, during the transfer of logs from stockpiles on to and off transportation vehicles.

Allocation losses are a result of the wrong product being made from a stem or a log product being sent to the wrong destination. Losses whcih occur through poor allocation are much less obvious than those which result from physical causes, and are likely to be much more important in terms of value losses. They include:

- sub-optimal bucking decisions, where the log-maker produces less value from a given stem than is possible.
- sub-optimal choice of log products, where a manager picks a sub-optimal choice of log grades to cut from a given stand to match his supply/demand constraints and harvesting machinery characteristics.

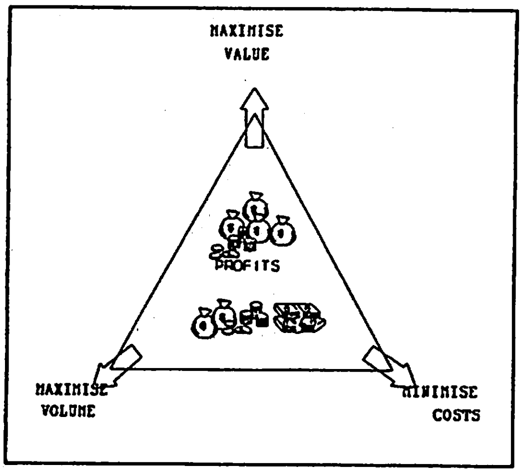

Figure 1. Value maximisation is one of the corner-stones of profitability.

As the simplified approach of Figure 1 attempts to show, overall profitability from harvesting is raised by focusing on all three key elements: volume, value and production costs. Too often the emphasis is on minimising production costs and maximising output, while raising product value recovery takes a back seat. Although forest management may want quality the contractor's performance is often measured in terms of volume produced.

RESEARCH WORK ON VALUE RECOVERY AT THE FRI

Work into improving value recovery at FRI began in the early 1970's with the development of the pre-harvest inventory tool, MARVL (Method of Assessment of Recoverable Volume by Log-type) (Deadman and Goulding, 1979), which is now widespread in its application for pre-harvest inventory. The plantation nature of the commercial resource in New Zealand, and the need to closely manage the resource to match tight supply and demand constraints, led to the development of this tool to assist in the prediction of log volumes by grade just prior to harvest. MARVL incorporates a dynamic programming algorithm to optimally determine the log products into which trees should be cut.

With the increasing use of MARVL by the New Zealand forest industry it was noticed that there were occasions where there were quite significant differences between the predicted and recovered volumes. Blame for the differences were naturally argued between the application of the tool, or the ability of the logging crew to correctly recover the volumes. The first attempts to more closely analyse the log-making processes by examining individual stems was undertaken by Ferrow and McEwen (1980) utilising MARVL. In a pilot investigation they found significant profit sacrificed. Over one-third of the total potential was found to be lost after examining the felling, extraction and allocation operations at one forest location.

Murphy and Gaskin (1982) also used MARVL to assess the impact of felling breakage patterns on value recovery. Working on steeper slopes, the impact of the pattern of lay out during felling was evaluated. Value losses ranged from 5 to 6% if the logs were to be supplied to a domestic market, and from 8 to 11% if the logs were to be supplied to an export market. Most of the stem breakage was attributable to three factors; crossing of logs, changes in slope, and the presence of malformed stems. Value savings in the order of 1 to 2% could be obtained by altering the felling patterns. Parallel felling is now common practice in most forest companies.

It has been estimated that breakage and damage during extraction only account for 1 to 2% in lost value in New Zealand (Murphy and Twaddle, 1986). Felling parallel and inlead, so that stems do not have to be turned through sharp angles, may be the most important value saving method which can be applied during extraction. Less breakage was also found to occur with butt-pulling than tip-pulling and was therefore recommended where possible.

At the other end of the harvesting process the loading and unloading of logs also creates the opportunity for value loss. Most log handling equipment is designed for economy of scale and can therefore handle multiple log lots. They therefore tend to be large items of equipment and have the capability of doing significant damage to individual logs, either by spearing of the log or log breakage. Recent investigations by FRI indicates that breakage is the most serious of these two effects. Approximately 1 in every 1000 logs handled at a major export facility in New Zealand is broken. It is likely that these figures are typical for other log handling facilities which use large forked loaders.

AVIS: A VERY IMPORTANT STEP FORWARD

From the early work undertaken at FRI on value loss it was obvious that the use of MARVL, which was designed as an inventory tool to be used on standing trees, was not satisfactory for examining more detailed aspects of single tree value losses. A new system was developed which incorporated some of the successful algorithm routines embodied within MARVL. After trial and error a method was developed called AVIS 'Assessment of Value by Individual Stems'(Geerts & Twaddle, 1984). AVIS is not an inventory method but a system for comparing an optimal value cutting solution, calculated by the computer, with one someone has actually used on the same tree.

AVIS was based on a manual system of objectively assessing the surface characteristic of the stems and noting positions of quality change independent of stem dimension. The challenge is to be able to measure and assess the tree's characteristics to a level of detail suitable for optimisation and used by log-makers in their decision process.

A set of predefined alphabetic codes was used to define quality, with each representing unique quality features, such as branch diameter, surface damage and form. Stem length and diameters were also assessed using linear tape and callipers and entered manually. When measured stems were extracted to the landing, the sequence of log grades and lengths each stem was cut into was recorded (Murphy and Twaddle, 1986).

The need to utilise such a recording system was to minimise interference to the logging crew so that a true indication of their log-making performance was gauged. While many other countries have incorporated optimising equipment onto their logging machinery, this is not so easily achieved in New Zealand due to the emphasis on motor-manual harvesting. Tree size is also such that it cannot be easily picked up by equipment such as a harvester. Radiata pine is generally too big to be handled in a single piece, or available machinery is prohibitively expensive.

A series of bench-mark studies were undertaken with AVIS to ascertain the levels of value loss which were occurring due to sub-optimal log allocation by the logging crews. In the first few studies, carried out in the early 1980's, the participating forest companies were asked to select the crews they considered to be their best at recovering value. When these crews were studied, value loss ranged from 12 to 26% when log-making was done on a landing (Table 1.).

The work undertaken at the FRI allowed the first opportunity to demonstrate the impact of the hidden losses of log-making to the local industry. Researchers at the Harvest Planning Group informed industry of the potential benefits (Twaddle, 1984, Twaddle, 1986a,) and suggested strategies to minimise value losses (Twaddle, 1986b, 1986c, 1988a). The key finding of all of this research was that it was much easier to add $1 to unit product value by improving bucking that it was to reduce $1 from unit costs.

Over the past decade further bench-mark studies have indicated that there has been a considerable improvement in the logging industry's ability to recover value during log-making. However, these studies show that between 5% to 15% of the gross revenue is still not being recovered by the average logging crew. A target of 5% or less should be achievable by all logging crews in the long term. It should be noted that this work has focused on the New crop stands which will be more typical of the managed stands of the future.

Experience gained from repeated use of AVIS has enabled many improvements to be made, the most important being the introduction of a method to objectively define sweep. One of the keys to the success of the tool is the ability of the person measuring the stem to grade it objectively and not be required to 'second guess' the actions of the log-maker. The issue of sweep was solved by incorporating flexible cutting zones which could be quality dependant. Thus a swept section of stem would be ignored in the algorithm if sweep-tolerant logs were being considered, but for other grades, such as peelers, it would influence the cut position, and grade of logs produced.

Data collected during various AVIS trials also had spin-off benefits, which allowed for the analysis of various value related issues. These included

- Quantifying the impact of changes in felling technique on butt log damage (Murphy and Buse, 1984)
- Evaluating the relative value of stem components after felling breakage (Twaddle, 1987a)
- The development of cutting strategies to minimise value loss when bucking for yarder extraction (Twaddle, 1987b)
- Investigations into the ability of logging crews to locate specialist high-valued log products (Twaddle, 1988), and to cope with new log grades (Twaddle, 1986d)
- Demonstration of the ability of different log-makers to make correct allocation decisions (Murphy and Olsen, 1988, Cossens and Murphy, 1988)
- Quantifying the impact of log-making location (stump, landing or centralised processing yard) on harvesting economics (Murphy *et al.*, 1988)

Table 1. New Zealand benchmark studies of log-making value losses

Study	Year	Crop type*	Log grades	Comment	% Value Loss
1	1983	Old crop Unpruned	4	-	26
2	1984	Transition Unpruned	4	No pruned logs	12
		Pruned	5	Pruned logs	12
3	1985	Transition Pruned	6	Logs cut on landing	24
				Logs cut on landing	23
				Logs cut at stump	23
				Logs cut at stump	30
				Logs cut at stump	32
4	1985	Transition Pruned	10	Test new grades	6
5	1985	*Pinus nigra* Unpruned	3	-	7
6	1986	New crop Pruned	5	Log cut on a muddy landing in winter	5
7	1987	New crop Unpruned	3	-	14
8	1987	New crop Pruned	8	-	6
9	1987	Old crop Unpruned	3	-	10
		Old crop Unpruned	3	-	14
10	1988	Transition crop Unpruned	3	-	12
		Old crop Unpruned	3	-	5
		Old crop Unpruned	3	-	9
11	1988	New crop Pruned	6	19 log-makers	4-10
12	1989	New crop Pruned	7	-	5
13	1990	New crop	9	2 log-makers	11, 18
		Pruned	5		8
14	1990	Transition crop		-	8

* Note: The terms Old crop, Transition crop, and New crop refer losely to management regimes and periods of establishment of *Pinus radiata* plantation stands in New Zealand.

- Comparison of mechanised versus manual processing (Cossens, 1991).

GETTING RESULTS INTO THE WOODS

The AVIS software, however, was only used by FRI as a research tool. It had grown into a collection of software programs, and was designed to run in batch mode on a large mini-computer. Therefore, while local industry were interested in the output from the system, it was not readily transferable. It might be up to several months before the results of an study were complete, by which time the logging crew may well be operating in a stand with differing characteristics, or be implementing a different cutting strategy. Also the results could not directly improve a log-makers decision ability, since the information from the results was directed to the management and not to the field crew.

Thus the time lag, and the inability to fully and practically convey the results back to those who most needed them, the logging crew, was a hinderance to the development potential of AVIS.

As a result of the informal information exchange network in the harvesting industry, the research path in optimal bucking adopted by Glen Young, University of British Columbia (UBC), was noted. It was innovative in its foresight in the in-field use of bucking tools, and its objective of linking the field tool with office machine strategies (Young, 1987). Spurred on by contact with the UBC programme, development commenced on making AVIS more mobile. The advantage of an in-field system was obvious in allowing the movement from what was essentially a research-based tool, requiring a field team to collect the necessary data, to an applied tool, able to be used by an individual.

A robust field-designed micro-computer, the English Husky Hunter, was selected as the best unit available at the time and an effort made to interest the forest industry in the project (Twaddle and Threadgill, 1986). The main AVIS programme was rewritten, in Pascal, to cope with the smaller capacity of the machine. At first, solution times were disappointing, but changes to the program dramatically improved the solution time (Threadgill, 1987) and data input. This lead to the availability of a tool specifically designed for training skidworkers, and enabling a supervisor to obtain a 'snapshot' view of his log-makers' performance.

The Husky Hunter programme was not foreseen as a daily production tool whereby the log-maker would enter all or most stems and act on the calculated decision. The requirement to measure lengths and diameters and enter them into a small computer was seen as being too clumsy and slow, and likely to meet user resistance, even though the loss in productivity would be compensated for by additional value recovery. Research effort is still continuing, however, to allow the full capacity of the tool to form part of an integrated system.

At the same time as the development of the Husky Hunter version, the bulk of the AVIS programs were transferred from a central mini-computer on to IBM-compatible PC's.

Computerised bucking aids assist in the training process and allow the ready testing of options. They do not necessarily provide the only method to reduce losses. Other measures should include (Donovan, 1989);

- Log-makers should be told the relative values of each log grade they are producing. A tendency in the past was not to reveal this information, but this makes it very difficult for the log-makers to assign priorities in their decision-making.
- Basic tools should be provided to assist in the decision process. Spring-loaded logger's tapes, lightweight calipers, and spray paint cans should be readily available.
- Log grade specifications and simple decision rules should be formulated in clear wording and be provided in a pocket-sized format with a weather and wear protected surface.
- Management should regularly meet collectively with the log-makers to discuss grading problems and other relevant issues.

TRAINING AND INCENTIVES FOR VALUE

With the development of a more practical tool, local industry have become more active in the area of log-bucking control. Log-maker training courses are now run which use the instant feed-back capability of the handheld micro-computer as an instruction aid. Some log-maker courses are provided by polytechnic institutes, while many of the larger forest companies run their own courses for their contractors. Recognition is now given to the importance of the log-maker in a number of ways, both informal and formal - from caps with a LOG-MAKER logo to a formal classification of the job by the New Zealand Logging and Forest Industry Training Board.

There are still many issues to fully overcome to ensure that a high level of value recovery is maintained. Not necessarily all of these problems will be solved by computer technology or training. The pressure on the log-maker to maintain a high level of productivity will continue. The need to develop incentive schemes which fully encourages loggers to emphasise value is evident. To encourage value maximisation, the forest companies are increasingly turning towards the use of differential logging rates to encourage product outturn to match the stands potential product outturn as predicted by pre-harvest inventories. The most commonly used system determines the price for each log type as a function of the percent of that log type in the stand and the relative stumpage value. It has been suggested that incentives be based on differential payments which apply to the workers as well as to the logging contractor (Duggan, 1990).

LOG QUALITY CONTROL

One surprising observation coming from the results of undertaking AVIS trials was the relatively high proportion of some log grades cut by the log-makers which did not meet specification. The proportion has remained consistent over some years (Twaddle, 1986, Cossens, 1990). Increasingly, emphasis is being placed by log purchasers on log quality so the pressure on log producers to reduce out-of-specification logs is also increasing. Logging contractors do not get paid for rejected logs and often have to pay for the transport cost to remove reject logs from the sawmill and export port.

A method to encourage the production of higher quality logs is to introduce some form of statistical quality control where regular quality measurements of log output (Cossens, 1990) or value recovery (Murphy and Twaddle, 1986) are made . The principals of control charting are well established in many other industries and could serve well as a mechanism to highlight individual logging operations where log-making should receive attention. Some New Zealand companies have instigated general schemes to regularly check log quality but have yet to adopt a more controlled formal system.

One area of log quality currently under attention in an FRI research project is the impact on value of splitting and slabbing during bucking. Most scaling rules for logs exported from New Zealand emphasise a 'defect-free' minimum small-end diameter. Thus a relatively small split in the small end of a log destined for export can result in a major reduction in that log's scaled volume, with a matching reduction in value. Preliminary investigations indicate that 5 to 10% of all exported logs have some small-end defect which can lead to a scaling volume reduction. This on-going investigation, which will quantify the level of value lost from this damage source, has previously received little attention from management as figures on scale reductions have not been kept.

SHORT-TERM STAND AND LOG ALLOCATION

Mechanical damage to logs can occur during the materials handling phase of harvesting. However of far greater impact on profitability are the 'unseen' losses from misallocation. While the early work of Ferrow and McEwen (1980) first highlighted the impacts of sub-optimal allocation at the landing, they also showed that by far a greater proportion was lost through the management choice of log grades to be cut from various stands.

This area remains as probably the most important opportunity to improve value recovery. Improved operational and mid-term harvest planning systems need to be developed to ensure that the log-making strategies, stand mixes, and market demands are matched to maximise overall profit (Twaddle and Goulding, 1989).

Allocation planning models in harvesting assist forest managers to decide which stands are to be logged and when, what forest products are to be harvested from them, and to which markets particular assortments of products are to be allocated. Over the last decade or more, it has been recognized that models are used to provide just one of many sources of information which the manager uses to make decisions. As such it is more profitable to use the term "decision support systems" to denote the whole harvesting information and planning system (Goulding, 1991).

FRI has been carrying out development work on many of the components needed for an integrated decision support system which would support forest and harvest planning from the short-term, one year allocation model through to the strategic one to two rotation length strategic yield regulation system.

These components include:

- geographic information system - incorporating or integrated with data base subsystems of stand records (areas, past silvicultural treatments, estimates of current condition) cutting unit records (areas, terrain models, logging and transport information) inventory data (plot locations, cruise data and summaries) permanent sample plot data (multiple measurements of monitoring and experimental plots).

- log assortment prediction system - inventory and growth prediction of plots, with facilities to interpolate between plot locations and aggregate groups of plots to provide stand or cutting unit summaries. Prediction of per hectare product and value yield tables from bare land.

- operations data base - approved planned operations for both silviculture and logging.

- silvicultural rate setting and quality control.

- logging and roading analysis package - roading layout and design steep and/or environmentally sensitive country - cable hauler planning costs and schedules of machinery.

- forest estate / resource allocation models - interactive simulator, linear programming optimizer, matrix generator and report writer (e.g., Garcia, 1984; Manley *et al.*, 1991).

SUMMARY: GUIDELINES TO IMPROVE VALUE RECOVERY

Value losses during the harvesting operation represent continual leaks in profitability. Each phase of the operation must be reviewed in terms of its impacts on product value. Opportunities exist with each phase to make improvements.

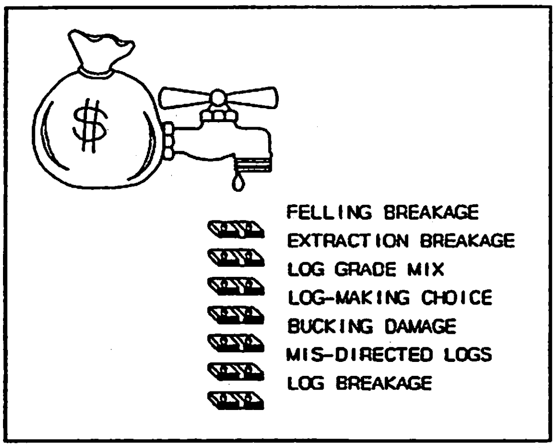

Figure 2. Value losses represent continual leaks in profitability.

1. Felling

Mature radiata pine stems usually break when they strike the ground after felling. Unless mechanical means are used to reduce the impact, little can be done to eliminate this breakage. However the severity of breakage can be influenced by felling techniques. Parallel felling will minimise breakage, and will also lead to productivity gains during the extraction phase (Murphy, 1982). Provision of a wedge and maul to the faller, and instruction on how to use them are essential. Using appropriate sawcuts during felling will also reduce value loss and damage to the butt of the tree (Murphy and Buse, 1984; Vaughan and Biddle, 1987). It is important that good felling techniques not be sacrificed for productivity.

2. Extraction

Extraction breakage, and resulting value losses, can be minimised if trees are felled parallel and in-lead and so that they can be extracted butt first.

3. Bucking

The problem with log-making is that the log-maker does not have the time nor the aids to play 'what if' games during his decision-making processes. Once logs have been cut they are rapidly moved into stockpiles, so there is little opportunity to judge if some alternative may have been better. Measures to substantially improve bucking practices include:

- The use of computer-aided tools, such as AVIS, for auditing value recovery performance and training log-makers.

- The important role of the log-making in overall profitability should be openly recognised, and measures taken to ensure that the log-maker receives suitable status. In New Zealand, the log-makers position has risen substantially in status over the past decade.

- A commitment to training and quality control is essential.

4. Mill handling

When machine operators handle several thousand logs per day they do not necessarily appreciate that each log may be worth a significant sum. While log breakage is not at a level that it is necessarily regarded as a problem, informing operators from time-to-time to take care, particularly when grappling a load of logs from stockpiles, will assist in minimising value loss from this source.

5. Resource/market woodflow optimisation

There are many opportunities to increase value recovery by improving operational and mid-term harvest planning systems which ensure that the log-making strategies, stand mixes, and market demands are matched to maximise overall profit. FRI scientists are actively working in this area.

To produce such a decision support system requires not only a practical and flexible allocation model, but also:

- preharvest inventory information on the likely log-product yield of the stands ready for harvesting

- a growth prediction method to project log assortment yield to the time of harvesting.

- accurate logging-setting planning, particularly for difficult country

- a database system to store and retrieve the large amounts of raw and processed data.

Estimates made by human eye can be very inaccurate and myths or rules-of-thumb can develop which may be misleading. The most important way to enhance value recovery is to develop some mechanism to objectively measure its loss. An emphasis on value recovery is also a state-of-mind. It is an attitude that must be installed into all of those in the management and production chain if it is to have an influence on the harvesting operation. An incentive mechanism can assist in ensuring value issues are kept in perspective.

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SESSION II:

OPERATIONS RESPONSE TO PUBLIC PRESSURE

PUBLIC PRESSURE AND THE FOREST INDUSTRY: TWO SIDES OF THE ISSUE

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ABSTRACT
The impact of public pressure on the forest industries of Canada and the United States is discussed by representatives of industry associations from these two countries. Public attitudes and perceptions in both countries are compared and contrasted to illustrate the parallel problems facing forest operations.

THIS PAPER WAS NOT AVAILABLE AT THE TIME OF PUBLICATION.

OPERATIONAL STRATEGIES FOR REDUCING SOIL DISTURBANCE IN THE INTERIOR OF BRITISH COLUMBIA

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ABSTRACT

Interim Harvesting Guidelines for the Interior of British Columbia, which limit harvesting-related soil disturbance, have recently been introduced to the province. It has been reported that soil-disturbance levels often exceed the limits of the *Guidelines* on steep-slope sites harvested with ground-based systems. Skid roads and skid trails are the major sources of disturbance on such sites.

Data from two studies conducted by the Forest Engineering Research Institute of Canada (FERIC) are reviewed to illustrate the influences of four factors on skid-road disturbance: slope and terrain; season of harvesting; types, sizes, and combinations of harvesting machinery; and methods of locating skid roads. The paper demonstrates how this information can be used to develop harvesting strategies that will reduce soil disturbance and meet the new guidelines.

Keywords:
Soil disturbance, ground skidding, Interior harvesting guidelines, skid roads.

INTRODUCTION

Recently the British Columbia Ministry of Forests established the *Interim Harvesting Guidelines for the Interior of British Columbia* (1989) to address concerns about harvesting-related soil disturbance and loss of site productivity. These guidelines are targeted toward the Region's conventional harvesting practices, which involve skidding with combinations of crawler tractors and rubber-tired skidders. Skid roads and skid trails associated with these harvesting methods have been shown to be the major sources of soil disturbance. Especially on steep slopes, disturbance levels often exceed the maximum allowed under the *Guidelines* (Krag et al 1986; Smith and Wass 1976; Thompson 1991).

The challenge now facing Interior forestry operations is to develop conventional harvesting techniques that consistently meet the *Guidelines*. To do this, it is necessary to understand what operational and environmental factors affect disturbance levels, particularly disturbance created by skid roads. The *Interim Harvesting Guidelines* are reviewed here to clarify the definition of disturbance. Next, data from two studies conducted by the Forest Engineering Research Institute of Canada (FERIC) in the British Columbia Interior (Krag and Webb 1987; Kockx, in progress) are presented to identify and illustrate the influence of several factors affecting skid-road disturbance. Finally, this paper demonstrates how this information can be used to develop harvesting strategies that will reduce soil disturbance and meet the new guidelines.

SOIL DISTURBANCE AND THE *INTERIM HARVESTING GUIDELINES*

The *Interim Harvesting Guidelines* define *soil disturbance* as that proportion of a cut block occupied by landings, unapproved haul roads, skid roads, heavily used skid trails, and backspar trails. *Unapproved haul roads* are roads that are "unplanned" and not identified on the approved harvesting plan. *Skid roads* are "bladed" or constructed, while *heavily used skid trails* are unbladed trails with ruts or impressions 5 cm or deeper in the mineral soil. The area occupied by skid roads is the product of the road's average horizontal width (measured from the top of the cut to the toe of the fill) and total horizontal length. The disturbance limits detailed in the *Guidelines* vary with a site's sensitivity to degradation caused by surface erosion, compaction, mass wasting, and displacement as defined by Lewis and Carr (1991). The limit is 19% of the total cut block for sites of low and moderate sensitivity, 9% for high sites, and 4% for very high sites. For all sites the limits include a maximum allowance of 4% for landings. Thus for a site of low or moderate rating there is a 15% allowance for skid roads, skid trails, and/or backspar trails.

FACTORS AFFECTING SOIL DISTURBANCE

Two FERIC studies in British Columbia, one in the East Kootenays and one in the Cariboo, suggest that there are four major factors, in addition to machine operator and supervision, that influence soil disturbance related to skid roads. These are: (1) slope and terrain; (2) season of harvesting; (3) types, sizes, and combinations of harvesting machinery; and (4) methods of locating skid roads.

Slope and Terrain

On steep sites it is usually necessary for crawler tractors to build trails (usually along the contour) for the skidders. Therefore, conventional ground-skidding operations (a crawler tractor working in combination with one or more rubber-tired skidders) usually create higher levels of disturbance on steep slopes (i.e. greater than about 30%) than on gentle slopes (less than 30%) (Smith and Wass 1976, Krag et al 1986).

Figure 1 shows average skid-road widths for slope classes in 10% increments, for both summer- and winter-harvested areas, for the East Kootenays study (Kockx, in progress). These widths are averaged for a variety of typical trail-building machines working on several study sites. Each graph groups results by season of harvesting because of characteristic differences between summer- and winter-built skid roads. (The reasons for these differences will be discussed later). The graphs show a gradual but distinct trend of increasing width with increasing slope, especially for winter-built skid roads. Widths of winter-built skid roads increase by an average of 20%, but widths of summer-built skid roads increase by only 10%, as slope increases from 30 to 60%. However, no relationship was evident between slope and skid-road density (average length of road per hectare). For blocks with similar average slopes, skid-road densities varied between 310 and 449 m/ha.

These data were obtained from sites with relatively uniform terrain. On complex terrain, trail construction and skidding patterns can vary considerably. Often the terrain dictates where trails must be located. Gullied or broken terrain can result in heavy skid-road disturbance; whereas on other sites, minor benches and grade breaks can be used for skid roads to reduce cuts and fills and thereby reduce disturbance.

Harvesting Season

Several studies in British Columbia have found that winter skidding on snow results in less soil disturbance than summer skidding operations (Smith and Wass 1976, Krag et al 1986). However, winter-harvested blocks in the Cariboo and Kootenay studies were found to have similar or even higher disturbance levels than summer-harvested units. The reasons for this lie in the definitions of soil disturbance used in these studies, and some characteristic differences of winter- and summer-built skid roads.

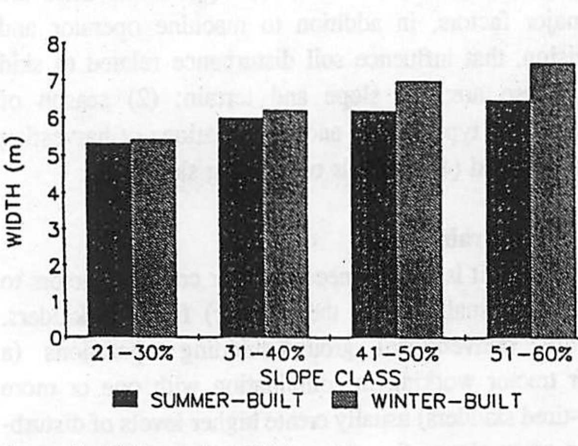

Figure 1. Skid-road width by slope class, for all trail-building machines.

Figures 2 and 3 show cross-sections of typical summer and winter skid roads. Typically, summer skid roads have a running surface of compacted mineral soil in both the cut and fill portions, and a loose, uncompacted sidecast consisting of a mixture of soil and organic debris. Winter skid roads, however, incorporate snow into the fill during construction, especially on steep slopes. As the snow melts in the spring, the outer part of the running surface collapses and leaves behind a loose mixture of soil and organic debris, similar to the sidecast material of the summer-built skid roads. In both studies, post-winter measurements showed that, due to slumping and ravelling of the unconsolidated fill and sidecast material during snowmelt, winter-built skid roads were wider than summer-built skid roads constructed with the same trail-building machine. However, the excavated portion of winter skid roads is usually narrower and shallower than the summer-built skid roads on comparable slopes. Figure 4 compares winter- and summer-built skid roads in the Kootenay study. Winter-built skid roads constructed with a Caterpillar D7 crawler tractor were an average of 26% wider than summer skid roads over the same three slope classes. However, though total widths were greater, the width of the excavated (or cut) portion averaged

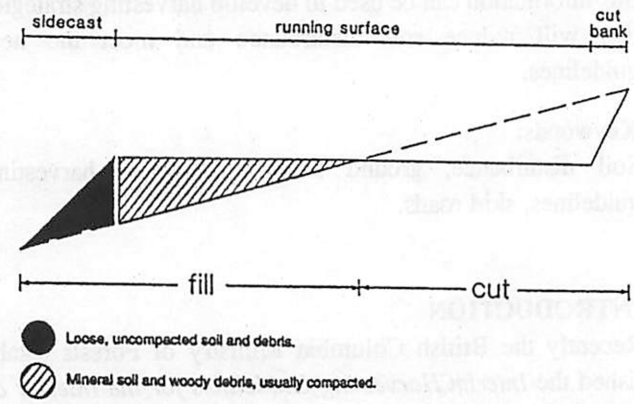

Figure 2. Cross section of a typical summer-built skid road.

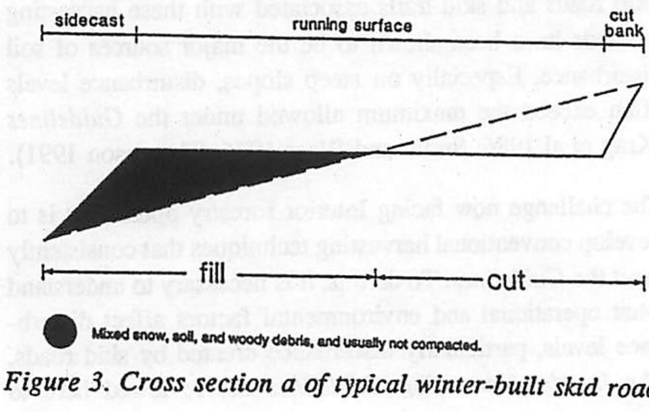

Figure 3. Cross section a of typical winter-built skid road.

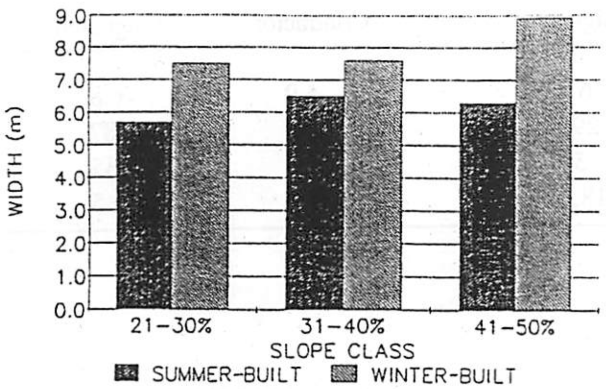

Figure 4. Comparison of summer- and winter-built skid roads, constructed with a Caterpillar D7.

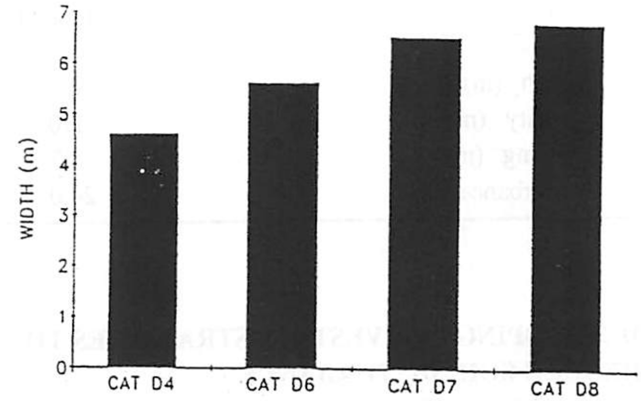

Figure 5. Comparison of skid-road widths for four trail-building machines, slope class 31-40%.

43% less for winter skid roads than summer skid roads. Therefore, although the overall width (i.e. from the top of the cut to the toe of the fill) of winter skid roads is greater, the extent of potentially detrimental disturbance is less than that of summer-built skid roads.

In the Cariboo study, skid road density in winter increased by 10% over summer operations. It is suggested that felled trees that did not reach the skid trail were more difficult to find and recover in deep snow, so logging contractors compensated by decreasing skid-road spacings in winter. No seasonal difference in skid-road density was detected in the Kootenay study.

Type and Size of Harvesting Equipment

As previously mentioned, the typical, or "conventional" harvesting system in the British Columbia Interior consists of one or more crawler-tractors and/or rubber-tired line skidders. A common variant is to use small crawler tractors instead of rubber-tired skidders. In addition to trail building, these machines are used for skidding and occasionally for minor road and landing construction. While most of the rubber-tired skidders are medium-sized machines, the size of trail-building machines can vary considerably.

Both studies report a distinct trend of increasing skid-road width with increasing machine size. Figure 5 compares average skid-road widths for four machines ranging in size from a Caterpillar D4 to a Caterpillar D8 crawler tractor. On slopes between 31 and 40%, skid roads built with a Caterpillar D7 or D8 were almost two metres wider than skid roads built with a D4 crawler tractor. For the same skid-road density, this increase in width produces almost a 40% increase in disturbance levels. The running surface widths of skid roads were also found to increase with the size of the trail-building machine.

Skid-Road Location

Most harvesting contractors in British Columbia locate and build their own skid roads. In this "contractor's choice" method, a main skid road is usually built prior to opening a falling face; secondary trails and roads are then located and built as harvesting progresses. Skid-road spacing using this method usually depends on tree height; typically an operator will space skid roads so that, when felled, trees will reach the skid road below. Another approach, the "designated skid road" method, is used infrequently in British Columbia, but is common in the Pacific Northwest of the United States. In this method, skidding patterns are planned in detail and skid roads are located and built prior to harvesting. Machine operators, harvesting supervisors, and layout personnel may all participate in locating skid roads. Skid roads are located to take advantage of terrain features such as benches. The distance between trails can be based on a predetermined minimum or average spacing.

Based on the Kootenay study, Table 1 compares skid-road disturbance levels associated with contractor's choice and designated skid-road methods for two side-by-side trials using the same operators and trail-building machines. On both blocks, skid-road densities for the designated-trail method were 20% less than for the contractor-choice method. Disturbance levels on the Cariboo Creek block were also 20% less. On the Donald Hill block, however, disturbance was reduced by only 8% because skid roads on the contractor's choice unit were much steeper and narrower than on the designated-trail unit.

Table 1. Comparison of Skid-Road Disturbance Associated With Contractor's Choice and Designated Skid Road Methods.

Unit	Cariboo Creek		Donald Hill	
	Contractor	Designated	Contractor	Designated
Width (m)	6.5	6.3	5.9	6.8
Density (m/ha)	370	295	355	287
Spacing (m)	27	34	28	35
Disturbance (%)	24.0	18.6	21.3	19.5

DEVELOPING HARVESTING STRATEGIES TO REDUCE SOIL DISTURBANCE

Although the specific results described in these studies may not be achieved in all situations, they illustrate techniques that harvesting operations managers can use to reduce disturbance. For the purposes of this paper, some of these specific results will also be used to show how to develop strategies to control soil disturbance.

Two interdependent tasks must be performed to develop harvesting strategies that minimize soil disturbance. First, it is necessary to identify feasible harvesting options for a given situation. A feasible harvesting option is one that has a reasonable chance of achieving a specified soil-disturbance target. Second, expected soil disturbance must be estimated for the feasible options and compared against the target level (Krag et al 1991).

Figure 6 graphs the relationship between skid-road width, density or spacing, and soil-disturbance levels. By matching an expected skid-road width with an expected skid-road spacing - based on slope and terrain, season, machine size, and trail-location method - an expected soil-disturbance level can be determined.

An example of this is highlighted in Figure 6. For a site with 40-50% slopes, a Caterpillar D6 would typically build 6.5-metre-wide skid roads. Skid-road spacings of 43 m or more would be required to achieve a 15% disturbance target, the maximum allowed for a site of low or moderate sensitivity. As an alternative, however, a Caterpillar D4 would construct 5-metre-wide skid roads, necessitating only a 33-m spacing to achieve the 15% target. If skid-road spacing was held at 43 m, the disturbance would be as low as 12%. If winter harvesting is prescribed, a 20% increase in skid-road width, depending on projected snow conditions, should be expected.

The above examples illustrate an approach to developing a harvesting strategy for achieving a desired level of disturbance. A number of harvesting alternatives may be possible

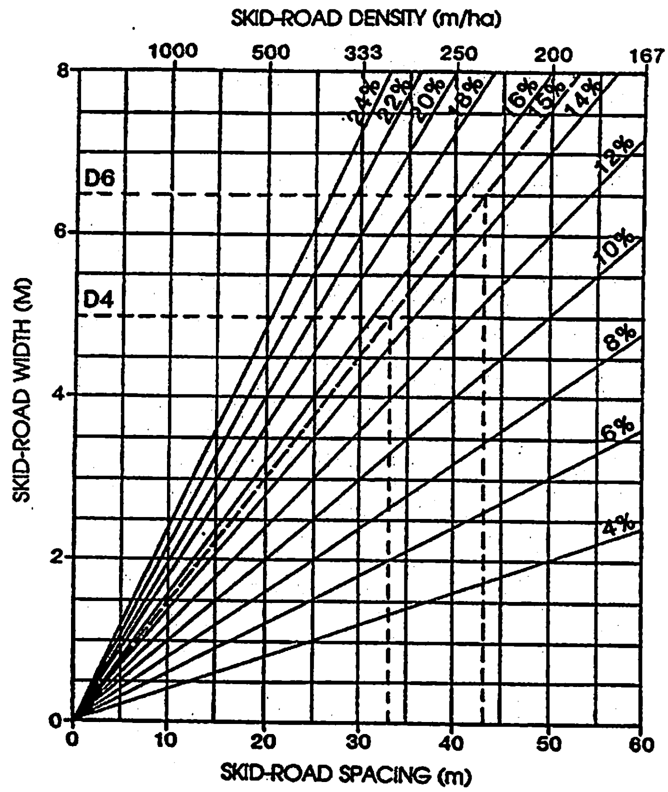

Figure 6. Soil disturbance vs. skid-road width and density (Krag et al 1991).

to meet or exceed soil-disturbance standards. Other factors such as cost, production, and system availability will affect the final choice.

CONCLUSION

With the implementation of the *Harvesting Guidelines*, forestry operations in the Interior of British Columbia, are challenged to meet or exceed soil-disturbance standards. Of primary concern are the levels of disturbance associated with skid-road construction on steep slopes. A number of operational and environmental factors have been found to affect skid-road-related soil disturbance. The results of two FERIC studies suggest that skid-road disturbance is strongly influenced by terrain and slope, harvesting season, type and size of harvesting equipment, and skid-road location. By predicting the extent to which these factors influence skid-road width and density (or spacing), an approach for estimating soil disturbance for a particular set of operating conditions can be developed. If soil disturbance is estimated in this manner, it is possible to analyze options and develop operational strategies that will achieve soil-disturbance targets.

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LOGGING REQUIREMENTS TO MEET NEW FORESTRY PRESCRIPTIONS

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ABSTRACT

The costs and logistics of ground skidding and cable logging are compared for three alternative silvicultural systems: clearcut, two-story and group-selection (1/2 acre openings). Two-story and group-selection layout was 2 to 5 times longer than clearcut layout largely due to detailed skidtrail and skyline road planning. On ground skidding units, total planning and logging cost for two-story and group-selection increased 16.4% and 2.4% respectively, over clearcutting. On cable units, total planning and logging cost for two-story and group-selection increased 23.4% and 24.7% respectively, over clearcutting. Logging safety around wildlife leave trees, felling logistics in future entries, and future cable system anchors need to be considered in more detail for silvicultural systems, such as group-selection, that involve repeated short interval logging entries.

Keywords:
New Forestry, Alternative Silviculture, New Perspectives, Harvesting, Logging Cost, Cable Yarding, Ground Skidding.

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INTRODUCTION

For the past 40 years, the standard technique used to regenerate even-aged stands of Douglas-fir (Pseudotsuga menziesii) has been clearcutting. This technique has been efficient for harvesting and regeneration of the timber resource throughout most of the Douglas-fir forests. However within the past few years, there has been a growing challenge to replace traditional even-aged silvicultural techniques with different regeneration methods and silvicultural systems. Currently we have a poor basis for evaluating the effects of alternative systems on economics, public acceptance, wildlife populations and tree regeneration.

One approach to development of new systems is to examine the intensities, patterns and frequencies of disturbances that once occurred in unmanaged forests. In Douglas-fir forests, disturbances occurred from a variety of sources such as competition, disease (root rot), insects, small ground fires, slope failures, windthrow and catastrophic wild fire. We should be able to produce a landscape that may partially imitate some of the structures and composition found in "natural" landscapes. However, approaches that imitate natural disturbances will likely have both economic and social trade-offs.

In the College of Forestry at Oregon State University (OSU), an interdisciplinary team of researchers has undertaken a study to compare timber harvesting, tree regeneration, wildlife, and social tradeoffs among three silvicultural systems that may partially imitate natural disturbances: clearcut (catastrophic fire), two-storied stand (windthrow), and group-selection (root rot diseases). Imposed on the three systems are differences in the arrangements of snags (scattered versus clumped). The specific timber harvesting study objective is to compare the costs and logistics of ground skidding and cable logging systems among clearcut, two-story, and group-selection harvests. This paper focuses on harvesting study results.

STUDY AREA AND METHODS

The study was conducted in 20 to 30 acre stands (logging units) in a 100 to 125 year old second-growth forest north of Corvallis, Oregon. These predominantly Douglas-fir stands regenerated naturally following widespread fires in the mid-to late-1800's. Certain mean stand characteristics are: diameter at breast height = 23 in., tree height = 107 ft., trees per acre = 60, basal area per acre = 187 sq. ft., and volume per acre (scribner bd. ft., 32 ft. log, 6 in. top) = 38,188 bd. ft. Silvicultural systems are outlined below:

1. Clearcut
   - retention of 2 trees per acre (snags created on 1.5 trees/acre by topping or blasting; 0.5 green trees/acre left)
   - snags scattered and grouped
2. Two-Story Stand
   - 12 overstory trees per acre left
   - 1.5 snags per acre created
   - snags scattered and grouped

- two-thirds of volume per acre removed compared to clearcut

3. Group-Selection
   - 1/2 acre openings
   - 1.5 snags per acre created
   - snags scattered and grouped
   - one-third of volume per acre removed compared to clearcut
   - remaining two-thirds of volume removed in two future entries

4. Control (Uncut)
   - no snags created

Three replications were selected and are being established in three consecutive years. Trees were planted following logging in all silvicultural systems. Harvesting cost and feasibility studies are being conducted on 2 replications although this paper deals with only one replication conducted between June 1990 to February 1991.

Ground skidding and cable yarding were studied on all silvicultural systems:

Logging Systems	Silvicultural Systems	Number of Units
Ground Skidding	Clearcut	2
	Two-Story	1
	Group-Selection	4
Cable Yarding	Clearcut	1
	Two-Story	1
	Group-Selection	2

Logging was completed by a contractor working on the OSU Forest; the contractor subcontracted felling and some hauling.

Ground skidding was conducted on terrain that was primarily less than 30% slope. Designated skidtrails spaced approximately 150 feet apart were layed out prior to felling and used for skidding in the two-story stand and group-selection stands. Landings and skidtrails were flagged by the researchers and reviewed by the logging contractor. In the clearcuts, designated skidtrails were not utilized and skidding was completed primarily with a JD 648 grapple skidder. The grapple skidder was also used in the group-selection units and for skidding logs located on designated trails in the two-story stand. An FMC 220 and FMC 210 with a winch were used for pulling logs to the skidtrail and skidding into the landing for other felled trees in the two-story stand. The FMC's were also used occasionally on steep portions of other units.

Uphill cable yarding was completed on units where a significant portion of the terrain was greater than 30% slope. Skyline roads (spaced approx. 200 ft - 250 ft) were layed out prior to felling and used for cable yarding in the two story stand and group-selection stands. Similar to the ground skidding units, landings and skyline roads were flagged by the researchers and reviewed by the logging contractor. In the clearcut, skyline roads were selected by the logger during the logging operation. A Thunderbird (TTY-50) mobile yarder was used for skyline yarding in all three treatments. Four operating lines were used for the slackline system with a mechanical slackpulling carriage (MSP). The MSP skyline carriage allowed for lateral yarding distances up to approximately 125 ft. on each side of the skyline. All skyline roads were logged as a single span; some required tailtrees to obtain necessary log lift and skyline deflection.

The following data was collected over a 9 month period:

1. Unit level logging planning and layout time by treatment
2. Logging shift level time and volume produced for felling, ground skidding, cable yarding and loading for all three silvicultural systems.

Shift level forms were completed daily by loader operators and lead cutters. They were collected weekly by either a OSU logging contract administrator or researcher. Data from the field sheets was entered into a spreadsheet and summarized. Equipment owning and operating costs were determined using the PACE software program. Equipment costs and labor rates were obtained from the USDA Forest Service Cost Guide for Empirical Appraisals - Revision 18.

LOGGING PLANNING AND LAYOUT

Logging planning with designated skidtrails and skyline roads was completed in the two-story stands and group-selection stands not only for the initial harvesting entry, but also for future entries. This is especially important in group-selections where only one-third of the volume is initially removed. Future openings must be logged without destroying previously planted openings. Figure 1 shows the planning scheme that we developed for a three entry-group-selection system. Skidtrails and skyline roads were first flagged on the ground for efficient logging. First entry skidtrail coverage ranged from 3% to 4% of the total area. Next, skidtrails and skyline roads were drawn on a topography map and 1/2 acre openings were identified for all three entries. Not all of the skidtrails and skyline roads were needed during the first entry. Additional spur skidtrails in future entries will increase the coverage to less than 8% of the total area. On group-selection cable units, we tried to concentrate as many openings along each skyline road as possible. The layout process was completed by using the design map to identify the appropriate first entry openings along the flagged skidtrails and skyline roads. Cut trees were painted roughly in a 1/2 acre circular shaped opening at each designated location. Following logging, main skidtrails and skyline roads were not planted so that they can be reused in future harvest entries.

Logging layout time is shown in Figure 2. On skidder units, since designated skidtrails were not used in the clearcut, an estimated skidtrail layout time, based on similar experiences in the other units, is also shown. On the cable units, an estimated layout time for the two-story stand without skyline road designation is also shown.

On clearcut units, the main planning activities were unit reconnaissance, flagging landings, running skyline ground profiles, marking wildlife leave trees and map work. On two-story units and group-selection units, the largest portion of planning activities involved flagging skidtrails and skyline roads along with additional time spent on developing detailed field maps. The maps however proved to be invaluable in guiding follow-up layout, logging and planting operations.

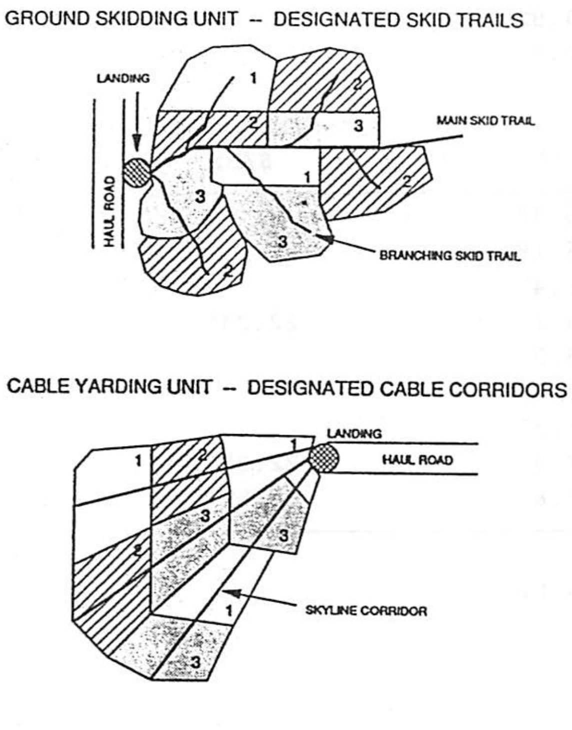

Figure 1. Group selection logging scheme (three entry system). Only portions of skyline spans, skidtrails, and group openings are illustrated.

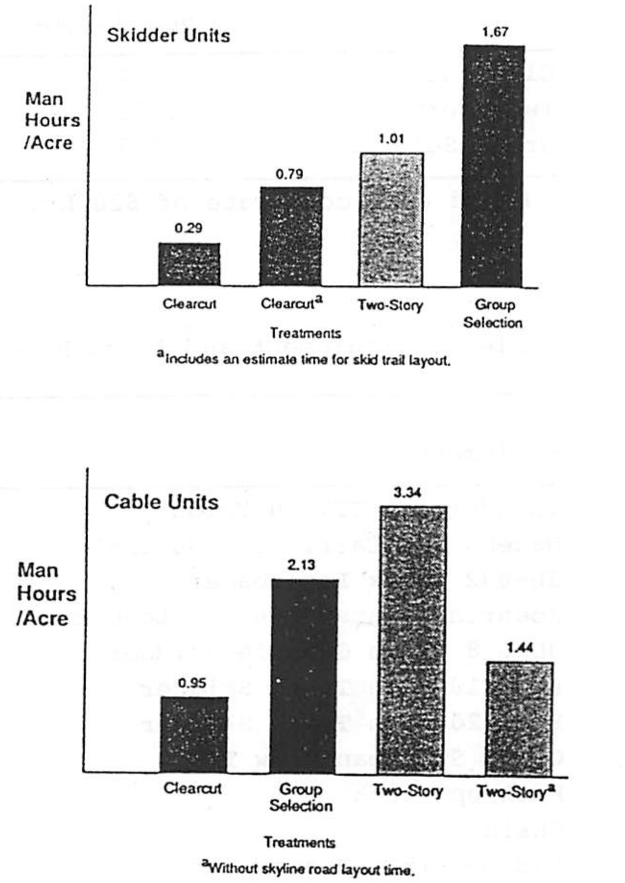

Figure 2. Logging layout times for skidder and cable units.

Logging layout time and cost related to the volume harvested is shown in Table 1. Lower volume removals in the two-story and group-selection treatments contributed significantly to higher cost. For example, in skidder units, group-selection layout took approximately 5 times longer per acre than clearcut layout (Figure 2) however the layout cost per MBF was approximately 19 times higher. Also, in cable units, group-selection layout took approximately 2 times longer per acre than clearcut layout (Figure 2), however the layout cost was approximately 6 times higher per MBF.

FELLING

Calculated equipment and labor rates used for felling, ground skidding and cable yarding cost determination are shown in Table 2. Felling production and cost are shown in Table 3. For all units, there were a total of 5184 trees felled, comprising 1781 total shift hours with 10 experienced cutters. The different cutters were evenly spread out over the three silvicultural systems. They had similar daily production rates within each silvicultural system.

Table 1. Logging Layout Time and Cost

Treatment	Skidder		Cable	
	Man Hours per MBF Removed Volume	$ per MBF[1]	Man Hours per MBF Removed Volume	$ per MBF
Clearcut	.007	$ .14	.019	$ .38
Two-Story	.036	$ .72	.126	$2.52
Group-Selection	.133	$2.66	.12	$2.40

[1] Based on a cost rate of $20/hr.

Table 2. Equipment and Labor Rates

Equipment	$/Hr	Combined $/Hr
Thunderbird TTY 50 Yarder	112.41[1]	118.10[2]
Danebo MSP Carriage (600 lbs)	1.25	
JD-892 Track Log Loader	54.61	60.06[3]
Koehring Bantam 266 Log Loader	39.23	44.68[3]
JD-648 Turbo Grapple Skidder	41.56	44.65[4]
FMC 210 Line Track Skidder	49.86	52.95[4]
FMC 220 Line Track Skidder	51.99	55.08[4]
Chevy Suburban Crew Truck	3.52	
Pick-up Truck	3.09	
Chainsaw	1.18	
Radio-Talkie Tooter	0.92	
Hydraulic Felling Jacks	0.69	

Labor	$/Hr[5]	Combined $/Hr
Loader Operator	16.84	
Yarder Engineer	16.18	
Chaser	15.47	
Hooktender	19.15	22.24[6]
Rigging Slinger	16.31	
Choker Setter, 2nd Rigger	13.23	
Skidder Operator	15.51	
Faller-Bull Buck	17.92	22.88[7]
Faller	16.80	19.52[8]

1 Includes all lines and rigging
2 Includes yarder, carriage, radio and crew truck
3 Includes loader, pick-up and 2 saws
4 Includes skidder and pick-up
5 Hourly rates include 40% burden
6 Includes pick-up
7 Includes chainsaw, pick-up and jacks
8 Includes chainsaw & 1/2 rate for pick-up

Table 3. Felling Production and Cost

Treatment	Average Log (Gross bd.ft.)	Production per Shift Hour (Gross MBF)	Felling Cost ($/MBF)	Percent Difference From Clearcut
Ground Skidding				
Clearcut	372	3.12	6.64	
Two-Story	261	2.76	7.43	+11.9%
Group-Selection	335	3.49	5.87	-11.6%
Cable				
Clearcut	391	3.89	5.33	
Two-Story	374	3.50	5.68	+6.6%
Group-Selection	391	4.03	5.15	-3.4%

Group-selection had the best results. Felling production was slightly higher and cost was lower compared with clearcut. In group-selection, all cut trees were painted in the approximate 1/2 acre openings and they were painted in the skidtrails and skyline roads. This made it relatively easy for cutters to identify trees for felling. There were typically several options for each tree lay. Many trees were felled into standing timber around the 1/2 acre openings. Since the timber stand was relatively lightly stocked, the risk of hangups and danger from tree tops breaking was minimized, however this could be a safety concern in other situations. Since many of the tree tops fell outside the 1/2 acre openings, slash levels were low which helped in tree planting.

The two-story stand had the lowest production and highest cost. Twelve leave trees per acre were marked and left in this partial cutting silvicultural system. Stage falling was completed in the ground skidding unit. Skidtrails were felled and skidded first, followed by partial cut felling to lead with the skidtrails. Wedging was often needed to fell the trees in an appropriate lay. We had expected more use of hydraulic tree jacks in both the two-story and group-selection treatments. However, wedging met most of the directional felling needs. Tree jacks were used occasionally to fell trees away from a riparian management area and a property line. When the jacks were used, felling time per tree increased approximately 83%.

Contrary to what would be expected, felling production was lower and cost was slightly higher in ground skidding units than cable units. The explanation for this is that logs were slightly smaller in the ground skidding units and the terrain was not excessively steep or broken in the cable units.

GROUND SKIDDING

Ground skidding costs are shown in Table 4. There was 3,417 MBF logged in ground skidding units. Total skidder and FMC machine hours was 576. Skidding cost was lowest in group-selection, followed by clearcut and two-story.

On ground skidding group-selection units, removing only 1/3 of the total volume did not adversely affect logging cost. This seems reasonable because the skidder could easily move into the openings and travel between openings along designated skidtrails. In fact the logging planning and layout work helped improve the operational phase. Skidder operators could easily find the 1/2 acre openings on the field maps they were provided. Trees were also layed in a good lead for easy hooking and skidding with the grapple skidder.

The two-story stand had a higher logging cost for two main reasons. First, designated skidtrails involved stage logging and winch line pulling which increased logging time. Second, there were some unit conditions and operational characteristics that contributed to lower skidding efficiency and production. This unit had the smallest average log size. In addition, part of the logging was completed in early fall and then stopped due to wet weather conditions. When logging resumed during a dry period in the winter, a relatively large crew size was used. In other more favorable conditions with larger logs similar to the other treatments, we would expect skidding cost to drop slightly but still remain higher than clearcutting.

CABLE YARDING

Cable yarding production and costs are shown in Table 5. There was 2,653 MBF logged in cable yarding units. Total

Table 4. Ground Skidding Cost

Treatment	Average Log (Gross bd.ft.)	Skidding Cost ($/MBF)	Percent Difference From Clearcut
Clearcut	372	25.89	
Two-Story	261	29.88	+15.4
Group-Selection	335	24.93	- 3.7

Table 5. Cable Yarding Production and Cost

Treatment	Average Log (Gross bd.ft.)	Production per Yarder Shift Hour (Gross MBF)	Yarding Cost ($/MBF)	Percent Difference From Clearcut
Clearcut	391	8.10	39.92	
Two-Story	374	6.51	48.13	+20.6
Group-Selection	391	6.38	49.33	+23.6

yarder machine hours was 371. Yarding crew size was typically eight: yarder engineer, loader operator, two chasers, rigging slinger, two chokersetters and a hooktender. An additional choker setter was used occasionally.

Yarding production dropped 12.8 MBF per 8 hour day (approx. 2.5 truck loads) and 13.8 MBF per 8 hour day (approx. 2.7 truck loads) in two-story and group-selection, respectively. In contrast to ground skidding, cable yarding cost in the two-story and group-selection silvicultural systems increased significantly (21% to 24%) over clearcutting. The main reason is that less volume is being removed in these partial cutting treatments. Unlike ground skidding, a substantial part of cable yarding time is spent setting up the yarder and changing cable roads. This represents a non-productive time when no logs are yarded to the landing. It is also a costly part of the operation because of a relatively large crew size and higher equipment cost compared to ground skidding. Therefore, overall yarding cost increased when a higher proportion of time was spent setting up cable roads and a lower proportion of time was spent yarding logs. This affect was exaggerated even more in one of the group-selection units where there were relatively short yarding distances and parallel cable roads. The parallel cable roads resulted in longer road change time because the yarder was moved each time. In this situation, yarding costs were approximately 45% higher than clearcutting.

It is interesting that the costs were only 3% higher in group-selection than two-story even though only 1/3 of the total stand volume was removed in the former and 2/3 was removed in the later silvicultural system. Our explanation is that cable yarding efficiency was better when logs were grouped in small clearcut openings than scattered among standing leave trees. The cable road planning and layout also contributed to the ease of yarding.

TOTAL COST SUMMARY

There were a range of factors that either increased or decreased logging cost between the three silvicultural systems studied (Table 6). Clearly an increased level of logging planning and field layout was required for successful implementation of two-story and group-selection silvicultural systems compared to clearcutting. The planning however paid off later in the logging operation but there were some significant up front time commitments and costs associated with low volume per acre removals.

The felling component was least affected by partial cut silviculture alternatives. In fact, felling costs were lowered in group-selection cable units and ground skidding units over clearcutting by 3.4% and 11.6% respectively. Ground skidding cost was most impacted in the two-story silvicultural system while cable yarding cost was most

Table 6. Total Cost

	Silvicultural Systems		
	Clearcut ($/MBF)	Two-Story ($/MBF)	Group-Selection ($/MBF)
Ground Skidding			
Logging Layout	.14	.72	2.66
Felling	6.64	7.43	5.87
Skidding	25.89	29.88	24.93
Total	32.67	38.03	33.46
Cable			
Logging Layout	.38	2.52	2.40
Felling	5.33	5.68	5.15
Yarding	39.92	48.13	49.33
Total	45.63	56.33	56.88

impacted in the group-selection silvicultural system. The bottom line in our study for ground skidding was an increased total cost for two-story and group-selection over clearcutting of 16.4% and 2.4% respectively. For cable yarding, the total increased cost over clearcutting for two-story and group-selection was 23.4% and 24.7% respectively.

FUTURE STUDIES AND CONCLUSIONS

There are additional logging items that need to be considered with silvicultural systems that involve future logging entries such as group-selection. First are wildlife trees recruited for future snags by top blasting or cutting. These snags can be future logging hazards and their location relative to future felling, skidding and yarding activities needs to be fully considered.

Second, future felling entries will most likely require more directional felling and limited options for tree lays in order to avoid felling large trees into patches of small trees. In the 1/2 acre opening design, some damage to small trees in replanted patches will occur because large-tall trees can not be contained in future 1/2 acre openings. In addition, there could be considerable tree damage in future entries if skidding or yarding through patches with small trees was needed. Laying out the primary skidding or yarding design at the same time for the first entry and future entries will minimize this problem.

Third, for cable yarding, consideration must be given for future yarder guyline anchors and tailtree or tailstump needs. In this study we tried as much as possible, to leave trees in appropriate locations for future guyline and tailhold anchors. In some situations, tailtrees can be protected during the first logging entry by using rigging gear such as tree plates or nylon straps. Even with this level of planning, future entries may involve more costly alternative anchors such as buried logs or substitute earth anchors. There may be alternative group-selection designs than the 1/2 acre circular opening that are more efficient for cable logging. In the third replication of this study, we are currently in the process of designing and evaluating alternatives such as small wedge-shape openings and rectangular strip-shape openings.

This study showed an example of the logging planning and operational requirements needed to meet new forestry prescriptions. It points out the need for technically trained forest engineers to be involved in the design and implementation of future silvicultural systems. The study also presented the increased cost of new forestry prescriptions. This is one piece of information for evaluating alternative silvicultural systems. In addition to logging cost, information on long range economics, public acceptance, wildlife populations, tree regeneration and future growth needs to be integrated together. This is the overall aim of the OSU interdisciplinary team of scientists working on this project.

SKYLINE CABLE YARDING IN THE INTERIOR OF BRITISH COLUMBIA: A CASE STUDY

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ABSTRACT

A small capacity skyline yarding machine, the Skylead C40, was evaluated on an Interior site in British Columbia to determine whether this type of yarding system would operate effectively under Interior conditions. Time study analysis indicated that this type of system can work effectively on moderate slopes, remaining productive and providing wood to the landing at an acceptable cost. Study results suggest that the yarder typically operates at 69 to 70 percent utilization, with few machine related delays. Productivity was observed to average between 20 and 25 m^3 per scheduled machine hour at an estimated cost of $5.60 per m^3. Turn size was shown to be a critical factor in determining the cost of this yarder, with optimal yarding volumes estimated to be slightly greater than observed volumes of 1.9 m^3 per turn. To effectively operate this type of system, more emphasis must be placed on matching layout and design with system capabilities.

Keywords:
Small capacity yarder, standing skyline, time study analysis, and machine cost analysis.

INTRODUCTION

The use of ground-based harvesting systems in the Interior of British Columbia can lead to soil disturbance, erosion, and detrimental visual impacts (Cottell et al., 1976). In addition, soil compaction on primary skid trails has been found to reduce productive growing area on sites harvested with ground-based skidders by 25 to 30 percent with significant reductions in stand growth (Wert and Thomas, 1981; Froelich et al., 1986).

In contrast, cable yarding systems hold a number of site related advantages over ground-based skidding such as reduced site disturbance, fewer roads or trails, and negligible soil impacts. These systems have occasionally proven successful in the Interior of British Columbia, but are not widely accepted due to problems with machine size, crew experience, and operating costs.

A study by Cottell et al. (1976) suggests that, to become widely used in the Interior, cable yarding systems should be productive in the smaller timber and lower per-hectare volumes common to the region. A yarding system for Interior conditions would generally be characterized by smaller payloads, lower operating costs, and lower investment costs. Few cable systems with these characteristics have been marketed in the Interior and, as a result, cable yarding has not been used to any significant degree in the region.

This study evaluates the Skylead C40, a small capacity yarder system which has potential application on many Interior sites. The Skylead C40 cable yarder is equipped with a 12.2 m tower powered by a separate 116 H.P. Cummins 4 cylinder diesel engine and is commonly mounted on a skidder frame. It is typically configured as a standing skyline using a conventional three-drum setup, and is also equipped with a strawline drum and three guyline drums. The C40 utilizes a Mini-Mak radio controlled hydraulic self-clamping carriage which uses the mainline for lateral yarding operations.

The purpose of the study was to evaluate the yarder system during operation and develop production estimates and per unit cost estimates. The study evolved as a joint project between the University of British Columbia Department of Harvesting and Wood Science and Canadian Forest Products Ltd. (CANFOR), a major forest products company with extensive operations throughout the Province.

STUDY METHODS

The study site was located in the Graham River area, approximately 75 kilometres southwest of Mile 101 on the Alaska Highway in Northeastern British Columbia. Approximately 0.5 meters of snow was present on the ground throughout the study and temperatures ranged from -5 Celsius to +5 Celsius.

Soils in the area were moderately deep to deep, poorly drained, of poor structure and low natural fertility. The topography of the study site can be best described as moderate to steep (20 - 40 percent slopes), with broken, gullied terrain. Timber on the study site was a mix of Engelmann spruce (Picea engelmannii) - comprising 44 percent of the net merchantable volume (NMV), lodgepole pine (Pinus contorta) - with 39 percent NMV, and subalpine fir (Abies lasiocarpa) - with 17 percent NMV. The total net merchantable volume on the site averaged 211 m^3 per hectare.

The yarder was configured as a conventional "shotgun" system, where the carriage runs downhill by gravity on the skyline. The carriage was not equipped with a skidding line. Instead, the mainline was passed through the carriage and controlled hydraulically to allow for lateral yarding for distances up to 50 metres. The operation was designed in an integrated manner where logs yarded to the machine would be re-choked onto a line skidder and skidded to a larger roadside landing for further processing and storage.

Generally, each turn was skidded to roadside immediately, but periodically two or three yarder turns were piled at the base of the yarder and skidded to the larger landing at one time. Interactions between the yarder and the skidder occurred during these operations, causing yarder delays associated with removing yarded logs from the landing.

The yarder was located on previously built skid trails or at the edge of previously located landings. It was observed working on six different yarding roads ranging in length from 120 to 140 meters slope distance, and ranging in slope from 28 to 35 percent. The skidder moved logs to two different landings during the study: one approximately 260 meters from the yarder; the other roughly 30 meters from the yarder.

A detailed time study was performed on the yarder for a five day period. The detailed timing data was collected with the aid of a previously programmed, hand-held computer. Each log was numbered as it arrived at the yarder, and hand-scaled on the landing between the forwarding and decking stages. The logs were scaled for gross volume to a 10 cm top. This enabled the subsequent allocation of volume to each turn yarded.

Continuous timing measurements of work cycle elements were taken throughout each day. These work cycles were broken down into the following time elements: outhaul, hookup, lateral yarding, inhaul, unhook, delays and yarding road changes. Observations pertinent to the various time elements were collected and input into the hand-held computer.

Yarded logs were hand-scaled and the measurements recorded manually. Company employees at the Fort St. John Division of CANFOR input the individual log measurements into a software program which provided an indication of gross log volume (up to a four inch top). The log volumes were assigned to their respective yarder turns in the spreadsheet to provide an estimate of gross volume per turn. A factor of 1.3 m^3/tonne was used to convert the cubic volume to mass (regardless of species) for each turn. This conversion factor was supplied by CANFOR, and is specific to the area studied.

The yarder data were plotted by work cycle element with time as the dependent variable and distance, volume, or number of pieces as the independent variable. Each plot was assessed, and outliers eliminated using a visual technique. Linear regression analysis was then performed on the data to develop estimators of machine productivity.

RESULTS AND DISCUSSION

Production Analysis

Table 1 details the timing results for the yarder. Timing elements were separated into either productive and non-productive categories.

Productive time includes outhaul, hookup, lateral yarding, inhaul, unhook, and yarding road changes. Hookup and Unhook elements required the greatest amount of time to complete, averaging 2.43 and 0.94 minutes per occurrence, respectively. Outhaul and Inhaul times averaged 0.45 and 0.52 minutes, respectively, while the Lateral Yarding element averaged 0.44 minutes per occurrence. A typical yarding cycle, based on these observations, was estimated to average 4.78 minutes per turn, excluding delays and road changes.

Non-productive, or delay, time for the yarder is detailed in Table 2. Yarder delays observed during the study comprised 28.5 percent of the total scheduled time and accounted for an average of 2.61 minutes per turn, based on a total delay time during the study period of 647.28 minutes for approximately 248 turns. Seven categories of delay were observed during the study with operational and personal delays causing the greatest percentage of total downtime, approximately 60 percent of the observed delays.

Operations were delayed 53 times while waiting for the skidder to remove logs from the landing with an average delay of 1.04 minutes per occurrence. This problem evolved due to the limited size of the landing and the need to keep the area in front of the yarder clear. On sites where the landing size is less critical, this delay element may be significantly reduced.

Operational delays, where the yarder was idle due to operationally related problems, were observed a total of 33

Table 1: Timing Results for the Skylead C40 Cable Yarder[1]

CYCLE ELEMENT	Mean Time (minutes)	Standard Deviation (minutes)	Number of Observations
OUTHAUL	0.453	0.524	272
HOOKUP	2.431	0.766	96
LATERAL YARDING	0.437	0.169	99
INHAUL	0.524	0.453	270
UNHOOK	0.939	0.449	102
ROAD CHANGES:			
YARDER MOVE[1]	19.487	19.395	10
TAILHOLD MOVE	10.780	4.221	12

[1] Yarder road changes sometimes involved changing both yarder and tailhold locations.

Table 2: Delay summary for yarder.

DELAY CATEGORY	NUMBER OF OCCURRENCES	MEAN TIME PER OCCURRENCE (minutes)	PERCENT TOTAL DELAY TIME[2] (%)
WAIT SKIDDER	53	1.04	8.6
MECHANICAL	5	18.05	11.8
PERSONAL			
Lunch	4	42.10	27.4
Other	24	1.12	4.4
OPERATIONAL	33	6.55	33.1
SERVICE	4	6.94	4.5
WARMUP	4	14.15	9.2
LOG PROCESSING	9	0.68	1.0
DELAY PER TURN[1]	248	2.61	100.00

[1] Delay per turn was estimated from 248 complete turns observed during the study.

[2] Based on a total scheduled operating time of 2154 minutes, the above delays accounted for 647.3 minutes, or approximately 30.05 percent of scheduled operating time.

times with an average time per occurrence of 6.55 minutes. These problems may have resulted from crew inexperience or site related difficulties.

Table 3 quantifies the independent variables associated with the yarding operation. Mean observed in-haul distance averaged 74.24 meters, while out-haul distance averaged 69.95 metres. The maximum yarding distance observed during the study never exceeded 140 meters. Lateral yarding distance averaged only 15.20 meters, but ranged to a maximum of 50 metres. Turn size averaged 3.77 pieces per turn with a standard deviation of 0.96 pieces and ranged from a minimum of 1 piece per turn to a maximum of 7 pieces. Volume per turn was estimated to average 1.90 m^3 with a standard deviation of 0.48 m^3, based on the observed number of pieces per turn and volume-per-piece estimates developed by CANFOR for the study.

Each work cycle element of the yarder was related to several different independent variables using ordinary least squares regression analysis to obtain model coefficients. Outliers were removed from the dataset prior to developing the regression equations. Table 4 summarizes the results of these regressions for each work cycle element. Regression models for the Outhaul and Inhaul elements incorporated one variable, yarding distance, to estimate elemental times. Hookup proved to be significantly related to lateral yarding distance and number of pieces hooked per turn. The estimator for lateral yarding time incorporated lateral yarding distance and volume per turn. Least squares analysis indicated no relationship between Unhook and any of the independent variables measured during the study. As a result, the average elemental time for Unhook was used when developing a model for estimating total cycle time.

Table 3: Summary statistics for independent variables.

INDEPENDENT VARIABLE	Observed Mean	Standard Deviation	Number of Observations
INHAUL YARDING DISTANCE (m)	74.24	35.69	250
OUTHAUL YARDING DISTANCE (m)	69.95	37.41	266
LATERAL YARDING DIST. (m)	15.20	8.07	263
PIECES PER TURN (pcs)	3.77	0.96	258
VOLUME PER TURN (m^3)[1]	1.90	0.48	258

[1] Volume per turn was estimated from scale data provided through CANFOR and the observed value for PIECES PER TURN.

Table 4. Work Cycle Element Regression Variables and R^2 Values

ELEMENT	AS A FUNCTION OF:	R^2
Outhaul	Yarding distance	0.190
Hookup	Lateral yarding distance Number of pieces per turn	0.257
Lateral Yarding	Lateral yarding distance Volume per turn	0.236
Inhaul	Yarding distance Volume per turn	0.300

The developed regression equations were then combined to produce a model for estimating yarder cycle times:

$$CT = 2.377 + 0.0124(x_1) + 0.053(x_2) + 0.033(x_3) + 0.196(x_4)$$

where:

CT = Cycle Time (productive minutes)
x_1 = yarding distance (m)
x_2 = lateral yarding distance (m)
x_3 = gross volume per turn (m^3)
x_4 = number of pieces per turn

The time required to change roads, estimated to contribute 1.371 minutes per turn, was added to better estimate the total cycle time.

$$TCT = 2.377 + 0.012(x_1) + 0.05(x_2) + 0.033(x_3) + 0.196(x_4) + 1.371$$

where:

TCT = Total Cycle Time (productive machine minutes)

Scheduled and unscheduled delays during operation accounted for approximately 30.05 percent of the scheduled operating time for the yarder (See Table 2). Machine utilization was estimated to average 69.95 percent, based on a total productive period of 1506 minutes and a total scheduled time of 2154 minutes.

Delay times were not included in the regression model for machine productivity. Instead, average delay time per turn was accounted for through the machine utilization rate. Estimates of productivity on a scheduled hour basis incorporate the machine utilization rate and account for delay time as a percentage of scheduled machine operating time.

Cost Analysis

The yarder was costed on a productive and scheduled machine hour basis using the conventional machine rate approach (Miyata, 1980). A cost summary for the system is detailed in Table 5.

Table 5: Summary of costs for estimating a machine rate for the Skylead C40.[1]

COST ELEMENT	COST PER SCHEDULED HR[2]	COST PER PRODUCTIVE HR[2]
OWNERSHIP COSTS		
Depreciation	$ 8.71	$12.45
Interest	$13.57	$19.40
Insurance	$ 0.86	$ 1.23
Total Ownership costs:	$ 23.14	$ 33.08
OPERATING COSTS		
Line Costs	$ 5.63	$ 8.05
Rigging Costs	$ 0.37	$ 0.53
Fuel Costs	$ 1.14	$ 1.63
Lube and Oil Costs	$ 0.11	$ 0.16
Repair and Maintenance Costs	$ 2.96	$ 4.23
Labour Costs	$60.08	$85.89
Total Operating Costs:	$ 70.29	$100.49
TOTAL COST:	$ 93.43	$133.57

[1] Based on an annual operating period of 1350 scheduled machine hours or 944 productive machine hours.

[2] Assumes a 69.95 percent utilization rate for estimating costs on a productive hour basis.

The Skylead C40 cable yarder as configured for this study averaged \$93.43 per scheduled machine hour (SMH), or \$133.57 per productive hour basis, to own and operate. This information was combined with the developed production equation to identify factors that most significantly affect per unit costs for the yarder system.

Figure 1 illustrates the impact of changes in mean volume and number of pieces per turn on costs. The analysis assumes that the average volume per piece remains constant at 0.504 m^3 and that volume per turn is increased only by adding more logs per turn. Thus, for this study, volume per turn averaged 1.9 m^3 and the expected cost - depending on average yarding distance - ranged from \$5.22 to \$6.47 per m^3. This simplistic comparison has some drawbacks in that no provision is made for increases in the number of road changes required for yarding shorter distances or variability in log size. For the mean yarding distance observed during this study, 74.24 metres, the expected cost for yarding a 2 m^3 turn is estimated to average \$5.60 per m^3.

The graphed cost data in Figure 1 suggest that the cost per cubic metre rapidly decreases as mean turn volume increases - at least initially. After reaching a mean load volume of 3 cubic metres, the cost per cubic metre for yarding falls less dramatically. Increases in turn size to 4 and 5 cubic metres per turn have little impact on per unit costs. Thus, an average turn volume of 2.5 to 3 metres per turn (5 to 6 logs in this study) should be targeted for production to reduce per unit costs. Any increase in turn volume to that point substantially reduces the cost per cubic metre when yarding with the Skylead.

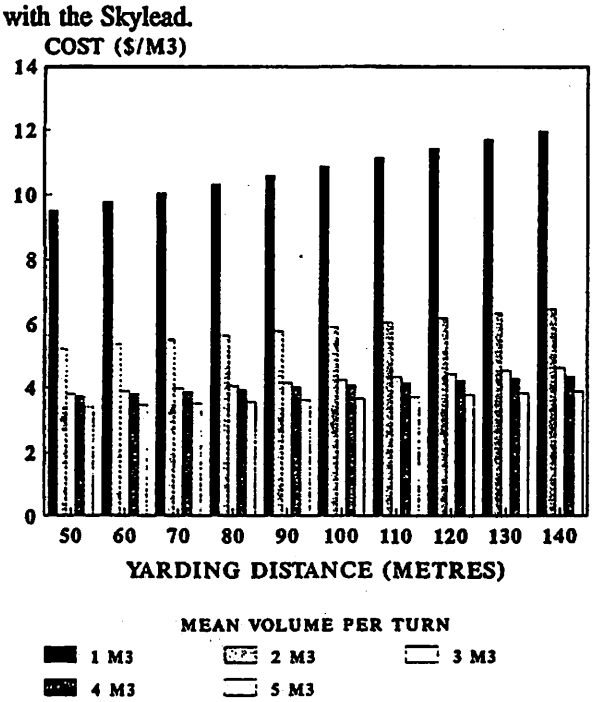

Figure 1. Cost comparisons for different average distances and turn volumes.

CONCLUSIONS

The Skylead C40 yarder, utilizing a standing skyline, a Mini-Mak carriage, and a "shot gun" gravity configuration, has demonstrated versatility in an area where conventional ground-based systems were considered inappropriate. And, unlike large capacity yarders used for Coastal applications, this system was capable of yarding logs at relatively low cost, less than \$6 per m^3 for this study.

During the study period, the yarder averaged 225 pieces and 59.75 turns per shift. This production is satisfactory, although piece size becomes a critical factor in production (See Fig. 1). Minor mechanical and operational delays associated with the yarder contributed to a machine utilization rate of 69.95 percent. However, this estimate may be optimistic, since little long-term delay data was obtained during this study.

The efficiency of any yarding operation is closely tied to the planning phase of forest development. The study area was originally laid out for a conventional skidding system. Emphasis on planning for small skyline systems such as the Skylead would probably improve yarder productivity and reduce per unit costs associated with yarding.

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CANFOR'S EXPERIENCE WITH LARGE SLACKLINE AND SKYCAR SYSTEMS

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ABSTRACT
Since March of 1990 Englewood Logging Division of Canadian Forest Products ltd. has been using a large slackline yarder with a motorized carriage in longline applications. Although the introduction of this system has not been without problems, by most standards of measure it has been successful.

Keywords
Slackline yarder, Motorized carriage (skycar), Longline.

FULFILLING A NEED
For too long forest managers have tended to address coastal accessibility problems by either avoiding the difficult terrain, or constructing road on questionable slopes in order to log with grapple or highlead yarders. The former "deferral" of the problem has resulted in concerns of licensees demonstrating their abilities to harvest the total profile of the calculated A.A.C. while the latter has resulted in some areas with slope stability problems, visual impact problems, site loss, and hazardous working conditions.

For the past two decades, longlines have been used extensively in Washington and Oregon to address these concern. After inventorying the suitable terrain within our TFL we toured many of these longline operations in the fall of 1989. Concluding that the large slackline and skycar system was the best solution for us and involving our crews in the process, we purchased the required equipment.

THE SYSTEM
The slackline yarder/skycar system combines the advantages of a live skyline with lateral yarding capabilities only partially achievable with mechanical slack pulling carriages. These include the ability to shotgun (gravity outhaul) and still use the dropline without a slack pulling line or Tag line and skyline clamp.

The slackline yarder consists of a mobile self propelled or trailer mounted 4 drum yarder (skyline, mainline, haulback, strawline). The spars range from 45' to 110' in height with from 3 guylines and buckle brace to 8 to 10 guylines on the large pipes. We opted for the largest available yarder in the used equipment category which was a 1972 Washington 217D. This is an 1 1/2" skyline rated yarder, self propelled on rubber with a 110' spar and 8 guylines. Capable of holding enough skyline to span 10,000' or more, it spools 3300' of 1 1/2" swaged skyline, 4000' of 1" swaged mainline and 6800' of 3/4" swaged haulback. It is powered with a 1710 cubic inch V-12 Cummins engine with a 5 speed twin disk transmission.

The carriage we chose was a new Boman Mark II skycar. This carriage weighs 8000 lbs., spools 750' of 5/8" swaged dropline on a gear driven drum powered through a 2 speed twin disk transmission by a 6 cylinder Deutz air cooled turbo charged diesel engine.

A line spooler and transfer machine are valuable accessories with the system.

APPLICATIONS
The slackline/skycar system can be sued in an uphill or downhill (across the valley backslope) configuration. Uphill is the preferred configuration due to the ability to shotgun and forego using the haulback. Yarding distance are limited to the spooling capacity of the running lines (mainline and haulback) but could include that distance anywhere along the skyline span if the landing and the yarder are on different roads. Skycars and other skyline carriages can have Tommy Moore shives enabling them to ride over flush pin shackles connecting skyline extension tags.

CRITICAL FACTORS
Social
As with any logging system the crew's safety, abilities, motivation, attitude and morale are key to the success of skyline logging. Attracting and keeping good people in these key jobs is a major challenge. The trend towards grapple yarding with mobile back spars has not encouraged development of all of the rigging skills required on the slacklines. We are fortunate at Englewood Division to have an excellent crew and committed foreman working on our first machine and anyone who has seen the shows can attest to the fact that they have not been creamy.

Physical
Deflection and skyline diameter are the most critical factors in determining skyline payloads. Leaving enough slack in the skyline to utilize its safe working load to handle a good turn and carriage weight requires layout with deflection preferably in excess of 10%.

Example: A 3000' span of 1 1/2" swaged skyline at only

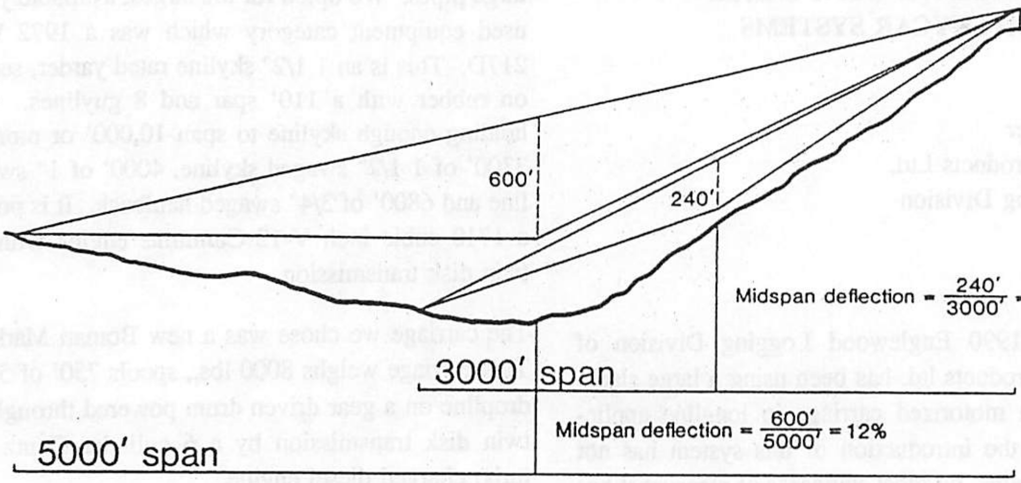

Figure I.

8% midspan deflection at 50% span slope with our 8000 lb. skycar has a net safe working load (fully suspended payload) of only 8000 lbs. A 5000' span of 12% midspan deflection of the same system with a 20% span slope has a nest safe working load of 19000 lbs. or a 137% increase.

Anchoring both the skyline and guylines adequately requires flexibility to utilize multiple stumps, standing trees tied back, rock anchors or dead men.

ADVANTAGES OF THE SYSTEM

Full suspension of logs over streams, rough terrain, and standing timber is a major advantage of longline, helicopter and balloon logging. However, longline yarding can also partially suspend turns which means overweight full length logs can be handled in steep terrain where bucking is a problem. As well hang ups are minimized reducing physical damage to root mat structure on sensitive slopes.

Reduction in the amount of midslope roading and the accompanying poor landing sites are a major plus in cost savings, safety and the environment.

Breakage reduction is a significant advantage of this system over grapple and highlead systems. Although difficult to measure, we feel saving of $\$0.50/m^3$ to $\$1.00/m^3$ are probably not unrealistic estimates of saving out logs that would have been otherwise damaged.

COSTS OF THE SYSTEM

Capital Costs

With the cost of building new large slackline yarders well over $1,000,000 and the number of used machines available from Washington and Oregon, we opted for a used yarder. Figure II shows the shift cost of operating the total system. The depreciation shown is comprised of a 10 year straight line figure based on Capital equipment cost of $600,000. This consist of the slackline yarder with new rigging, one new carriage ($100,000) one spare rebuilt carriage ($60,000), transfer machine, and line spooler.

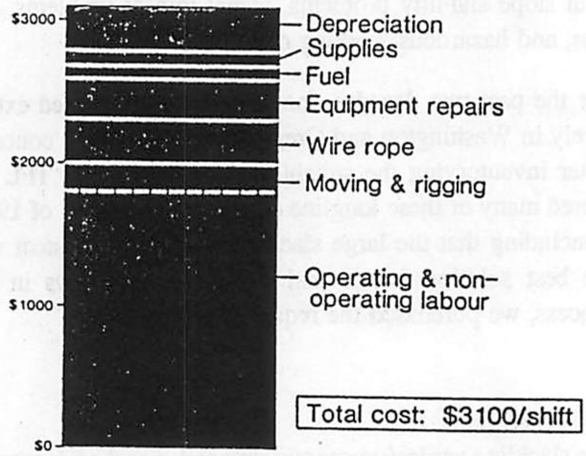

Figure II.

Operating Costs

The operating costs shown on Figure II are our actual costs less non recurring start up costs. These include landing construction but do not include travel and crew bus time.

Productivity averaged 224 cu. metres/shift for 147 operating shifts.

Appraisal Costing (Figure III)

For comparative purposes, I plotted yarding distance versus tree to truck cost ranges from the Ministry of Forest appraisal manual for grapple/highlead, skyline (grapple/highlead plus skyline additive) and helicopter. Added to this is our actual experience with various average yarding distances. These show that costs incurred are generally within reasonable range of the skyline allowance. More experience is necessary for detailed comparison with confidence.

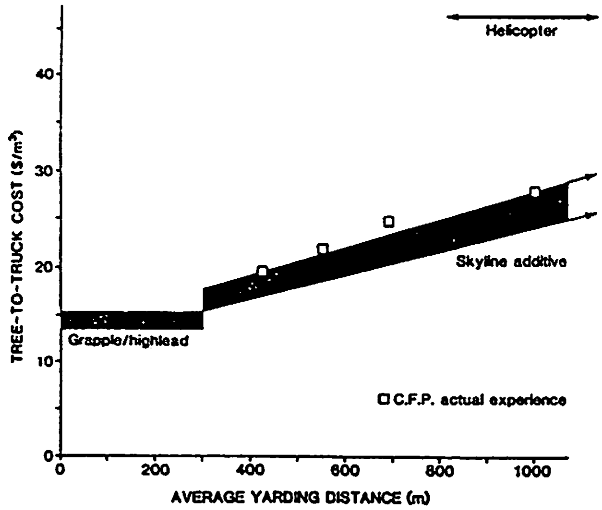

Figure III.

CONCLUSIONS

From our experience, in terms of costing and environmental considerations, the slackline/skycar represents a system capable of bridging the gap between grapple yarding and helicopter yarding.

On measure of how successful the slackline/skycar longline system has been for us is that we have already purchased our second system and have successfully started up this May.

SESSION III:

HARVESTING THE NEXT FOREST

EVALUATION OF ROTTNE CUT-TO-LENGTH HARVESTING SYSTEMS

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ABSTRACT

In the winter of 1990/91, the Forest Engineering Research Institute of Canada (FERIC) evaluated a cut-to-length system, consisting of single-grip and double-grip harvesters, operating under winter conditions in small-diameter stands in Central Alberta. Cost and productivity results were established for individual machines and for the systems. Merchantable fibre utilization, site disturbance, slash loading, and road requirements were also evaluated and compared to mechanized full-tree harvesting systems operating under similar conditions.

Keywords:
Single-grip harvesters, Double-grip harvesters, Forwarders, Productivity, Cost, Fibre utilization, Self-loading shortwood trucks.

INTRODUCTION

In the fall of 1990, the Forest Engineering Research Institute of Canada (FERIC) undertook a project to evaluate a cut-to-length harvesting system clearcutting stands of small-diameter softwood trees in Central Alberta. The project originated from the increasing interest of FERIC's Western members in cut-to-length systems. These systems are being considered as alternatives to roadside processing systems for harvesting small-diameter softwood stands. However, existing cost and productivity data and other criteria pertinent to selecting a cut-to-length system are limited. Many Western Canadian forest companies have, therefore, been reluctant to commit themselves to this harvesting approach.

The project was conducted in cooperation with Millar Western Industries in Whitecourt, Alberta, and with financial support from the Forest Industry Development Division of Alberta Forestry, Lands and Wildlife. The objective was to examine and quantify operational aspects that directly or indirectly influence cut-to-length harvesting practices and decisions to implement cut-to-length harvesting systems.

The purpose of this paper is to present an overview of the results to date. Detailed results from the various individual studies will be published in upcoming FERIC reports.

STUDY DESCRIPTION

The field data were collected between October 1990 and February 1991 at Millar Western's cut-to-length operation in Swan Hills in Central Alberta. Table 1 shows the average stand characteristics of the harvest site.

Table 1. Typical Stand Characteristics

Utilization information:	
Minimum dbh (cm)	13.6
Stump height (cm)	30
Top diameter (cm)	11
Volume and size information:	
Gross volume (m^3/ha)	248
Lodgepole pine (%)	72
Black spruce (%)	24
Balsam fir (%)	4
Net volume (m^3/ha)	218
Average green dbh (cm)	21.1
Average snag dbh (cm)	18.7
Average total height (m)	18.8
Average merchantable height (m)	13.6
Merchantable stems/ha	990
Snags/ha	150
Average gross volume/tree (m^3)	0.25
Average net volume/tree (m^3)	0.22

Two different types of harvesters—the Rottne/Rapid EGS 85 single-grip and the Rottne/Rapid Snoken 860 double-grip—and two forwarders of different sizes—the Rottne/Rapid 10-tonne and the Rottne/Rapid 14-tonne—were evaluated. As much as the conditions allowed, the double-grip harvester operated in the areas with the largest diameter trees, while the single-grip harvesters felled the areas with the smaller diameter trees. However, no formal boundaries existed between their respective work sites, nor were the logs produced by individual harvesters separated during the forwarding phase.

The trees were felled and processed into fixed-length sawlogs (3.78 m, 4.47 m, and 5.02 m) and random length pulpwood bolts (3.6 m - 5.1 m). The minimum (inside bark) diameters for sawlogs and pulpwood bolts were 10 cm and 5 cm respectively. Any conifer that could be processed into a minimum-size pulpwood bolt was potentially a merchantable tree. Dead trees (snags) with bark firmly attached were also accepted as merchantable trees.

Normally, neither the harvestors nor the forwarders made any attempt to separate the sawlogs and pulpwood bolts. However, in certain mixed spruce/pine stands (no less than a 25% mixture), the pine and spruce logs were sorted by the harvesters, and forwarded separately to the roadside.

The cut-to-length logs were delivered to the company's mill yard by self-loading dual- and triaxle trailer configurations (GVW 55 600 and 56 600 kg respectively). Each trailer carried two tiers of logs (maximum log length 6.0 m). FERIC also evaluated a Swedish tractor/full trailer configuration capable of carrying three tiers of 5-m logs, and with an allowed GVW of 60 000 kg (for test purposes).

Loaded log trucks were weighed at the millyard scale before they proceeded to designated unloading sites. The shortwood trucks normally unloaded themselves, but occasionally the millyard portal crane did the unloading. During the study, the logs were first stockpiled, and later recovered by an overhead crane and fed into the sawmill. Proposed modification to the millyard will allow the shortwood trucks to unload directly into an infeed bin to the sawmill.

RESULTS AND DISCUSSION

Harvesting Operations

Machine Cost and Productivity. Table 2 shows the estimated hourly operating costs of the Rottne/Rapid harvesters and forwarders in the study. Costs are based on an operation with 200 working days per year, 10 scheduled hours per day (single-shift), a machine depreciation period of 5 years. Costs were calculated using FERIC's standard format (Appendix 1); therefore, the Table 2 costs are not the actual costs incurred by Millar Western Industries.

Table 3 shows the productivties and the unit wood costs from selected detailed-timing studies of the single-grip and the double-grip harvesters. The difference in the design of the single-grip and the double-grip harvesters is the major reason for the difference in their productivities. Unlike the single-grip harvester, the double-grip harvester must transfer the felled trees to its processor before processing can commence.

Table 2. Calculated Machine Charge-Out Rates (with operators) for the Rottne/Rapid Equipment

Machine	Charge-Out ($/PMH)
EGS 85 single-grip harvester	126.37
Snoken 860 double-grip harvester	139.13
10-tonne forwarder	94.98
14-tonne forwarder	118.87

Table 3. Productivities: Single-Grip and Double-Grip Harvesters, Calculated from Selected Detailed-Timing Studies

	Harvesters			
	Single-grip		Double-grip	
	Small-diameter trees	Large-diameter trees	Small-diameter trees	Large-diameter trees
Average stand conditions[a]				
Merchantable tree dbh (cm)	13.8	20.8	15.3	19.5
Merchantable height (m)	5.4	11.5	6.3	10.5
Merchantable volume/tree (m^3)	0.07	0.28	0.10	0.24
Machine Productivity[b]				
Trees/PMH	119	90	81	52
Logs/PMH	176	205	155	145
m^3/PMH	8.3	25.2	8.1	12.5
Average logs/tree	1.5	2.3	1.9	2.8
Unit wood cost ($/$m^3$)	15.23	5.01	17.18	11.13

[a] Based on minimum 10-cm dbh, and 10-cm top.
[b] Includes delays and non-productive work with a duration <15 min/occurrence.

This extra handling, which typically adds between 0.1 - 0.2 min to each tree's felling and processing cycle time, makes the double-grip harvester less productive in stands with small-diameter trees.

Tree size had the greatest effect on the harvesters' productivity. Although the faster processing time (about 0.15 min/bolt produced) for small trees increased the harvesters' hourly tree count in small wood, it was far from enough to offset the effect of the low merchantable volume per felled tree.

The productivity of the harvesters was also affected by the number of unmerchantable trees in the stand. Most unmerchantable trees, except for the very small or very rotten ones, had to be cut down using the felling saw. In stands with an unmerchantable to merchantable tree ratio of 1:2.5, the single-grip and the double-grip harvesters spent 13% and 8% of their respective productive time removing unmerchantable trees.

The harvesters were found to be capable of doing a two-way sort (either separate sawlogs from pulpwood bolts, or spruce logs from pine logs) at 100% efficiency with no significant effect on their productivity.

Table 4 shows the productivity and the unit wood costs from selected detailed-timing studies on the two forwarder sizes, based on forwarding distances of 100 m. The two forwarders differ mainly in their payload capacity, but this difference was not always reflected in either recorded payload or hourly production.

Two factors had a significant impact on the forwarders' production: size (volume) of the log piles created by the harvesters, and forwarding distance. The total loading time (active loading and moving between log piles), which generally constitutes the major portion of the forwarders' turn-around time, increased significantly when the volume of the log pile decreased (Figure 1). This is also the primary reason why forwarding sorted products (which reduces the size of the average log pile) increases the forwarding cost. The forwarders' loaded and unloaded travel speeds, which typically ranged between 30-40 m/min on the flat and frozen logging site, did not differ significantly. Travel speeds were most likely determined by the effect the ground obstacles (stumps) had on the operator's comfort, rather than by the machine's capabilities.

The unloading time at roadside was not significantly affected by the average piece size in the load, only the volume of

Table 4. Productivities: 10-tonne and 14-tonne Forwarders, Calculated from Selected Detailed-Timing Studies

	Forwarders			
	10-tonne		14-tonne	
	Small-diameter trees	Large-diameter trees	Small-diameter trees	Large-diameter trees
Average operating conditions[a]				
Estimated tree dbh (cm)	13.5	20.5	13.0	19.0
Estimated tree volume (m^3)	0.07	0.28	0.06	0.21
Merchantable volume/log (m^3)	0.043	0.116	0.037	0.091
Forwarding distance (m)	100	100	100	100
Machine Productivity[b]				
Logs/PMH	264	158	327	242
m^3/PMH	11.4	18.3	12.1	22.1
Average m^3/load	8.4	11.1	9.0	11.6
Unit wood cost ($/$m^3$)	8.33	5.19	9.82	5.38

[a] Based on minimum 10-cm dbh, and 10-cm top.
[b] Includes delays and non-productive work with a duration <15 min/occurrence.

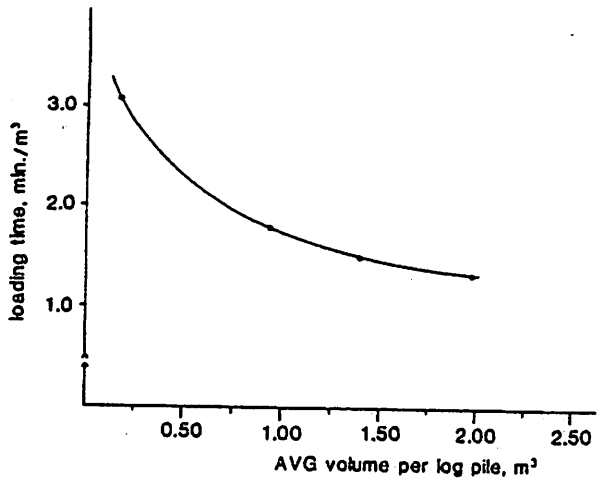

Figure 1. Total Loading Time vs. Average Volume Per Pile.

wood in the load. The unloading time for both harvesters was typically 0.50 min/m^3.

System cost and productivity. The harvesting cost at roadside for a single-grip harvesting system was calculated to be \$23/m^3 in small wood (0.07 m^3/tree or 14.3 trees/m^3), and \$10/m^3 in large wood (0.28 m^3/tree or 3.6 trees/m^3). The corresponding productivity for the system in these two tree sizes was estimated to be 30 m^3/man-day and 66 m^3/man-day respectively.

The harvesting cost at roadside for a double-grip harvesting system was calculated to be \$24.50/m^3 in small wood (0.10 m^3/tree or 10 trees/m^3), and \$16/m^3 in large wood (0.24 m^3/tree or 4.2 trees/m^3). The corresponding productivity for the system in these two tree sizes was estimated to be 30 m^3/man-day and 49 m^3/man-day, respectively.

Fibre utilization. The company's objective was to utilize trees down to a 5-cm diameter top, but this was not achieved. The best estimate with the present data is the average topping diameter of the utilized trees was less than 10 cm, but not as low as 5 cm.

With its ability to harvest small trees, the cut-to-length systems recovered more trees than the company's roadside delimbing systems (full-tree to roadside, tree-length delivered to mill). This is evident when comparing the average tree sizes from the inventory cruise and the roadside scale (Table 5). However, the magnitude of increased fibre recovery in terms of volume is not as obvious when the cruised and scaled volumes from the various cutblocks are compared.

Site disturbance and on-site harvesting slash. Data concerning site disturbance and on-site harvesting slash are presently available for only one cut-to-length block harvested during winter conditions (frozen ground with about 30 cm snow cover). Table 6 presents the information for that

Table 5. Cruise and Roadside/Millyard Scale Information

	Systems			
	Cut-to-length		Full-tree	
	Block A	Block B	Block C	Block D
Cruise Summary [a]				
Gross volume (m^3)	9126	7093	12042	3223
Net volume (m^3)	8002	6112	10435	2792
Average tree dbh (cm)	19.8	20.8	20.6	20.7
Average gross volume/tree (m^3)	0.20	0.25	0.24	0.24
Average net volume/tree (m^3)	0.18	0.22	0.21	0.21
Roadside/Millyard scale				
Volume recovered (m^3)	10795	6568	10881	3230
Average volume/tree (m^3)	0.14	0.13	0.22	0.23

[a] Minimum dbh = 13.6 cm, top diameter = 11.0 cm

Table 6. Site Disturbance and Slash Loading

	Systems	
	Cut-to-length, winter, Block A	Full-tree, winter, Block C
Site disturbance [a]		
Disturbed (%)	0.0	0.2
Undisturbed (%)	100.0	84.8
Other [b] (%)	0.0	15.0
Slash loading		
Slash at stump (m^3/ha)	126.4	111.4
Piled at roadside (m^3/50 m)	0	61

[a] British Columbia Ministry of Forests guidelines.
[b] Evidence of machine travel and disruption, but not to the degree of disturbance as described in the guidelines.

cutblock and for a similar adjacent cutblock harvested by a full-tree system in December 1990. There was no site disturbance on the cut-to-length block, and only minor disturbance on the full-tree block.

The data show surprisingly little difference in the amount of slash left on the two blocks, but the type of material left on the site was different. The cut-to-length block had considerably more fine material (e.g. pieces <5 cm in diameter), while most of the material on the full-tree block was coarse. The slash was also distributed differently on each block; the full-tree block had a relatively even slash distribution (except at roadside where trees were decked), while the cut-to-length block had an uneven slash distribution.

Roads in cutblock. The initial results show that 50 m of road per hectare were built in the cut-to-length blocks, while 90 m of roads per hectare were built in the full-tree blocks. However, this is based on a small sample. Moreover, the analysis has not yet considered the difference in the shapes of the cutblocks as a reason for the difference in road density.

LOG TRANSPORTATION AND MILLYARD HANDLING PHASES

The productivity of self-loading shortwood trucks is potentially less than that of tree-length trucks, mainly because shortwood trucks have smaller payloads and longer loading and unloading times. Table 7 shows the average load size for tree-length and shortwood trucks when hauling wood from cutblocks with similar tree sizes.

The total loading time (loading, tie down load, etc.) for the shortwood trucks ranged from 40 to 55 min/load, while the tree-length trucks were loaded (by Caterpillar 235C hydraulic loaders) in 15-20 minutes when there was no waiting time at the loader. The complete self-unloading time in the millyard for the shortwood trucks ranged from 30 to 40 min/load, while the tree-length trucks were unloaded (by the overhead crane in two "bites") and ready for their next trip within 10 minutes (no wait).

However, because the self-loading shortwood trucks operate independently of loaders, queuing in the bush or at millyard (except at the mill scale) does not occur.

Initial results did not indicate a difference in the travel speed of the cut-to-length and tree-length trucks when operating on public highways. Speed on forest roads of various qualities may be different, because of the difference in load configurations.

A comparison of the hauling costs associated with the shortwood and tree-length trucks has not yet been completed. The handling cost in the millyard and the merchandising of the tree-lengths must also be included in the overall cost analysis.

CONCLUSION

The cut-to-length system evaluated in the study was able to

Table 7. Shortwood and Tree-Length Truck Loads from Cutblocks with Similar Tree Sizes

	Hauling systems			
	Shortwood		Tree-length	
	Block A	Block B	Block C	Block D
Cruise Information [a]				
Tree dbh (cm)	20	21	21	20
Merchantable height (m)	10.2	13.6	13.2	12
Average net volume/tree (m)	0.16	0.22	0.21	0.18
Roadside/Mill scale				
Average volume/tree (m^3)	n/a	0.13	0.22	0.23
Truck/2-axle trailer				
Sample size (loads)	14	8	265	76
Average load (m^3)	36.8	32.7	41.1	42.5
Standard deviation (m^3)	3.2	1.4	n/a	5.6
Truck/3-axle trailer				
Sample size (loads)	22	37		
Average load (m^3)	39.5	41.3		
Standard deviation (m^3)	3.6	2.9		
Truck/full trailer (test unit)				
Sample size (loads)	16	16		
Average load (m^3)	46.3	47.5		
Standard deviation (m^3)	2.6	1.4		

[a] Minimum dbh = 13.6 cm, Top diameter = 11.0 cm.

successfully harvest stands of small-diameter conifers. The single-grip harvester was found to be more suitable to stands with small-diameter trees than the double-grip harvester.

Tree size and the number of unmerchantable stems in the stand had the greatest impact on the harvesters' productivity, while the volume of the log piles (created by the harvester) and the forwarding distance had the greatest impact on the forwarders' productivity.

Two-product sorting did not significantly affect the performance of the harvester, but because sorting would result in smaller log piles, the productivity of the forwarders would decrease in operations where sorting is done during the harvesting phase.

Compared with full-tree systems, the cut-to-length system recovered more small trees during harvesting, but the additional merchantable volume could not be quantified.

Although more harvesting slash was left on the cut-to-length sites than on the full-tree sites, the main difference appeared to be the type of slash left and its distribution. The cut-to-length site contained a large amount of fine slash material that was often concentrated in heaps or windrows.

The productivity of self-loading shortwood trucks is potentially less than that of tree-length trucks because of smaller load sizes and longer loading and unloading times. However, the impact of queuing is reduced for the self-loading shortwood trucks.

Wood handling at the millyard is potentially less costly for self-loading shortwood trucks than for tree-length trucks that require loaders. However, the portion of the millyard handling cost that should be allocated to the two log transportation system is difficult to quantify, and further analysis must be done before more precise total system costs can be established.

APPENDIX 1

Calculation of Machine Charge-Out Rates for Rottne/Rapid Harvesters and Forwarders

Machine type	Harvesters		Forwarders	
	EGS 85 Single-grip	Snoken 860 Double-grip	10-tonne	14-tonne
INPUT VARIABLES				
Purchase price ($)	350 000	400 000	240 000	320 000
Salvage value (% of purchase price)	20	20	20	20
Depreciation period (yr)	5	5	5	5
Operating days/yr	200	200	200	200
Scheduling (SMH/day	10	10	10	10
Machine utilization (%)	75	75	80	80
Operating hours (PMH/yr)	1 500	1 500	1 600	1 600
Annual investment ($)	231 200	272 000	163 200	217 600
Interest on investment (%)	12	12	12	12
Insurance (%)	3	3	3	3
Fuel consumption (L/PMH)	17	17	17	28
Fuel cost ($/L)	0.40	0.40	0.40	0.40
Oil consumption (% of fuel consumption)	6	6	5	5
Oil cost ($/L)	2.40	2.40	2.40	2.40
Repair/maintenance ($/PMH)	23.33	26.67	16.00	21.33
OPERATING COST PER PMH				
Depreciation ($)	37.33	42.67	24.00	32.00
Interest on investment ($)	18.50	21.76	12.24	16.32
Insurance ($)	4.62	5.44	3.06	4.08
Repair/maintenance ($)	23.33	26.67	16.00	21.33
Fuel cost ($)	6.80	6.80	6.80	11.20
Oil and Lube cost ($)	2.45	2.45	1.63	2.69
Operator wages ($)	26.67	26.67	25.00	25.00
Fringe benefits ($)	6.67	6.67	6.25	6.25
TOTAL CHARGE-OUT RATE ($)	126.37	139.13	94.98	118.87

COMMERCIAL THINNING: A NEW TOOL IN B.C. HARVESTING

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ABSTRACT
Although used as both a silvicultural and fiber recovery tool in many parts of the world for a considerable number of years, commercial thinning has been practiced in British Columbia on only a very small scale, and for a comparatively short time. A number of initiatives have, and continue to be made toward implementing commercial thinning operations. To the present, these operations have been marginally economic, and of a generally low profile. This paper explores selected a spects of commercial thinning, makes comparisons with other parts of the world, outlines a variety of benefits and constraints, and makes recommendations as to certain basic steps that should be followed to assist making commercial thinnings a success.

Keywords:
Commercial thinning, mechanization.

INTRODUCTON AND DEFINITION OF COMMERCIAL THINNING

Thinning forest stands is a dynamic intervention in the cycle of growing a stand of trees. The operation is designed to produce some specific objective by controlling stand density and species composition. Commercial thinnings are most simply defined as those in which all or part of the felled trees are extracted for a useful product, regardless of whether their value is great enough to defray the cost of operations (Smith, 1986).

Commercial thinning has been carried out in many parts of the world, and forms a significant component of the fibre supply in such countries as Sweden and Finland, amounting to some 25% of the total merchantable volume produced in Sweden (Skogsarbeten, 1985; Skogsstyrelsen, 1987), and over one-third of the production in much of Finland (Appelroth, 1986). Sophisticated systems, both operational and managerial, have been developed, and allied with product marketing, have a major economic impact on both the economy and development of the forests of regions where it is carried out.

Detailed description of the types of thinning systems and their implementation, are outside the scope of this paper, although selected examples will be given to illustrate their potential, and applicability, to the younger forests of British Columbia. This paper is confined to general descriptions of the purpose, basic components, selected benefits and application constraints associated with the operation. Many items throughout this paper are noted in "point form", including a number of recommendations as a "checklist" for those who may be considering commercial thinning, rather than as detailed dialogue.

THE PURPOSE OF THINNING

Thinning forest stands has been carried out for many years, and is used, as a general rule, to promote benefits to the residual trees within the stand with some specific end result in mind. As a stand develops, the size of the material cut during thinning operations increases. If market conditions permit, material can be removed for sale, making the thinning commercially viable.

A number of distinct thinning methods have been developed (Smith, 1986), each reflecting a particular philosophy and designed to produce a particular result.

The reasons for thinning may include some or a combination of the following:

- to adjust species composition to satisfy long term management objectives
- to "release" the residual crop trees and promote increased growth on the remaining trees, thus shortening the rotation to merchantable size
- to produce a specific shape of stem including control of taper
- to create uniformity within the stand to lower future harvesting costs
- to salvage potential mortality (trees that would otherwise die through competition)
- to promote wildlife values such as enhancing thermal and fugitive cover, and winter range
- to improve aesthetics and landscape appearance
- to remove fuels and lower fire hazard
- to stabilize stands against windthrow
- to promote "other " values such as water quality, snow retention, fish habitat or recreation
- to improve the general health of a stand by removing trees of low vigour or diseased or infected stems
- to improve grazing values for domestic animals.

Confusion sometimes arises between "partial cutting" and commercial thinning. Partial cutting, either in the form of a shelterwood or selection system (or variations), is a component of a regeneration system designed to replace one crop by another. Aside from the difference in primary objective, there are a number of differences in the system design, equipment employed, skills of operators, managerial aspects, safety considerations and costs.

Thinning, whether pre-commercial or commercial, is a cultural activity designed to change and/or improve the current crop for some specific purpose. There are similarities between partial cutting and thinning when initiating a Preparatory Cut in a Shelterwood System. However, it should be noted that although similar from the operational point of view, their objectives are markedly different.

In summary, it must be emphasized that thinning is carried out to achieve a specific stand improvement objective, and should never be undertaken without such directives being clearly understood, and the appropriate operational expertise to successfully carry out the operation.

BASIC COMPONENTS OF A COMMERCIAL THINNING SYSTEM

Operationally, commercial thinning can be achieved in a number of ways, and historically, these operations have produced considerable innovation. The removal of trees from a stand without damaging the residuals and with a minimum disturbance to the ground is a challenge. Figures 1 and 2 illustrate various examples of thinning systems.

The major methods can be characterized by the means of felling the tree, processing the tree stem (stripping branches and cutting to length) at some point in the activity, and yarding the produce to a central location for transportation, either for re-manufacture or to an end user. The method employed is determined by the amount of material scheduled for removal, the size of individual pieces, the location of the candidate site and terrain, and "other" factors (possibly imposed by ecological considerations) determined at a local level. The more effectively the felling, yarding and processing are matched and activities optimized, the more efficient and cost effective the operation.

Bearing in mind the components (felling, processing and yarding), commercial thinning can be generally categorized in the following ways (note that "mechanized" refers to the mechanization of the yarding system or combination of felling and yarding; felling using hand power equipment (e.g. chain saw) is classed as a "manual" activity):

Non-mechanized

Non-mechanized systems are those that do not use machines for extracting produce. In Canada, such systems involve hand falling, and then extraction by horse (or some other non-mechanized means). A past example of this type of commercial thinning would be water flumes used to extract shake blocks.

Cable systems (hand felling and using winches to haul produce over extended distances to a road or landing)

Cable systems involve the use of wire ropes attached to tractor or trailer mounted winches to haul produce to roadside. Basically the same concept as the present generation of high lead and allied equipment, the small cable systems (developed mainly in Europe although in recent years a number of mini-yarders have been developed in North America) operate in "rackways" cut through the standing trees. This system is generally restricted to steeper sites inaccessible to ground based systems.

Ground-based, semi-mechanized

The ground based, semi-mechanized systems involve manual falling, followed by a machine that removes the felled material to roadside. Depending on the system in use, either the faller will "process" the tree (delimb and buck to length), or this will be done by a machine mounted processing head.

Ground-based, fully mechanized (felling, processing and yarding)

In ground based, fully mechanized systems, machines replace all manual felling and processing. These systems usually require two machines, one to fall, delimb, buck the stem and stack ready for the forwarder, and the forwarder that moves the processed material from stump to roadside. The felling and processing unit can either be integrated (single grip harvester), or a two-phase operation, with the felling head on the end of a crane, and the processing unit on the base machine (two grip or double grip harvester). The harvester incorporates computer controlled mechanisms for precise bucking and recording work completed.

BENEFITS

Many of the benefits are included in Section 2, "Purpose of Thinning" and are summarized here under the general headings of biological, managerial (including economic) and social values. The success of the operation is best judged by the results as compared with the objectives and goals.

Biological

Biological benefits focus on the residual stand and the enhancement of the residual trees to produce some specific product at some time in the future. These are summarized under the following:

- to adjust species composition
- to "release" the residual crop trees and promote increased growth

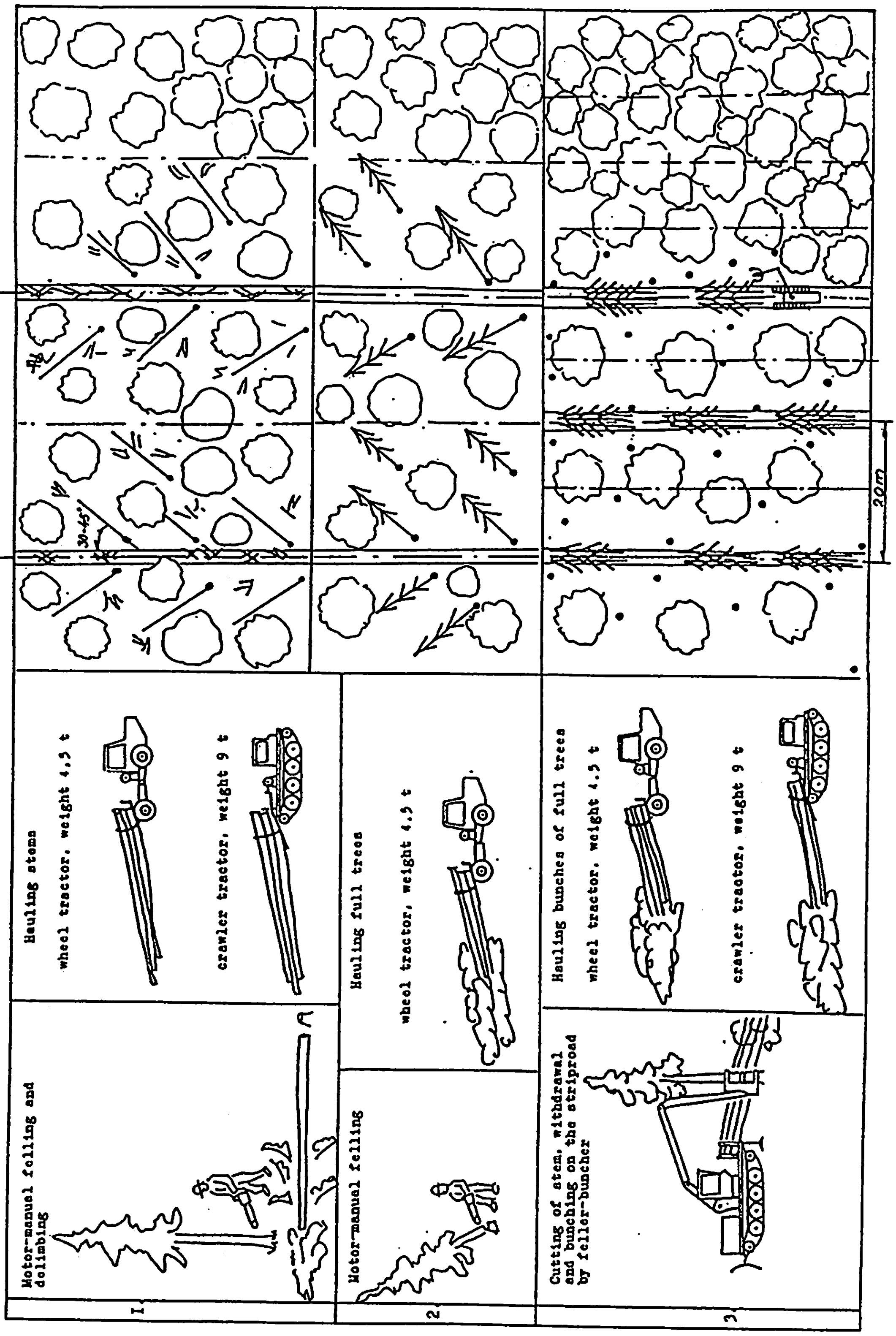

Figure 1. Examples of thinning systems: Tree length methods (Epalts, 1990).

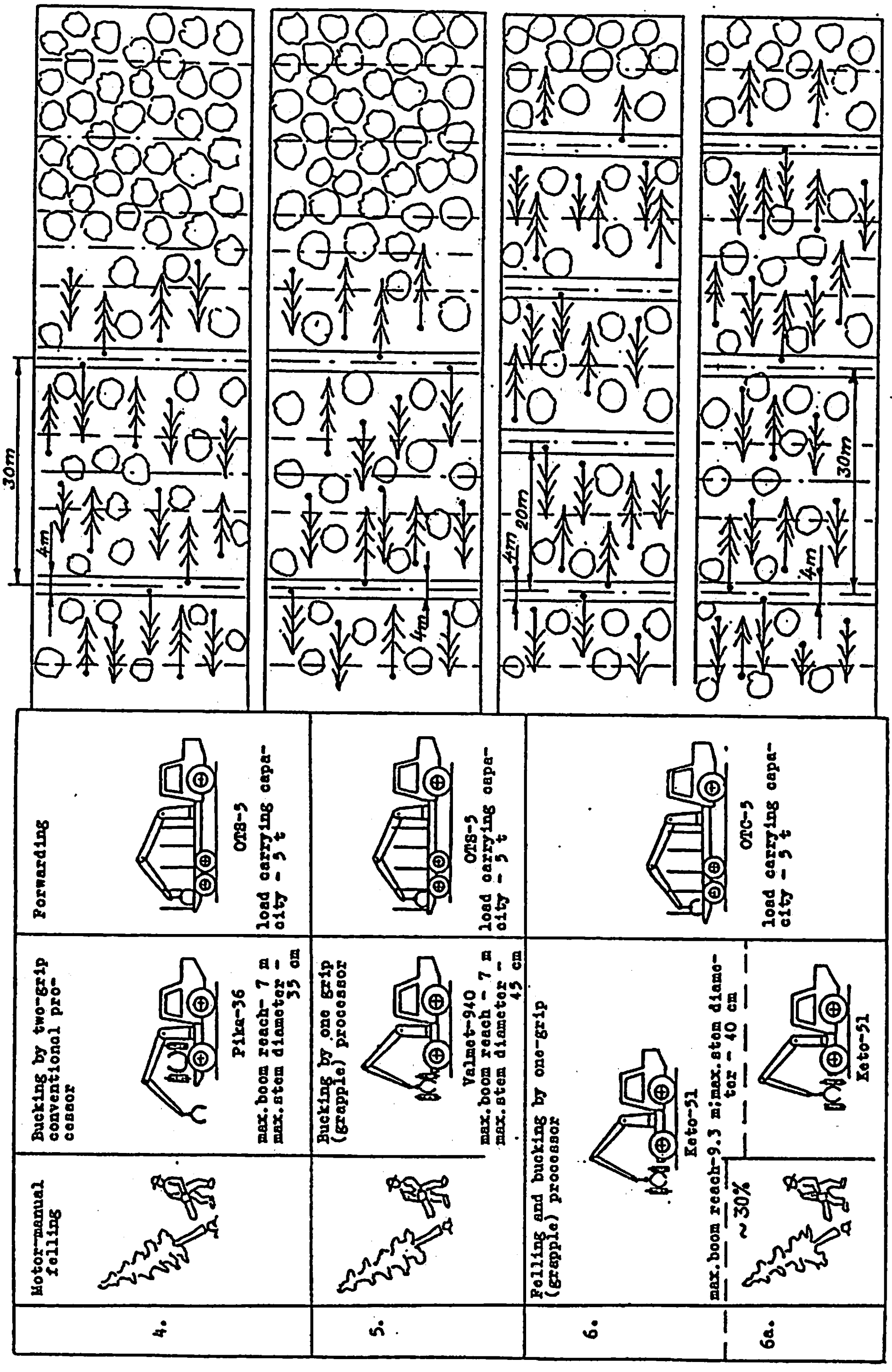

Figure 2. Examples of thinning systems: Shortwood methods (Epalts, 1990).

- to increase the general health of the stand by removing diseased or insect (or parasite) infested trees

Managerial

Managerial benefits focus generally on financial returns, tending the forest for future financial returns, and increasing the ease of future operations. As will be noted below, there are other management benefits, but in any fiber based economy, the financial returns and flow of fiber to the industrial sector are of paramount importance.

- to shorten the rotation to merchantable size
- to create uniformity within the stand to make future operations more cost effective
- to remove and recover salable material from trees that would otherwise die through competition
- to promote fire protection values (short and long term) by removing fuel
- to provide revenue from sales, and where revenue does not fully cover the cost of the operation, lower the costs of silvicultural treatment

Social

Social benefits cover a number of "intangibles" as well as some that can be directly measured. Selected social benefits could equally well be listed under Managerial and Biological but are included here more for the sake of convenience than for any other reason.

- to improve aesthetics
- to stabilize stands against windthrow
- to promote "other" values such as water quality, fish and wildlife habitat or recreation
- to improve the general health of a stand
- to improve grazing values for domestic animals
- releasing fiber for local industry, thus acting as a economic "multiplier"
- creating a new source of fiber, thus stimulating new economic activity
- can alleviate local timber shortages, unemployment
- reduced manual labour and improved work environment with increasing mechanization (Epalts, 1987)
- with mechanization, fewer workers in the woods but with greater skills

Thus it can be seen that although the primary purpose of thinning is stand improvement, it can also provide a number of other benefits. In terms of timber production, the value of the final crop trees may be increased by improving growth and piece size, concentrating the merchantable fiber on the most valuable species, and shortening the time to final harvest. Costs at final harvest may be lowered, mainly by creating stand uniformity, permitting the use of a machine matched specifically to the piece size, thus making a more efficient and cost effective operation. Further, after thinning, there are generally fewer unmerchantable stems to contend with (i.e. lowering residual, on-site debris), and costs of site preparation and planting can be reduced.

Salvaging potential mortality increases the value derived from the stand over the rotation, generating a cash flow prior to final harvest and thus lowering carrying charges (if financial matters are handled this way). This helps to defray the costs of other silvicultural investments, and provides timber supply and jobs during local shortages. It can also help to protect stand investment by lowering risks such as fire hazard, climatic damage (e.g. windthrow) and disease.

Other benefits, such as improvement of aesthetics, wildlife habitat, or grazing values can be extremely important. Commercial thinning might well be done primarily for such reasons, especially on smaller private holdings or in high value wildlife or recreation areas.

CONSTRAINTS

Commercial thinning has a number of constraints. These can be listed under:

Operational
Physical (Biological)
Social

Operational

Operationally, the piece size is generally smaller, and hence the cost per unit for handling is higher, making the operation less financially attractive than final harvest. While this may not appear a major drawback, the tendency is for management to increase the volume removed beyond the biological optimum, possibly detracting from the primary objective (regardless of what that objective might be). Further, as there is generally less volume per unit area, greater distances and areas have to be covered per unit volume, again making it less financially attractive than clear cutting.

Skills and attitudes required to successfully carry out commercial thinnings are different from the conventional clearcutting operations. In British Columbia, a high degree of expertise (together with the equipment to support such expertise) has been developed in large scale clear cutting operations. Such skills, attitudes and equipment do not necessarily lend themselves to commercial thinning, and re-training and re-equipping is required. In the past, there have been a number of attempts at commercial thinning using unsuitable equipment, equipment too large for the material to be yarded, resulting in damage to the residual stand and leaving a legacy of problems to be faced later with respect to disease and windthrow.

Although thinning can, in the long term, reduce fire hazard, fire risks tend to increase in the short term as a result of debris left after merchantable material is removed. This can be reduced using certain equipment (e.g. single grip harvesters that scatter or run over thinning debris) and high utilization standards, but additional fire hazard is a management problem that requires addressing prior to commencing operations.

Biological

There is often a limited operational window during which commercial thinning can be carried out due to trees flushing early in the year. Thinning must be avoided at this time, as the bark is loose on the tree, and the young foliage is susceptible to damage (through tattering) when trees are felled. Scheduling thinning operations is a challenge similar to working around "break up" in the interior. Further, damage can occur to the roots of residual trees (by machinery moving over the ground), or merely by opening up a stand in such a manner that it is vulnerable to climatic elements such as windthrow, snow damage and sun scald. Yet other crown damage occurs as shade adapted foliage is exposed to full light.

Virtually all operational damage can be eliminated by matching machine type and size to the operation, through operator training, and with correct stand layout (particularly, placement and minimization of strip roads). Climatic damage, however, is difficult to overcome, and although to some extent is predictable, its severity is subject to climatic vagaries and "events" that are specific to a region or climate pattern over which management has little control. The major tool in overcoming climatic damage is the prescription and the combined skills of both the silviculturist and the thinning operator.

When machines move over the ground, not only can roots be damaged, but the actual soil can be subject to degradation through compaction and rutting. Wästerlund (1990) found that Norway spruce alongside strip roads in Sweden could lose up to 30% of their growth on average, during a five year period following such damage. As noted earlier, this can be largely overcome by placement of thinning debris on the skid roads, and this is an accepted practice when using single grip harvesting machines that process the stems across the front of the machine, providing a bearing surface for the machine to pass over.

Lighter machines, although less cost effective in terms of the harvesting operation, will lower the costs inflicted on the stand (Sirén, 1990). A good deal of research in Scandinavia is currently being done to make forwarders more environmentally sound. For example, Eriksson & Friman (1990) have found that a hydrostatic transmission may reduce damage to tree roots and the forest floor, as compared to a stiff mechanical transmission, by reducing wheel slippage.

Related biological risks or more correctly, changes, include the removal of current and future wildlife habitat, primarily for birds. On the other hand, thinning debris can be used by a variety of birds for nesting and capturing insects. There could be short term habitat degrade for ungulate populations as thermal cover is changed, and movement can be hampered by residual debris. Here again there could be short term benefits in the form of greater quantities of ground cover due to increased light penetration of the canopy after thinning.

Social

Although workers in commercial thinning should be highly trained (as noted under "Benefits"), and are considered to work under improved conditions due to mechanization, there has been a tendency for machine owner-operators to work long hours and more days per year. Liden (1988) found that in Sweden, more than half the owner-operators surveyed have considered leaving their business, citing too much work, poor health, too much intrusion on family life, and poor returns. One-third of all machine owners worked 60 or more hours per week. Further, occupational hazards change with mechanization and although the new machines have been "ergonomically" designed, the long hours and extended work year have not always been be neficial to the worker in the forest (Nilsson, 1990).

SELECTED RECOMMENDATIONS

Like many other activities, organizing a commercial thinning can be done through some form of "check list". The checklist consists of a series of headings designed to identify possible issues and constraints. Not all will require action, but all should be considered.

As noted earlier, the objectives must be clearly identified and if this is done effectively, many of the activities to be planned will "fall out" in a logical sequence. For the purposes of convenience, the check list has been broken down into biological, physical and management (and operations). A final group of "Other Considerations" are included to round out the checklist.

Biological

- stand characteristics
  - species (and/or species composition)
  - stand age
  - structure
    - present
    - desired

- potential for damage (resilience)
- ecosystem unit
  - sensitivity to disturbance
  - moisture/nutrient regimes
- biological "windows" of accessibility
- insect and disease hazards

Physical
- terrain
  - slope
  - topographic nature (ruggedness)
- soil sensitivity
  - texture
  - soil type
- degradation potential
- local climatic constraints of snow and wind

Managerial and Operational
- management objectives (stand development goals)
- size and shape of area
- access
  - road
  - within stand
  - required access development
- volume of timber to be removed
  - categories of produce
  - storage time
- harvesting system
- stand layout
- produce stacking areas (landings vs. roadside)
- residual debris
- supervision and auditing
- markets for produce
- contract vs. direct labour work
- training, safety and health
- produce flow

Other considerations may include:
- investment requirements
- availability of trained operator(s)
  - silvicultural expertise
  - machine operation & maintenance
  - layout and method
- mechanization
  - imported technology
  - adaptation of existing and imported technology
  - innovation, research, development, trials
- local supply
  - incentives
  - identification of potential commercial thinning, region by region
  - linked to market transition
  - government role
- local market
  - shorter wood
  - incentives?
- layout
  - match to capabilities of system/equipment
  - consider stand structure
  - consider soil and terrain
  - " " management objectives
  - strip roads
    - % area
    - timing of placement (earlier operations)
    - optimizing alignment & length
    - types (access only vs. pickup/yarding)
  - landing vs. roadside stacking
  - piece size/types
  - allowable residual stand damage
- standards/targets (devised through research, trials)
  - production
  - stand damage (eg. national standards in Sweden)
  - linked to training/education

DISCUSSION

There is a considerable body of literature on thinning, and many examples of commercial thinning elsewhere in the world. The literature covers not only the types of thinning, but operations and measurement. This paper has outlined a number of general considerations to assist persons embarking on, or considering, commercial thinning. With the predicted "fall down" in fiber supplies over the coming 25 years and conversion to second growth, commercial thinning could be used to fill part of the supply gap. Further, if sufficient expertise is forthcoming, then commercial thinning will provide not only employment opportunities for persons displaced by advancing technology and plant closures, but long term industrial (and hence social) benefits.

Certainly there are a number of both operational and legal barriers to overcome, but there are also major opportunities for the introduction of advanced technology and development of new techniques. British Columbians have demonstrated in the past their ability to accept such challenges, and with the land base available for such activities, it is with considerable optimism that the authors look to the future.

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TIMBER HARVESTER: A TOOL FOR AUTOMATIC SELECTION OF TIMBER HARVESTING SYSTEMS

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ABSTRACT
The potential gains that could be realized from mechanization and automation of timber harvesting are significant. Mechanization increases production output and efficiency, and product quality.

However, selecting an appropriate degree of mechanization to avoid under utilization of expensive resources is a critical decision, and requires that the product mix, and environmental and user constraints be matched against the available technology and required performance criteria. This paper describes a computer based system which queries a user on the logging and market conditions. The system then matches these user's needs to a level of mechanization that would maximize the efficiency of the production operation. The computer accomplishes this by searching a set of data bases containing information on available technology and its impact on production efficiency, economics and the environment. The level of mechanization is determined by specific combinations of existing machines.

This tool is intended to aid long term strategic level planning by both public agency engineers and private industry managers and owners. It could also be used for short term tactical planning by contractors.

Keywords
Harvesting system selection, Computer program mechanization, Maximum efficiency.

INTRODUCTION
The annual harvest of timber in the United States is about 67 billion board feet. Approximately 1.3 million direct forest industry jobs result from employment. Each forest industry job generates about two service jobs. In Oregon alone, the annual payroll of directly employed lumber and paper industry workers is three billion dollars. The harvesting activity, the focus of this paper, accounts for about one-third of the total processing cost.

One approach for increasing productivity, efficiency, quality and safety while at the same time decreasing production costs is through mechanization and automation. Mechanization increases production output and efficiency. Yet there is much evidence to suggest, both in manufacturing and service industries, that automation for automation's sake can be costly and inefficient.

Selecting a specific degree of automation and mechanization requires that the product mix, environmental constraints and limitations (such as topography, soil type and road access), and user constraints (such as labor force, capital, risk and safety) be matched against the available technology and required performance criteria. In effect, what is required is a model (or scenario generation capability) for selecting alternatives for a given environment. These alternatives can then be evaluated, using for example, simulation, for selection and implementation.

BACKGROUND
Model Generation and Analysis
Modeling and evaluation of timber harvesting systems can be done using analytical modeling. However, mathematical analysis of such a complex process is extremely difficult to conduct. Besides complexity, other factors that limit the use of analytical models include: (1) failure to account for interaction among the different factors in the system, (2) difficulty in quantifying certain factors or interactions, (3) deterministic nature of most analytical techniques, (4) rigid structure imposed by the analytic algorithms, and (5) information intensive nature of the harvesting process.

Simulation is the most common technique used for analyzing complex systems such as timber harvesting. Typical simulation analysis efforts consist of three cyclic phases (Law and Kelton, 1982), beginning with defining the system to be modeled. From this definition the system is translated into a simulation model program. The program is fed data, output is then generated and analyzed. Current simulation applications primarily focus on the second of these three phases, that is, given an alternative to be simulated, translate it into a simulation model followed by execution. Some effort has been made in developing output analyzers. However, little if any development effort has gone into the first phase, that of model or scenario generation. Model formulation is recognized as the most difficult phase in building a simulation model, yet all simulation techniques start with the premise that this phase is complete and correct. The critical consideration in effective use of simulation is to "identify the system to be simulated" and "provide the appropriate data for the model to function".

Modeling and Analysis in Timber Harvesting

Paralleling the trends in simulation technology, there have been a number of simulation models that have been developed for analyzing different facets of log harvesting, but very little effort has been expended on timber harvesting equipment selection. Fisher, Geddes and Gibson (1984), Fisher and Geddes (1983) and Gibson, Jones, Barrett and Shih (1986) describe a prototype expert system for timber harvesting equipment selection. The knowledge base of this system consists of information derived from a small number of "experts" and from literature references. The system reasons through the rule base to make recommendations for selection of equipment about a specific phase of the process. The prototype expert system reported in these references focuses on a subset of harvesting environment factors in making a selection for a specific phase. More importantly, (1) it does not consider "user-constraints" such as capital and risk levels, (2) it does not consider the entire system; for example, the choice of a piece of equipment for one single phase may be incompatible with equipment prescribed for other phases of the process, and (3) it requires identifying, and extracting information and combining knowledge from experts, which is a very difficult process, at best. In addition, for such a modeling system to be of any pragmatic value, it must be integrated with appropriate data bases for specific problem solving needs such as equipment characteristics and cost estimates, and with an analysis module that would analyze the scenarios selected in the modeling phase.

The system described below is specifically designed to generate modeling scenarios for timber harvesting. The resulting scenarios represent the sequence of steps (processes, machines, phases, etc.) required in a harvesting system. No method to query and use the fragmented data base now exists. Decisions on the level and type of equipment are made without adequate information. Since a single machine can often cost as much as a quarter million dollars, an incorrect decision is an extremely expensive mistake.

The models (or alternatives) generated using this methodology may then be analyzed using a simulation model, such as the LOGSIM model developed by the authors. LOGSIM is a computer-based simulation system for modeling the entire harvesting process from the felling operation until the log arrives at the sawmill or timberyard. Other characteristics of LOGSIM include: a front-end interface for obtaining the system description and input parameters from the user which is then internally translated into the simulation constructs; system analysis and output at three different levels - the machine level, the operation level and the system level; and a graphics utility package that produces visual aids for analyzing simulation results. For details on LOGSIM, see Randhawa and Olsen (1990); Randhawa and Olsen (1989); and Wiese, Olsen and Randhawa (1988).

'TIMBER HARVESTER' SYSTEM

The TIMBER HARVESTER was designed to automatically generate feasible timber harvesting systems. System selection is based on the interaction of two major components: the user's specific harvesting environment, and the available harvesting equipment's operating attributes.

The user is required to build the user environment by selecting the appropriate environment attributes. The harvesting requirements represent constraints that determine the direction of search for feasible alternatives. An example of the requirements might be the allowance or prohibition of using a shear type feller buncher for felling. Each piece of harvesting equipment is assigned to a harvesting operation. If a piece of equipment is multi-operational, it is included in each operation to perform that operational task.

The TIMBER HARVESTER uses a best-first search algorithm to determine feasible alternatives. The use of this algorithm is based on production cost as the driving factor. The search algorithm will map the user environment to the available equipment data base to produce feasible harvesting alternatives. The system generates all feasible systems as well as identifying the lowest cost alternative. These alternatives may then be used as inputs into the simulation program LOGSIM for analyzing equipment balancing and other system specifics.

User's Harvesting Environment

The user's environment is defined by three set of variables: site, stand and requirements.

1. Site Variables

   a) Ground Firmness: firmness of the ground, defined using a discrete 1-5 scale; 1 representing soft ground firmness and 5 defining a hard ground firmness.

   b) Ground Roughness: roughness of the ground, defined on a discrete 1-5 scale; 1 defining a mild ground roughness and 5 defining a severe ground roughness.

   c) Slope: average slope on the given site.

   d) Haul Distance: average transportation distance from the woods to the landing or roadside.

2. Stand Variables

a) Acres: size of the stand (in acres).

b) Dbh: average diameter at breast height of the major species in the stand.

c) Merchantable Trees: number of merchantable trees per acre.

d) Species: major species on the given site.

e) Tree Height: average tree height (in feet) for a stand.

f) Unmerchantable Trees: number of unmerchantable trees per acre.

3. Requirement Variables

a) Shear Felling: determines if a shear attachment may be used during a felling operation.

b) Suspension: determines if a log or tree must have one end suspended during transport.

c) Finish Product Required and the location of the finished product.

Table 1 summarizes these variables along with the measurement units and their measurement scale range for each attribute. These three sets of variables can be expanded or modified to fit particular organizational concerns.

Table 1. User Environment Variable Summary

Variable	Measurement	Range of Measurement
SITE VARIABLES		
Ground Firmness	Discrete scale	1-5, 1:soft 5:hard
Ground Roughness	Discrete scale	1-5, 1:mild 5:severe
Slope	Percentage slope	-30 to 30
Haul Distance	Distance (feet)	N/A
STAND VARIABLES		
Acres	Size of stand (acres)	N/A
Dbh	Avg. diameter (inches)	1 to 40 inches
Merchantable Trees	Merch. trees/acre	N/A
Species	Species name	N/A
Tree Height	Avg. height (feet)	N/A
Tree Volume	Volume (cubic feet)	N/A
Unmerchantable Trees	Unmerch. trees/acre	N/A
PRODUCT REQUIRED		
Product	Finished product name	N/A
Shear Felling	Binary discrete scale	True or False
Suspension	Binary discrete scale	True or False

Equipment Data Base

The equipment data base contains different equipment used in timber harvesting operations. An operation is defined as a procedure that takes an input material form at a particular location and transforms the material into an output form at a particular location. The output form and location must be consistent with the operation for which a given piece of equipment is assigned. For example, for a felling operation the input form would be standing timber and the output form would be a complete tree. It would obviously be inconsistent to have a piece of equipment categorized for felling doing delimbing, because the output form would be a delimbed tree. Some equipment will have an output form that is the same as the input form and the only difference is the change in location (eg skidding).

Once an operation is defined in the system, equipment can then be added under that operation to produce that operation's output form. Furthermore, an equipment is defined in terms of specific attributes. Assigning attributes to a given piece of equipment is nothing more than giving it a unique identity. These attributes are accessed during program execution to calculate production costs and to determine suitability of the equipment with the current user environment. The equipment attributes in the system data bases include:

1. Accumulation: refers to the input accumulation state of the material the equipment can accept, and the output accumulation state it produces.

2. Attachment: refers to a prominent attachment (such as shear attachment for feller buncher or a grapple attachment on a skidder) for the equipment.

3. Dbh: range of diameter at breast height accepted by the equipment.

4. Ground: defines ground roughness and ground firmness capability.

5. Horse Power Class: describes the horse power class of a given equipment.

6. Product: this attribute described in two parts refers to the input product accepted by the equipment and the output product produced by the equipment.

7. Location: refers to the location where output product is located after processing.

8. Operations: this attribute can have a significant impact on the solution. A piece of equipment assigned to performing a given operation needs to know what possible operations can follow the operation it performs. For example after manual felling, there may be more than one possible way to proceed with harvesting. Alternatives would be bunching the trees before skidding, skidding whole trees by themselves, or delimbing the trees. Then the following operations would be included in the attribute, operations, for felling: bunching, skidding and delimbing. These operations are all considered to be valid moves after felling.

9. Production Cost: may be a constant or computed from a production (regression) equation included in the "equation data base"; the later method implies that the production cost depends on other variables.

10. Production Equation: defines the equation to be used in computing the production cost.

11. Slope: represents the range of slope over which the given piece of equipment can operate.

12. Suspension: represents a piece of equipment's ability to suspend one end of the product or log during transport.

Support Data Base

Besides the equipment data base, TIMBER HARVESTER uses three support data bases that are accessible by the entire system.

Skidder Speeds and Loads Data Base. This data base contains the travel speed information needed when calculating the production cost for different kinds of skidding equipment. The data base is organized by the type of attachment of the skidding equipment (this can either be a cable or a grapple), and by horse power class and slope. A typical data table is shown in Table 2. Similar data bases will be developed for other equipment types.

The Wood Density Data Base. This data base contains information on different tree species and the associated density values. The density is used in calculating the total load for a given species, which in turn determines the production cost.

Production Equations Data Base. The production equation data base is a collection of production equations used in calculating an equipment's production costs. As an example, the production equation for a feller buncher without cab leveling is given by the following expression:

Table 2. Example Skidder Speeds and Loads Data Bases

HORSE POWER CLASS: 90
ATTACHMENT CLASS: CABLE

Slope (%)	Load (1000 lb)	Loaded Speed (mph)	Empty Speed (mph)
-30	11.0	19.00	4.40
-20	11.0	19.00	5.90
-10	11.0	19.00	9.30
0	11.0	4.90	19.10
10	9.0	3.70	19.00
20	8.0	2.50	19.00
30	7.0	2.20	19.00

Trees per machine hour =
214.7 - 0.0134*(stand density / 0.4047)
- 53.1*(unmerchantable trees/merchantable trees)
- 4.2*(dbh*2.54)
+ 29.7*[4.36-0.12*(dbh*2.54)
-0.00052*(unmerchantable trees/0.4047)]

Before running the equipment matching algorithm, the user must specify the goal operation and the final product desired. The program then begins the search process. The search process finds all possible systems (i.e., a combinations of equipment that end in the required goal operation and satisfy the product requirements), and specifies the best alternative.

Matching Algorithm. The interaction among the various components of TIMBER HARVESTER is shown in Figure 1. The harvesting environment is the basis of the specific user work environment and constraints, if any. This information is matched against the equipment data base to determine a viable alternative for achieving the harvesting objectives. The matching procedure is achieved with the "best-first" search algorithm using production cost as the driving criterion. The equipment and the support data bases are used during this search process to match equipment and to determine production costs and values of other relevant attributes.

Given a user environment and an equipment data base, the problem of finding a feasible alternative (i.e., combination of equipment) from the equipment data base is a search process. The best-first search algorithm (Rich, 1983) is guaranteed to find a solution if one exists, provided there are finite number of alternative paths leading to the solution. The algorithm uses production cost to guide the search process in the direction of obtaining a solution which minimizes the total production cost.

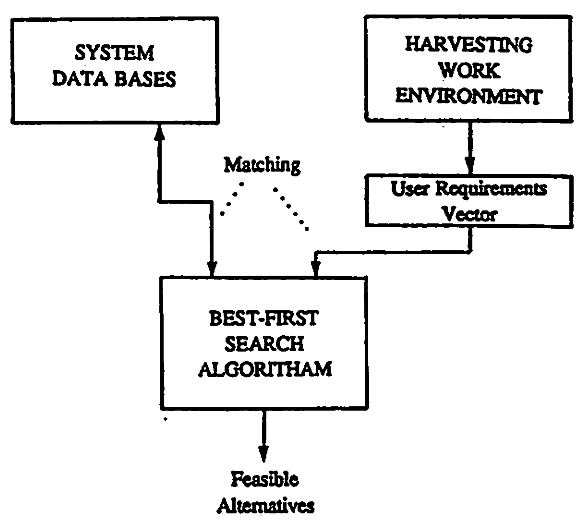

Figure 1. The Matching Procedure

IMPLEMENTATION

TIMBER HARVESTER has been implemented using SMALLTALK (SMALLTALK/V Tutorial and Programming Handbook, 1986) for a personal computer system. SMALLTALK is an object-oriented based programming language ideally suited for data representation and matching procedure. For details on object-oriented programming, see Frost (1986), Cox (1986), Booch (1986), and Stefik and Bobrow (1986).

TIMBER HARVESTER has been implemented such that a user with no knowledge of SMALLTALK or object-oriented programming can interact with the system successfully. It is a completely menu driven system (using mouse). To operate the system the user is required to make an appropriate selection from a menu and click on the mouse. The system uses a networked-menu system, that is, a choice on a menu leads to a sub-menu and so on. At each step, a "text window" explains the menu options and parameters to be specified.

In addition to executing the matching algorithm, TIMBER HARVESTER provides complete editing capabilities for the equipment and support data bases, and the user environment. Specific functions provided in TIMBER HARVESTER include:

1. Creation, modification and removal of harvesting operations.

2. Creation, modification and removal of harvesting equipment for specific operations.

3. Assignment and modification of equipment attributes.

4. Creation and modification of the contents of the support data bases.

5. Defining harvesting requirements (site specifics, stand specifics, etc).

The alternatives selected by TIMBER HARVESTER depend on the information provided in the equipment and support data bases. There is a wide range of mechanized equipment available for the many different tasks in a harvesting operation. To reduce the task of finding production equations for every machine to manageable size, similar function machines were grouped together as a generic machine type and further broken down by subcategories such as horsepower class. Suitable published production equations were used for the production rates for the generic machine types in the system. Where production equations were unavailable or inappropriate, individual machine studies were grouped together and production rates transformed through regression analysis to develop production equations for the generic machine class. If no production data was found, "ball park" estimates were created to enable the program to operate. The user has the option of overriding the production figures, if so desired.

Production rates for individual machines were obtained from published production studies from organizations such as: Forest Engineering Research Institute of Canada (FERIC), Logging Industry Research Association (LIRA), Canadian Pulp and Paper Association (CPPA), manufacturers handbooks and articles published in trade magazines.

Production rates for harvesting equipment are very specific to the individual machines and conditions at the time the studies are undertaken. As such, the production equations developed for the generic machine classes give only an indication of the possible production levels achievable on that specific site. As our research activity progresses the production equations will be refined and the accuracy of the production estimates improved.

System Application Example

TIMBER HARVESTER has been verified for accuracy and validated using a timber harvesting problem domain. To illustrate the application of TIMBER HARVESTER, consider the subsystem of a larger problem domain shown in Figure 2. The system shown in Figure 2 starts with a stand of timber to be harvested; the beginning product state is therefore a complete tree. Each node in the figure shows the product state after the foregoing operation (shown on the branches) is complete. Table 3 summarizes the equipment built in the data base that may be used by the processes in the application system. Table 4 summarizes the a set of attributes for the timber harvesting environment.

The completion of each operation gives rise to three important variables: product state, accumulation state and location. These three variables define equipment capability. For example, many grapple skidders require the material to be bunched before skidding. Therefore any system that does not use a bunching operation before skidding will not be able to employ grapple skidders, that is, the grapple skidders are sensitive to the accumulation state of the material. It should be noted that the output variables of one operation are the input variables to the successor operation.

The objective is to generate all feasible harvesting alternatives and identify the most cost effective alternative. During execution the TIMBER HARVESTER displays each alternative that meets both the goal operation and final product requirements. For the system in Figure 2, assume that the goal operation is set to be hauling and the required harvest-

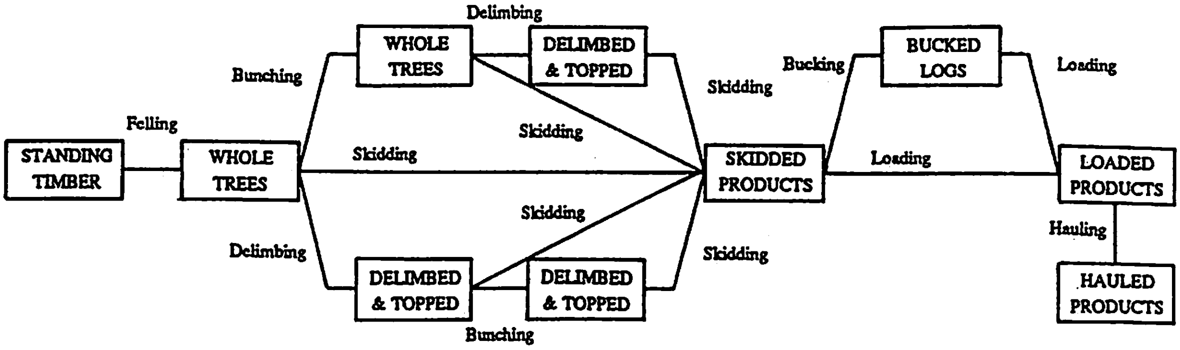

Figure 2. System Application Example.

Table 3. Available Equipment Used in System Application Example

Operation: FELLING		
1.	Manual	(manual)
2.	Feller Buncher 90 hp	(FB1)
3.	Feller Buncher 100 hp	(FB2)
4.	Feller Buncher 110 hp	(FB3)
Operation: DELIMBING		
1.	Manual	(manual)
2.	Processor	(processor)
Operation: SKIDDING		
1.	Cable 90 hp	(CatCab1)
2.	Cable 110 hp	(CatCab2)
3.	Cable 145 hp	(CatCab3)
4.	Grapple 90 hp	(CatGrp1)
5.	Grapple 110 hp	(CatGrp2)
6.	Grapple 145 hp	(CatGrp3)
Operation: BUNCHING		
1.	Feller Buncher 90 hp	(FB1)
2.	Feller Buncher 100 hp	(FB2)
3.	Feller Buncher 110 hp	(FB3)
4.	Wheeled Grapper 145 hp	(WGrp1)
Operation: LOADING		
1.	Boom-type Loader	(boom)
Operation: HAULING		
1.	Log Truck	(truck)

ing product is log-length. The information on the alternatives generated by the search algorithm is shown in Figure 5. The number on the far left correlates to the state number the search algorithm assigned to the system; it serves as the identification number for the report. The next number in square brackets is the logging cost per mbf. The following list of equipment identifies the harvesting system. After the system identifies a suitable system the user can display (or print a hard copy) of the system specifics (Table 6). Furthermore, the user may query TIMBER HARVESTER for details on specific equipment of the system identified.

Table 4. Harvesting Environment for System Application Example

```
Acres = 500
Dbh   = 13 inches
Ground firmness = 3
Ground roughness = 3
Haul distance = 300 feet
Merchantable trees per acre = 134
Product = Log length
Shear felling allowed = no
Slope = -10 (down hill haul)
Species = Douglas-Fir
Suspension = false
Tree height = 70 feet
Tree volume = 33 cubic feet
Unmerchantable trees per acre =  25
```

Table 5. Output during the Search Process

```
a BestFirstSelection starting with standing timber

110: $[83.2]  manual->manual->CatCab1->manual->boom->truck
129: $[95.2]  manual->WGrp1->manual->CatGrp3->manual->boom->
                      truck
148: $[107.2] manual->WGrp1->manual->CatGrp2->manual->
                      boom->truck

a suitable system is 110
```

Table 6. Output Report

Operation	Machine	Product	Location	Accumulation
felling	manual	wholeTree	stump	random
delimbing	manual	treeLength	stump	random
skidding	CatCab1	treeLength	roadside	bunched or decked
bucking	manual	logLength	roadside	bunched or decked
loading	boom	logLength	onTruck	bunched or decked
hauling	truck	logLength	concYard	bunched or decked

Harvesting cost = $83.2 per mbf

CONCLUSIONS

The design, evaluation and control of mechanized timber harvesting systems is a problem of considerable importance in the forest products industry and has economic as well as societal relevance. The type of processing that is chosen affects the type of log that is delivered to the mill, and ultimately the finished wood product. No previous work has provided a design and evaluation tool in this important area of application. TIMBER HARVESTER provides a modeling tool for identifying feasible alternatives for a specific harvesting environment by including such factors as production costs, production efficiency and environmental considerations in the decision process.

Although the design and development of TIMBER HARVESTER was the central focus of the research reported in this paper, a major value is the development of equipment and support data bases. We feel that this brings together a large body of research and makes it available to users of timber harvesting systems.

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CUT-TO-LENGTH HARVESTING SYSTEMS FOR NORTH AMERICA

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ABSTRACT
The application of Scandinavian cut-to-length harvesting systems for North American conditions is explored with several examples of where these systems have proven successful. System components are detailed with specifications for different applications provided.

THIS PAPER WAS NOT AVAILABLE AT THE TIME OF PUBLICATION.

OPERATIONS FORUM

SUCCESSFUL APPLICATIONS OF SKYLINE LOGGING IN BRITISH COLUMBIA

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ABSTRACT

The term "skyline" includes many different cable systems, each with unique capabilities and limitations. Skyline systems have potential in B.C. to reduce logging costs and/or extend yarding reaches, with fewer roads and reduced environmental impact. However their implementation is dependent on more intensive planning, equipment selection, layout, and training than is customary for highlead logging. Some of the specific issues involved are discussed in this paper.

Keywords
Skyline, Logging costs, British Columbia planning, Layout.

INTRODUCTION

Those unfamiliar with skyline logging may have a mental image of long spans, expensive logs, and fantastically complex rigging. Some systems do indeed conform to this image, but many others do not. It is important to understand the diversity of systems and their capabilities and economics.

Skyline logging, defined here as any cable yarding system employing a carriage to provide partial or full support to a turn of logs, employs a great diversity of rigging systems and equipment classes, that have equally diverse operating characteristics. The successful application of skyline logging requires that the capabilities and limitations of these systems be thoroughly understood by production and layout personnel. Furthermore, it is necessary to do a thorough job of planning and layout.

Skyline logging, on the same piece of ground and with comparable yarding distances, often results in higher productivity and lower costs than highlead yarding. It may also be feasible to reach much farther, reducing road construction costs and/or environmental impacts, and making it feasible to reach timber simply not accessible for conventional systems. However, achieving reduced costs or longer reaches or lower environmental impact depends on which system is used, and on which piece of ground.

Successful skyline implementation for a B.C. company with limited experience with these systems is likely to result if these steps are conscientiously followed:

1. Understanding skyline systems: The diversity of systems and equipment is very great.
2. Planning: A total chance plan will show what equipment is required to fit the ground, rather than trying to match the ground to the equipment.
3. Selecting the right equipment: The equipment needs to be matched to the timber, the terrain, the reaches required, and the stumps to tie it down.
4. Layout: Compared to highlead/grapple layout, skyline logging demands a higher standard of engineering.
5. Training: The average highlead crew requires fresh skills to log safely and productively by. Additional engineering skills are also required.

This paper is an attempt to outline these steps.

SKYLINE SYSTEMS

The term "skyline" refers to the line used to support a carriage that carries the turn of logs. Skyline systems have relatively few other characteristics in common.

There are scores of different systems, each with unique capabilities.

The simpler, non-slackpulling skyline systems, such as the common shotgun and slackline, work fine in clearcut logging in timber of reasonable size. Where the timber is small, or scattered, or a partial cut is required, a slack-pulling system may be called for. This increases the complexity of the equipment and rigging. There are numerous slackpulling systems available, each suited to a unique set of operating conditions.

THE PLACE OF SKYLINE SYSTEMS IN BRITISH COLUMBIA

Skyline systems have a definite place in B.C., for two basic reasons: lower costs and greater reaches than conventional systems.

On the same piece of ground, skyline productivity is greater simply because a carriage with the front end of the turn clear of the ground can move faster than butt rigging dragging logs along the ground, with additional drag from haulback tension. For much B.C. Coastal timber, the addition of a carriage to a highlead tower should result in a 20% production increase. The added daily cost should be negligible where the tower is suited for shotgun operation, so there is a 20% reduction in cost. Furthermore, the faster outhaul/inhaul speeds make longer reaches economic. For these reasons, shotgun is often the system of choice in the U.S.

Much of the remaining old growth timber in B.C. is located on terrain that is expensive to road for conventional systems. Road construction in this terrain also carries environmental risks. The skyline can make it feasible to access such timber, since with longer yarding reaches fewer roads have to be built, and the most environmentally-risky roads can be eliminated. However, longer yarding is not usually cheaper than shorter yarding. Long spans should be used only where they can be justified by the consequent savings in road construction and/or environmental impact.

Much of the remaining old growth is also small in size, and sometimes scattered. Certain skyline systems, notably the slackpulling configurations, can log small or scattered timber more cheaply than can highlead or grapple.

Achieving these advantages, however, means overcoming certain limitations inherent in most skyline systems. These are:

1. Much greater tensions are commonly exerted in the lines of skyline systems. Therefore the tower and lines require much better anchoring than highlead/grapple. The selection and placement of anchors is critical. Many a new skyline logger has tied his tower down as though it were a highlead tube, only to have it tear itself down a few turns later.

2. Without adequate deflection, the skyline will not work. Highlead can fight turns over a Roman nose; skyline will not.

3. Skyline rigging is more complex, to a greater or lesser degree depending on the system, requiring a skilled crew.

PLANNING

A mistake that is sometimes made in skyline implementation is to order the yarder before knowing what job it will have to perform. Classic errors abound, such as the company that purchased two new slackline yarders only to park one of them after a year, and the other a few years later, when they ran out of suitable terrain.

It is essential to prepare a total chance logging plan in advance of any equipment selection. The plan should show a complete road, landing, and setting layout. The work is typically done on paper, from aerial photos and topographic maps, with a modest amount of field checking. The engineer doing the planning must be very familiar with skyline equipment and rigging techniques. Many of the most critical planning decisions are made in operationally marginal areas, for example where desired anchoring zones are problematical, such as muskeg or steep downhill pulls.

From the total chance plan may be tabulated machine requirements in terms of line size, reach, and class of rigging system.

Surprises often come out of this exercise. For example, in total chance plans prepared recently by our firm in B.C. we have found a much smaller proportion of the terrain to require long-span logging than our clients expected. We have been able to identify extensive areas with severe anchoring problems, dictating the use of a 1-1/8" rather than a 1-3/8" skyline. In parts of the northern Coast Range of B.C., we have found the shape of the landforms to limit deflection over large areas. These areas have required a greater density of roads than anticipated and also a requirement is inferred for those systems using light carriages, rather than those utilizing large, heavy carriages.

Most importantly, after a total chance plan is prepared, the company knows what equipment mix is required, what operational issues exist, and the preferred cutting sequence.

We have found numerous problems to have been created where the first pass of cutting in a drainage was done without a total chance plan. The result in many cases is that the easy timber within reach of a highlead tower was logged, leaving a strip of merchantable timber on the upper valley slopes. Such a strip, by itself, may be no longer economic to log, but would have been economic to have yarded with the timber below had logging followed an integrated plan for the entire drainage. Similarly, we have found anchors to have been lost from critical anchoring zones due to earlier logging, where this could have been avoided by adequate planning.

EQUIPMENT SELECTION

Prior to narrowing down to particular brands or models of yarder and their various mechanical features, the key specifications need to be scoped as follows. The total chance plan provides the basis.

The tower must be matched to the size of timber being yarded, and especially to the anchors available to tie it down. The combinations of speed and line pulls must match the timber and yarding distances. High line pull/low speed is not unacceptable at short distances, but for long reaches high-speed inhaul is necessary to be economic.

The yarder must have enough drums to operate the systems desired, remembering that it is advantageous to be able to operate a variety of systems in response to changing timber and terrain.

Drum capacity is a critical selection criterion, in order to ensure the yarder can reach all of the timber it is supposed to. It is usually possible to use skyline extensions to reach farther than the drum capacity might suggest, but only if there is sufficient haulback capacity. Even if the haulback is not required to skin the carriage back, e.g. with a gravity application, it must be assessed whether it will be required for the purposes of rigging the skyline. Haulback capacity is most often limiting to the reach of a yarder.

Equipment weight and mobility are issues in many areas.

There are many carriage models available, each with unique operating characteristics and suited best to specific applications. There is no one "best" carriage. The successful skyline logger usually owns several carriages for each yarder.

Tower height is another critical selection criterion. It is important for creating deflection, not only out on the unit but often more importantly at the landing. Particularly for tree length logging but also in bucked logs, a small 15 m (50-foot) tower can have serious problems getting enough lift over the edge of the landing. This has been one of the main reasons for the trend from 15 m to 21 m (50-foot to 70-foot) towers on the smaller yarders. On a tree length landing, it is also easier to keep trees and booms clear of the guylines with a taller tube.

LAYOUT

High production results when the layout engineer has planned the entire integrated road and logging layout with all operational details taken into account. The key items to consider are:

1. Engineering and production people must coordinate so that the layout engineer knows the distance and systems capabilities of the available equipment that he is laying out for. He must also know what crews are capable of. For example, there is no point in marking tail trees if the skills to rig them are not currently available in the area. The engineers must envisage the entire operation, including specific rigging configurations for the entire setting. They must understand the relationships between costs and yarding distance and stand variables, in order to optimize the layout.

2. Layout engineers should plan for maximum application of the most productive/lowest cost yarding systems, consistent with an economic and environmentally acceptable road network. For example, slackline yarding with 600 m reaches should not be planned where a substantially similar road system would permit shotgun yarding with 400 m long corners.

3. It is essential to check deflection. B.C. companies do a good job of running deflection lines, but the analysis of these for skyline is much more complex than for highlead, and also highly equipment-specific and system-specific. The layout engineer needs to evaluate tower height requirements, back spars, and moving the tailhold zone as means of creating deflection. He must be able to evaluate spar trees in the field.

4. Anchoring difficulties often dictate the equipment and systems used. All anchoring zones must be identified on paper, and checked on the ground if questionable. Practical solutions to anchoring problems such as undersized or rotten trees, muskeg, an absence of trees, or steep downhill pulls (especially on talus) must be identified at the layout phase.

TRAINING

None of the above is readily achieved except by either hiring experienced people, or training existing employees. The costs of not training adequately are:

1. Sub-standard production and cost performance.

2. Accidents resulting in property damage, injury, or death.

Planning and layout engineers, assuming they are already competent in forest road engineering and highlead layout, need to become familiar with skyline engineering and operations, as well as the nature of basic cost relationships.

Logging crews need to acquire fresh skills. Highlead logging skills are only a partial preparation for skyline logging. In particular, loggers need to learn good anchoring configurations, rigging techniques, and skyline systems configurations. Hookers at least, and if possible others, need to have the fundamentals of skyline engineering explained in a form intelligible to a non-engineer.

PRODUCTIVITY AND COST ESTIMATORS FOR CONVENTIONAL GROUND-BASED SKIDDING ON STEEP TERRAIN USING PREPLANNED SKID ROADS

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ABSTRACT

Continuous time and motion study techniques were used to develop productivity and cost estimators for the skidding component of ground-based logging systems, operating on steep terrain using preplanned skid roads. Comparisons of productivity and costs were analyzed for an overland random access skidding method, verses a skidding method utilizing a network of preplanned designated bladed skid roads. Productivity levels decreased while costs increased as the amount of winch line cable needed to be pulled to choke logs increased. Although estimated skidding costs were higher when the designated skid roads were used, the increased costs may be offset by a reduction in adverse stand and site impacts, and a reduction in the safety hazards often associated with ground-based skidding on steep terrain.

Keywords:
Ground-based harvesting, harvesting costs, productivity.

INTRODUCTION

In the eastern United States, most timber producers transport felled timber from the stump to the landing by skidding. Skidding is defined as the moving of whole trees or tree sections from one location to another by connecting a cable or chain or a grapple to one end and dragging them with a skidder or other suitable machine to a location where they can be loaded onto trucks for transport to the mill (Matthes and Watson, 1981). Rubber-tired skidders with their advantages of cost, flexibility, and modest skill requirements are currently the most economical means of removing timber from level to moderately steep terrain, and will likely remain the method of choice from an operational standpoint (Stuart and Carr, 1990).

Increased environmental concerns coupled with increased harvesting costs have renewed interest in the impacts of ground-based harvesting systems on steep terrain. Harvesting impacts include such things as erosion risk, soil and site disturbance, residual stand damage, and unfavorable aesthetics. When ground-based systems are used, these adverse impacts become increasingly severe as slopes become steeper and logging difficulty increases.

Traditional skidding practices typically involve a random entry/exit overland skidding method. The greatest single advantage of overland skidding is its simplicity. The method requires little if any preplanning since the skidder operator simply travels whatever random route he chooses to reach and skid timber to the landing. Disadvantages with the method arise when slopes become moderately steep (30-40%) and begin to limit the mobility and efficiency of rubber-tired skidders, at which time the potential for adversely impacting the site increases (Sloan, 1990). When slopes increase to the point where skidding in an overland fashion becomes too hazardous, alternative methods must be used.

An alternative skidding method that can be used on steep slopes is one which utilizes a system of designated preplanned bladed skid roads. When using designated roads the operator travels the constructed trails to points where timber can be choked by pulling winch line to the felled trees while the skidder remains on the trail. Skid road spacing is crucial as it determines the cable pull distances necessary in the log choking process, which can have a major impact on system productivity. Advantages with this type of skidding include: reduced damage to residual trees since the machine is not operating within the stand; a reduction in total forest floor area disturbed; reduced soil compaction within the stand; better control over drainage and sensitive area crossings; and increased safety since the operator is not required to negotiate steep side slopes which can increase the hazard of machine rollover. Disadvantages include skid road construction and maintenance costs, and reduced productivity due to the additional time required to pull cable from the skid roads to the felled timber to be choked. Bladed skid roads have the potential of being a major source of erosion and adverse aesthetics, although these can be alleviated through careful pre-harvest road planning and layout, and post-harvest use of proper best management practices for skid road closure, including installation of water bars and other erosion control structures.

There is currently little information available for assessing the productivity and costs of steep slope skidding with conventional ground-based equipment. Such information would be useful in preparing National Forest timber sales, private commercial sales, and could be used by loggers in determining operating costs. The information may also be useful in comparing the productivity and costs associated with ground-based harvesting systems versus those of traditional steep slope cable operations (Fairweather, 1991, Fight *et al*, 1984, LeDoux and Baumgras, 1990). A more complete understanding of operating ground-based systems on steep terrain using preplanned skid roads may also help to capitalize on an existing work force that is familiar with the method, while avoiding the expensive retraining and layout required in cable yarding systems.

This paper presents the results of an investigation undertaken in part to compare productivity and costs for ground-based skidding on steep terrain using random entry/exit overland skidding from stump to landing, versus skidding on a system of preplanned bladed skid roads. The discussion and results reported will focus on an analysis comparing system productivity and costs as influenced by the variable degrees of winch line pulling necessary to skid felled timber in a commercial thinning operation. These comparisons will help to explain the magnitude of the cost differentials between the random access overland skidding method where the operator generally positions the skidder as close to the felled timber as possible to minimize the length of line to be pulled in the choking process, versus the method used in this study where the skidders remained on the designated skid roads and cable was pulled to the felled timber.

STUDY AREA

Data for the study was collected from a commercial logging operation on the West Virginia University Experimental Forest, Preston County, West Virginia. The harvested area was approximately 30 acres in size. Terrain varied with slopes ranging from moderately steep to steep slopes of 20 to 40 percent with varying degrees of rock outcropping and shelf rock. Terrain characteristics found on the study area are common to Appalachia, extending the usefulness of the study results to other harvesting operations in the region.

Initial stand characteristics consisted of mixed Appalachian hardwoods averaging 84 square feet of basal area per acre and 10,632 board feet per acre in trees 12 inches DBH and larger. Average stand diameter was 16.5 inches in trees 12 inches and larger. Species composition included white oak, red oak, chestnut oak, scarlet oak, soft maple and yellow-poplar along with a few other species of lesser importance (Table 1).

Marking of the timber to be harvested in the thinning was done following recommendations based on the initial timber cruise. Average diameter of marked timber was 19.3 inches DBH, ranging from 12 to 40 inches, with an average of 45.3 ft^2 of basal area per acre marked for harvest. Total marked volume was estimated at 166,397 board feet, or 5547 board feet per acre (Table 1).

METHODS

Skid Road Layout

Following the timber mark, a single centrally located landing and a network of skid roads spaced 150 to 200 feet apart were flagged in, center staked, and surveyed for bearing, distance, slopes, and side slopes. The skid roads, consisting of two main and 8 variable length spurs totaling 7577 feet in length, were constructed with a dozer prior to logging. Skid roads were located to take advantage of natural terrain features, while avoiding sensitive areas as much as possible. Slopes were kept under 15 to 20 percent whenever possible. By maintaining the narrow spacing between skid roads, it was intended that all skidding activities be limited to the roads, which should minimize the adverse soil and site disturbances, while keeping the winch line pull distances to a tolerable and cost effective level in the log choking process.

Table 1. Initial conditions and marking summary for study unit.[a]

Trees/Acre initial	Trees/Acre marked	BA/Acre (ft^2) initial	BA/Acre (ft^2) marked	Vol./Acre[b] initial	Vol./Acre[b] marked	Mean DBH initial	Mean DBH marked
56	22	84.1	45.3	10632	5547	16.5	19.6

[a] Includes only trees 12-in dbh and greater.
[b] Board feet International 1/4-in rule.

Skidding

Felling and skidding of the marked timber was done in the early spring of 1990. Trees were chain saw felled and skidded tree-length to the landing where they were either decked or loaded directly onto trucks. Although three machines were used in the operation, the analysis and discussion reported here will focus only on a John Deere 440C[1] cable skidder in order to simplify discussion. This skidder was the primary machine used in the harvest operation and skidded nearly 65 percent of the total volume removed in the thinning.

Persons stationed both in the woods and at the landing recorded continuous time and motion data for all skidding elements, both productive and nonproductive, with electronic stopwatches. Additional turn parameters including maximum skid slope distance, number of trees skidded per turn, winch line pull distance, pull slope, and several other variables were also recorded and used in the productivity and cost analysis.

RESULTS

Cycle Time Model

Forest engineers responsible for making estimates of ground-based skidding productivity have commonly used techniques based on analysis of time and motion data (Olsen and Gibbons, 1983). Multiple regression techniques were used to develop a regression model which would estimate an average productive cycle time as a function of the skidding parameters recorded during the time study. The model was developed using data from 282 skid cycles containing complete and valid data records for the JD440C skidder. Significant variables in the regression equation included skid distance, turn volume, number of trees per turn, amount of winch line pulled, whether or not an operator sets his own chokers, and a function of the amount of adverse slope encountered during a skid. Average values from the 282 turns used to develop the model for one way skid distance and turn volume were 833 feet and 81.3 ft^3, respectively. Frequency distributions for total length of winch line cable pulled per turn and line pulls by slope class (referenced from the skidder to the felled tree) for the 282 turns are given in Figures 1 and 2.

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

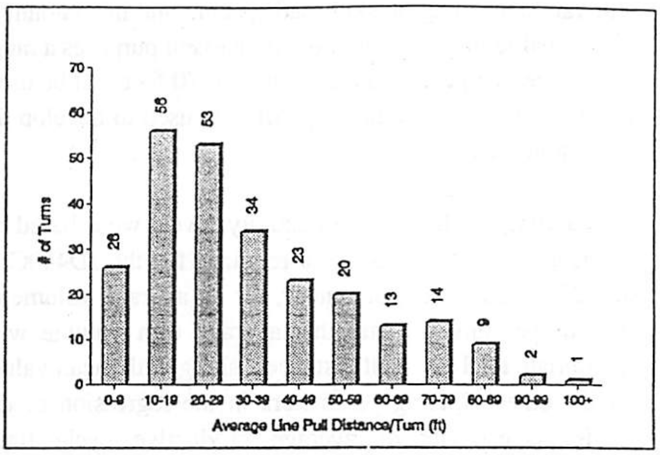

Figure 1. Actual total line pull distances per turn for 28.2 skid cycles, mean pull distance = 34 feet.

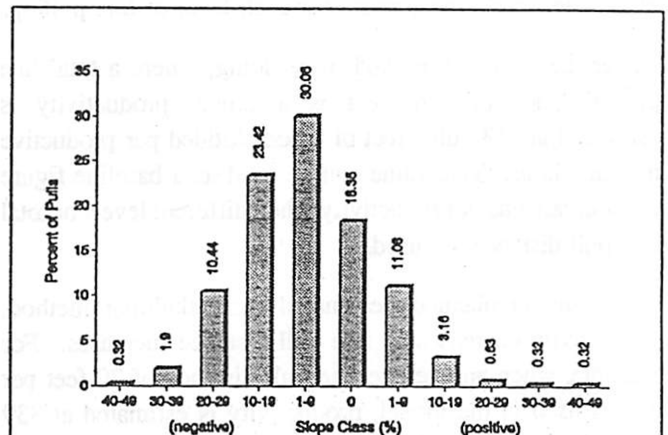

Figure 2. Proportional distribution of pulls by slope class (referenced from skidder to felled tree) for 28.2 skid cycles.

Preplanned Roads vs Random Access Skidding

The regression model was used to perform a sensitivity analysis based on differing levels of average line pull distance per turn. By varying the total line pull distance while keeping all other variables constant, the influence of this single parameter on skidding productivity and costs could be evaluated.

In an overland random access skidding method one can assume that total line pull distances will average out to negligible levels, since the operator will generally position the skidder as close to the felled timber as possible before choking. In the discussion we will assume an average pull distance of zero feet for the overland skidding method.

When using a designated skid trail system to skid timber, line pull distances will average out to higher values which will vary depending on skid road spacing and the amount of directional felling utilized. For comparison purposes a range of average line pull distances from 0 to 70 feet will be used, which are well within the range of data used to develop the regression model.

Productivity. Machine productivity levels were based on the actual 295 turns that were required for the JD440C to skid 23814 cubic feet of timber, for an average volume of 80.7 ft^3 per turn. Using this average turn volume with appropriate total line pull distances, along with mean values for the other skidding parameters in the regression model yields an estimate of average productive cycle time. Multiplying the estimated cycle time by the total number of turns gives the number of productive hours the skidder was used in the harvest operation for the average total line pull distance selected. Hourly machine productivity for the different levels of line pulling were then calculated by dividing the total volume skidded by the estimated number of productive skidding hours for each level of line pulling.

Under the overland method of skidding, where a total line pull distance of zero feet is assumed, productivity is estimated at 413 cubic feet of wood skidded per productive machine hour. This value can be used as a baseline figure for comparisons of productivity when different levels of total line pull distance are used.

Under the preplanned designated road skidding method, productivity decreases as line pull distance increases. For example, when an average line pull distance of 70 feet per turn is used in the model, productivity is estimated at 339 cubic feet of wood skidded per productive machine hour. With an average line pull distance of 70 feet per turn, productivity is reduced by 17.9 percent as compared to the overland skidding method. A graphical representation of productivity levels per productive machine hour for incremental line pull distances of 10 feet is included in Figure 3.

Skidding Costs. A machine rate calculation method was used to estimate equipment costs for skidding (Matthews, 1942, Miyata, 1980, Burgess and Cubbage, 1990). Published rates and cost factors (Anonymous, 1981, Brinker *et al* 1989, Miyata, 1980, Werblow and Cubbage, 1986) altered to fit the needs of this study where necessary, were used to determine hourly machine rates, both fixed and operating. Based on these calculations, fixed costs per scheduled machine hour were estimated to be $7.35, while operating costs per productive machine hour, exclusive of labor, were estimated at $8.56 for the JD440C skidder.

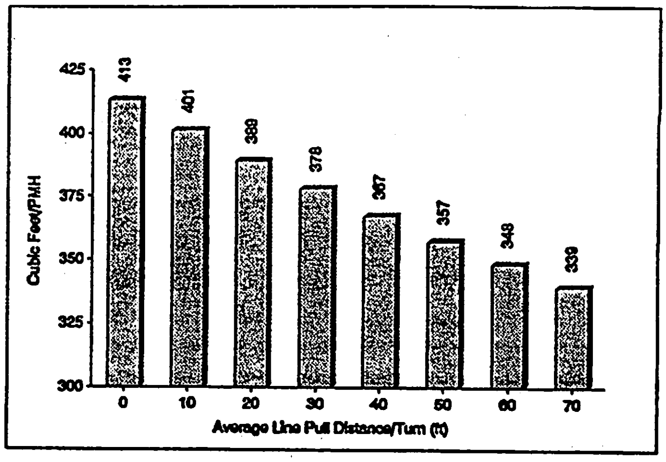

Figure 3. Estimated skidding productivity per productive machine hour by variable average total line pull distances per turn.

Labor rates were based on a machine operator, and 50 percent utilization of a choker setter. In addition to a base wage, labor rates included employer contributions for Workmen's Compensation, Social Security, Unemployment Insurance, and employee benefits and totaled $13.91 per scheduled machine hour. All costs reported in the following discussion will include labor.

A unit production cost analysis similar to the one presented by Miyata and Steinhilb (1981), was used to calculate total skidding costs under a range of average total line pull distances. Total skidding costs for the tract increased by $60.81 for each additional 10 foot increment of average line pull distance per turn. Based on the total volume skidded by the JD440C skidder, total skidding cost for the tract ranged from a low of $1925.72 when a line pull distance per turn of zero feet was assumed, to a high of $2351.36 when a line pull distance per turn of 70 feet was assumed. A graphical representation of total skidding costs for incremental line pull distances of 10 feet is included in Figure 4.

In addition to the increased costs of skidding due to pulling cable when designated skid trails are used, the cost of skid road construction and maintenance must also be included to get reliable estimates of total skidding costs. The cost to blade in and maintain skid roads will vary depending on soil and terrain characteristics, as well as the size of dozer used for construction.

1989. Machine rates for selected forest harvesting machines. Alabama Agric. Exp. Stn. Circular 296, Auburn, AL. 24 p.

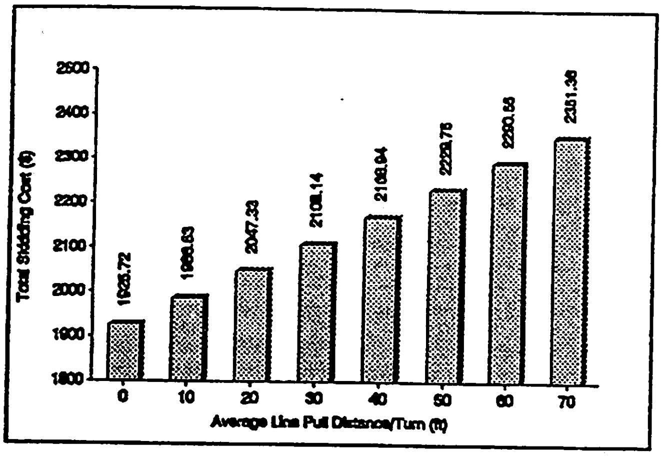

Figure 4. Estimated total skidding costs for skidding 23814 ft^3 of timber by variable average total line pull distances per turn.

CONCLUSION

Productivity and cost estimators for two ground-based skidding methods are provided which may be useful for a variety of applications. These estimators include costs for the skidding component of a harvest operation, the component that is traditionally the weak link and least productive function in ground-based harvesting (Hassler *et al*, 1983, Lawrence and Dyson, 1967). By using the productive cycle time model developed from the time and motion data, it was possible to show how skidding productivity and costs are affected by variable degrees of line pulling. The results of this case study indicate that productivity is clearly influenced by the amount of line pulling required to choke a turn of logs. As line pull distances increase productive cycle times increase, which in turn reduces productivity and results in a corresponding increase in skidding costs. The extent of the reduction in productivity and increase in costs when using designated skid roads will depend on road spacing and the amount of directional felling used. Although skidding on a network of preplanned skid roads results in higher skidding costs, increased environmental concerns over the impacts of harvesting on steep terrain may force the use of such skidding practices to minimize the extent of adverse stand and site impacts in the future.

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DEVELOPMENT OF A GEOGRAPHIC INFORMATION SYSTEM FOR TIMBER SALE PLANNING

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ABSTRACT
Timber sale planning on the National Forests is becoming increasingly complex. Current methods used to develop Land and Resource Management Plans are time consuming, require evaluation of large amounts of site-specific information, and involve complex spatial relationships. GIS is an efficient tool for maintaining and analyzing the spatially referenced resource information. The development of a GIS-based Spatial Decision Support System for Timber Sale Planning on the Jefferson National Forest is described.

Keywords:
Harvest planning; GIS; Decision support; U.S. Forest Service.

INTRODUCTION
Harvest planning is becoming an increasingly complex task that requires evaluation of a variety of environmental and socio-economic factors. No where is this more evident than for U.S. Forest Service (USFS) resource management and planning on the National Forests. Current resource planning models used by the Forest Service are too complex, lack the ability to analyze spatial problems, and are extremely difficult to implement at the District level (Hof 1987; Sedjo 1987). The large volume of information that must be analyzed and the complexity of the decision-making process necessitates that a computerized decision support system (DSS) be developed.

The Forest Service plans to acquire a geographic information system (GIS) to help integrate and manage their resource information needs during the 1990's (Haskell 1990). The USFS considers GIS as the most effective and efficient way to store, retrieve, analyze, and present the spatially referenced resource information necessary for managing the National Forests. Instead of viewing GIS as simply a software package for map production, the USFS recognizes that GIS provides an opportunity to develop system-wide digital and tabular resource databases that will be compatible with existing business management functions to create a truly integrated natural resource management computer environment.

Several National Forests already have GIS systems and are using it to support forest management projects and other applications. For the past several years, the Jefferson National Forest (JNF) has been developing digital databases for each of its six Ranger Districts in Virginia. This involves digitizing each District's resource layers so that the attribute data and graphic files are complete and accurate. The JNF utilizes "Opportunity Area Analysis" (OAA) to structure their Land and Resource Management Plans (LRMP). The OAA planning process involves planning various resource-integrated site-specific projects over a 10-year period for individual opportunity areas. For each opportunity area, public attitudes are assessed to identify site-specific issues, concerns, and opportunities for all resources. The issues and concerns identified are then combined with the agency's objectives to develop comprehensive management alternatives.

This paper describes the development of a GIS-based system that facilitates Opportunity Area Analysis on the Jefferson National Forest; specifically, a Spatial Decision Support System (SDSS) for Timber Sale Planning. The SDSS attempts to model the OAA planning process by analyzing the site-specific data necessary to evaluate the environmental and social concerns, and balance the silvicultural and economic impacts of timber harvesting activities on the National Forest.

TIMBER SALE PLANNING
Since harvest planning and timber sale preparation are an important part of LRMP development, a cooperative project was initiated with Virginia Tech's Department of Forestry to develop a prototype GIS-based model to assist in developing various timber management alternatives. The Spatial Decision Support System (SDSS) for Timber Sale Planning (Kenney 1990) is designed to bridge the gap between forest-wide resource allocations and site-specific resource management alternatives developed at the District level.

GIS/Database.
The Clinch Ranger District, located in southwestern Virginia, was the first district on the JNF to have an integrated spatial and attribute database. Of the fourteen OAAs on the Clinch District, the Wallen Ridge Opportunity Area, approximately 9,700 acres in size, was identified as the most suitable study area because OAA planning is currently in progress. This would provide an ideal situation to test, evaluate, and compare the effectiveness of the SDSS timber sale planning model with the manual approach currently being used.

The digital database for SDSS includes the USGS Primary Base Series (PBS) information layers containing Forest

Service ownership, land management areas, roads, streams, and other thematic layers containing forest stand, soil type, and wildlife areas/point data. In addition, coverages delineating Visual Quality Objective (VQO) and Recreation Opportunity Spectrum (ROS) classifications, and slope/aspect classes generated from USGS Digital Elevation Model (DEM) data have been included. The map coverages are linked with the Continuous Inventory of Stand Characteristics II (CISCII) database which contains stand level tabular information. The SDSS model was developed on DEC MicroVAX II using ARC/INFO (Version 5.0) GIS software. The SDSS modules are programmed using ARC/INFO AML Macro Language.

Spatial Decision Support System.

The prototype SDSS for timber sale planning evaluates the effects of harvesting on soil and water quality, visual and recreational use, fish and wildlife habitat, and the harvest economics for candidate stands in the Wallen Ridge opportunity area. The SDSS model does not attempt to optimize timber sale planning; instead it replicates the manual process that the District timber sale administrator employs in developing harvesting alternatives.

The SDSS user interface consists of a hierarchical AML menu structure for controlling the decision making process. The menu system is designed so that the user selects sequential menu operations, from left to right, as he/she proceeds through the planning process. The screen display is organized with the menu header across the top, thematic map displays in the center of the screen, and an area for general analysis information and a map legend to the right. A variety of map displays and tabular reports are provided to supply the planner with the information required for advancing through the timber sale planning process.

The SDSS decision process consists of four steps:
1. Identification of suitable stands;
2. Evaluation of environmental and social objectives;
3. Analysis of harvest economics; and
4. Development of harvesting alternatives.

Identification of Suitable Stands. The LRMP for the JNF partitions the Forest into 8 Management Area (MA) classifications. Each MA has a unique management prescription which details the general directions, standards, and guidelines for management activities on that land area. MA 7 is designated as multiple-use, general forest capable of producing quality sawtimber and other forest products. MA 8 stands are classified as multiple-use with the emphasis on wildlife management, and are generally considered "unsuitable" for timber harvesting.

The first step in the decision process evaluates whether or not an individual stand is classified as MA 7 (i.e. suitable) or MA 8 (i.e. unsuitable) for timber harvesting. The first level of suitability is based on three parameters: site index, steepness of slope, and stand accessibility. If a stand meets the suitability criteria established for each parameter, SDSS considers that stand a potential candidate for further consideration (i.e. MA 7). The remaining stands are classified as MA 8 and dropped from initial solution set.

The next step evaluates the appropriate logging system to be employed and timber product objectives for each candidate stand identified. Logging system selection is based on percent slope, soil properties, watershed characteristics, and silvicultural treatment. On the Clinch Ranger District, three systems are currently used: conventional rubber-tired skidders, cable yarding, and specialized fast track skidders. The final step in identifying suitable candidate stands considers the timber product objectives that are included in the LRMP. Factors such as tree diameter and rotation age for each forest type are used to determine harvest suitability.

Evaluation of Environmental and Social Constraints. In the next step, SDSS revises the set of "suitable" candidate stands by evaluating the environmental and social objectives that effect timber harvesting. SDSS considers the following:
1. Recreation Opportunity Spectrum (ROS);
2. Visual Quality Objectives (VQO);
3. Featured Wildlife Species;
4. BMP's/Streamside Management Zones; and
5. Areas with highly erodable soils.

ROS classifies land areas in terms of recreational experience opportunities and the extent to which the natural environment satisfies those needs. VQO's attempt to quantify the public's concern for scenic quality as well as diversity of natural features. The "wildlife featured species" module evaluates the current situation, desired habitat components, and proposed allowable changes in the forest vegetation or habitat. Best Management Practices (BMP's) specify the minimum water standards and guidelines for stream protection. For each type of stream, buffer zones of varying widths are prescribed so that soil disturbed during harvesting or road construction does not impair the water quality standards for nearby streams. Hazardous or unstable soils are also evaluated to minimize the impact of potential soil erosion and sedimentation from timber management activities.

After evaluating the environmental conditions and social constraints the SDSS appends the results of these analyses to the attribute database for each candidate stand. This process allows the user to verify that a potential timber harvest will not adversely affect any of these other resource values. After evaluating these factors, the candidate stands that are acceptable timber sale areas are then advanced to the next phase of the decision process.

Analysis of Harvest Economics. For each potential timber sale area, an economic analysis is conducted to determine stand volume, estimate stumpage value, estimate cost adjustments, and to assign fixed operating costs to each candidate stand. The economic analysis module relies heavily upon user inputs for current information. The majority of SDSS output from this module is in tabular form rather than map displays.

The SDSS permits the user to determine timber volume by entering current volume estimates or by matching similar stands from a database of historical timber sale data. Stumpage value is estimated by entering current base prices for sawtimber and pulpwood, and then adjusting the base value to reflect differences in the type of harvesting system used, woods to mill transport distance, construction of temporary roads, and several other factors. The last step in the economic analysis incorporates district-wide overhead costs associated with timber management activities on the JNF. These include harvest administration, planning/resource support, and general administration costs.

Development of Harvest Alternatives. At this point, the timber sale planner has identified stands suitable for harvest (Step 1), evaluated the effects of environmental and social constraints (Step 2), and quantified the economics of harvesting each candidate stand (Step 3) in the opportunity area. Throughout these analyses, the planner has the opportunity to review the results of each module and modify decision parameters based on their personal knowledge of the area. Once accepted, the results of each decision module were appended to the attribute file for each stand. This information is now used to assist the planner develop timber harvest alternatives.

In the final step, SDSS ranks candidate stands based on specific resource management objectives, and assists the planner in developing several harvesting alternatives. This is an iterative process which ultimately produces a final timber harvest schedule for each year. Currently SDSS can generate a harvest schedule for 10-year LRMP based on allowable cut levels or develop a schedule for a shorter planning period. Other considerations include the location and size of recent or planned cuts and maximum clearcut acreage limits that are part of Forest Service operating guidelines.

Refinement of these alternatives is done interactively by the planner by viewing screen displays and map outputs produced during each phase of the planning process. Only a limited amount of summary information can be displayed on-screen, but more detailed reports and thematic map coverages can be produced to document the analysis process.

SUMMARY

The current version of the SDSS model for timber sale planning is being evaluated by Forest Service personnel. Part of the testing program will include a comparison of the SDSS generated plan alternatives with the harvest alternatives currently being developed using the traditional manual approach. Comparison of the two approaches will be needed for refining the model and ultimately for developing successive versions of the prototype SDSS.

When implemented, the GIS-based Spatial Decision Support System for Timber Sale Planning is expected to improve current methods of timber sale preparation. These improvements include: (1) faster access to current information for resource planning; (2) improved map production and report generation; (3) better definition of the decision process; (4) greater flexibility in forest plan development; and (5) the ability to quickly develop/compare more alternatives.

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COORDINATED CONTROLS - A NATURAL WAY TO OPERATE MACHINES

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ABSTRACT

Coordinated control of heavy equipment for forest application has been under development in British Columbia since 1985, although discussions date back to the late 1970's. This form of control, called "resolved motion control", significantly reduces the learning time required by novice operators compared to current machine control systems. The benefits are achieved because the operator's control motions are naturally related to the task being performed. Simultaneous motion of multiple control levers and/or foot pedals are not required. Control is achieved via a single three-axis joystick.

Resolved motion controls have been applied in B.C. to an excavator and a log loader, and a simplified form of resolved motion has been applied to a grapple yarder.

Resolved motion is discussed as a component of the larger framework called teleoperation. Resolved motion can achieve some of the potential benefits of teleoperation, but some are still to be realized.

THIS PAPER WAS NOT AVAILABLE AT THE TIME OF PUBLICATION.

Machine Operator Selection and Training

by

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Key Words: Machine operators, training, selection, logging, mechanized harvesting, productivity.

Abstract:

Describes the potential contribution of machine operator selection and training programs to productivity. Selection results come from a validated selection project with 101 log loader operators. Training options are outlined for vocational education, machinery suppliers, associations of companies and individual companies. An economic decision model is used to assess expected training gains. Useful decision guidelines are listed for considering selection and training strategies.

INTRODUCTION

Machines for timber harvesting are increasing in use in the western United States and Canada for a variety of reasons.

* Productivity improvement - Machines offer potentials for productivity increases.
* Smaller tree sizes - Machines are now better matched to tree sizes harvested compared to larger timber of the past.
* Labor force reasons - Machines reduce labor demands for workers.
* Safety benefits - Machines reduce exposure to certain types of injuries, especially those associated with chainsaws.
* Improved machines - Better and more reliable machines are now available, e.g. options for steeper slopes.
* Others - Quality improvements, resource protection, silvicultural options, double shifting, etc.

MACHINE OPERATORS

While interest increases in specific machines and systems, less efforts have been directed toward the source of a machines' productivity: the human operator. Cottell, et al. (1976) early demonstrated that 64% of the variation in performance was attributed to the operators in similar operations. However, operator selection has not been operationally tested to see if research potentials can be realized. Training is often discussed as a need but few training schools, curricula or training materials are available in western North America compared to the number of operators needed now or in the future. Current operator selection and training are described below.

ISSUES OF SELECTION AND TRAINING

A substantial list of issues and obstacles to use of operator selection and training can be generated. Obstacles have been identified as: the small size of firms, lack of personnel to do selection and training, preferences for traditional approaches, union obstacles, laws and regulations, contractor relationships, costs and others. Specific issues in implementation involve roles and responsibilities of wood processing firms with logging labor, contractors and contractor associations, machine manufacturers, educational and training institutions, unions, safety organizations and government organizations. Only a willingness of managers in these organizations to change attitudes about selection and training can lead to needed trials at the operational level. From the author's review of mechanization in the Nordic countries and eastern North America, it is amazing to see the rush to mechanization proceed while ignoring the errors of the past regarding the importance of the operators.

GAINS FROM SELECTION AND TRAINING

The uncertainty about the magnitude of gains from selection and training may cause managerial reluctance for trials. Consider that some managers who tried to implement mechanization in the absence of training found failures in achieving target gains (Saucier, 1977). The costs of "falsestarts" in selecting machine operators who fail to make successful operators largely goes unmeasured. Without normative production databases, logging managers have difficulty telling whether operators are above or below normal. Gains from selection and training need to be incorporated into decision models to help managers allocate resources among business potentials.

CURRENT OPERATOR SELECTION AND TRAINING

In a 1985 survey of western U.S. mechanized operations, Schuh and Kellogg (1988), found the following approaches in firms for selection and training of operators (n=85 firms).

<u>Selection</u>

43% select based on level of experience with similar machinery
30% hired based on some skills assessment
21% could hire only experienced operators

<u>Training</u>

Most new operators receive informal training from a previous employee
20% receive no training whatsoever

Only 2% of responding owners provided a formal training program

There is little reason to suggest that these approaches are changed at the present time in western North America. Trials are needed to offer proven alternatives to logging firms who "make do" with the approaches above.

DESIGNED MACHINE OPERATOR SELECTION

It has been demonstrated that humans differ in basic abilities needed to operate machines in harvesting operations (Norwegian Forest Research Institute, 1976a,b; 1977; 1987; Hall, et al. 1972). A study of log loader operator selection was undertaken in 1980-81 and results have recently been made available (Weyerhaeuser, 1981; Garland, in publication). Twenty five individual survey scales were administered to 101 log loader operators in Weyerhaeuser western regions. The design of the project followed the flow chart of figure 1.

[PLACE FIGURE 1 HERE]

Correlations between the performance measures and the various survey scales were sufficiently strong so that an "optimal combination" of survey scales could be selected. Given the needs of 120 new operators over six years, the gain from a designed selection procedure was estimated as between $5510 and $6496 (Weyerhaeuser, 1981).

Economic objections to designed selection procedures and concerns of meeting equal employment opportunities are not sufficient to merit the lack of trials. It is of more concern that recruitment into logging occupations has been so influenced by negative publicity that harvesting managers must be satisfied with whatever workers elect the profession. An even greater concern is whether logging managers are sufficiently acquainted with designed selection procedures to evaluate the potential contribution. Some logging managers cling to erroneous and biased selection criteria.

A major finding of my work in logging training is that designed training programs serve as selection procedures themselves. When specific performance checks are combined with feedback and counseling to trainees, it is rare that trainees elect to continue in the face of documented and repeated failure. They would likely opt for other employment than as a machine operator when they see the futility of their lack of success. Selection then becomes an element of designed training programs.

TRAINING NEEDS

One of the worst misconceptions is that training is a one-shot affair. Training is no more a "magic pill" or "quick fix" than other efforts to improve productivity. Too many training efforts of this sort had expectations beyond realities. Training ought to be incorporated into a firm's strategic planning recognizing different training needs.

Machine operator training should be considered a modular approach that addresses the needs below.

Whole-Concept Training

Too many workers do not understand their position in the firm. They do not understand the overall objectives of the firm and the upstream and downstream implications of their own particular job. The idea of "whole-concept" learning is important to adult learners. Machine operators want to know not only how to perform operations but also why their actions are essential. A one-line statement in a company policy is not the same as a complete understanding. One example of whole-concept training is illustrated by a 40 minute video that shows harvesting processes from stump through processing at the sort yard (Garland and Mediatek, 1982). Individual firms are so unique as to make this training specific to each organization.

Maintenance and Control Functions

Machine manufacturers have allocated resources to training on maintenance and control functions. It is in their best interests to have operators properly maintain the equipment. Obviously, operators must be familiar with control functions as soon as possible. In contrast to other industries, there are no standard control patterns used in mechanized harvesting operations. Manufacturers solely focusing on this training area provide only the most rudimentary manuals and on-site training--ranging from a few pointers as the machine is delivered to one to three days of training by a factory representative.

Fundamental Functions

Harvesting machine operators require competency at a series of fundamental functions. Firm owners expect their operators to transfer their skills from other machines to the new one. Some European manufacturers offer one to two week factory training courses, and some North American manufacturers will place a factory representative with the purchaser's operator for one to three weeks.

As important as these fundamental functions are, the emphasis by manufacturers overstates their importance. Within a few months or so, operators gain the fundamental functions dependent on motor skills, depth perception, and other physical abilities. Effective operators move from acquisition of physical skills to developing the mental judgments needed in the fuller tasks of the job.

Limits of the Machine

Designed training on the limits of the limits of the machine is needed in both a fundamental sense and more advanced operational sense. Fundamental training may begin with machine lift charts and other engineering criteria. Later in the training, the machine's limits must be related to the expected operating conditions of slope, terrain, tractability, tree characteristics, silvicultural prescriptions, and so forth. Substantial repair and maintenance problems can be attributed to operators consistently operating beyond the limits of the machine.

Production Behaviors and Special Techniques

The most important training for machine operators are those behaviors that increase production and the special techniques that solve problems. These behaviors and techniques can be articulated by job experts and often by experienced operators themselves. These behaviors and techniques may come after years of experience and trials and errors. These are the "tips" that fathers pass on to sons, or experienced operators pass on to those who don't threaten their positions or who have earned their respect.

Production behaviors are exemplified by "ways to limb a tree as it falls to the ground" or "placing piles so they can be easily loaded by the forwarder", and so forth. Special techniques include: "handling oversize trees or logs by...(list)," and "recognizing wet spots by vegetation", or "working from the front to the back placing odd sawlogs along the way so they can be picked up on the top of pulp loads" and so forth. Production behaviors and special techniques are the mental processing and judgements used often by excellent operators. Other industries have specified such behaviors and techniques in "classic" training materials or apprenticeship documents. In logging they have come by word of mouth through informal training and relationships. However, they can be reduced to identified specific behaviors and techniques in designed training programs.

Silviculture and Site Impacts

Training needs related to silviculture and site impacts vary across a wide range of machine operating conditions. While general principles may be distilled, localized training is needed to use harvesting machines to accomplish silvicultural objectives. The same is true of training to minimize site impacts; local regulations and conditions vary significantly. I find it difficult to see how operators can learn operational techniques without costly trials and errors in the absence of designed training.

Crew Productivity Training

Even when an individual machine operator is skilled, the entire harvesting system may suffer from a lack of productivity. Individual operations need to be combined such that machine operations are working together and other functions in harmonious balance. Examples of crew productivity training are not numerous but they do exist (Beaulieu, et al., 1988).

TRAINING ORGANIZATION

It is beyond the scope of this treatise to elaborate on the full process of training design; however, discussion is needed on who might conduct the training; the need to match training pace with the learning rate of the trainee; and the control and feedback functions of trainers.

Who Might Conduct Machine Operator Training?

Without question, individual logging firms will need to take more responsibility for operator training in the fullest sense. The first step is for owners to recognize potentials of training as an investment in human capital. Consortiums of owners, associations, and cooperators in the public and private sectors are potential allies to firms in their training objective. Unfortunately, the track record of individual firms sustaining a training effort is dim with only a few good examples. Note that earlier discussion emphasized how tailored the training needs to be for individual firms.

Manufacturers and vocational institutions might combine along the model of Nordic training schools to provide training in maintenance and control functions; fundamental functions, and limits of the machine. These would allow firms to focus their training resources to do on-the-job training. Better recognition is needed that neither manufacturers nor vocational institutions produce fully qualified operators for logging firms. A private sector trial of this training would be an interesting challenge. The private sector has not found viability with logging training of this type.

Pace of Training Matching That of Learners

Another key element of training design is to schedule the pace of training within some notion of what learners can assimilate. Traditional machine operator training of a "sink-or-swim" approach is suboptimal compared to designed training. A better sequence of learning is first whole-concept learning, basic principles and then followed by practice on techniques first at a slow pace, then with skills developed, practice at production rates.

Feedback and Performance Checks

Designed training uses feedback and performance checks to give trainees knowledge of how they are progressing. Feedback involves coaching techniques relying on motivation principles and good communications. Performance checks can be key behaviors associated with productivity, safety, and so forth. They are unbiased and not subjective; trainers and supervisors need ratings training to avoid charges of discrimination. Examples from a performance check are listed in figure 2.

[PLACE FIGURE 2 HERE]

When performance checks are soundly developed and valid, they can serve as a potent selection mechanism as described earlier. Within this counseling format, employes can seek other jobs rather than continue long term employment as an unsatisfactory machine operator.

MAGNITUDE OF GAINS

The magnitude of gains from operator training are remarkably undocumented. In the Nordic countries with the longest history of training machine operators, I could only find work by Lehtonen (1975) and Hall, et al (1972) that documented training gains quantitatively. With training schools in place, these countries found it strange that a researcher from Oregon would be asking for such obvious results. Casual evaluations of training successes are made by the Nordic manufacturers, but designed experiments or data were not available to me. Anecdotes abound but data are lacking.

Gains from selection are even more difficult to document. Few full scale projects have been implemented in logging and I know of none studied. The triangle of cooperation in the Nordic countries between research, manufacturers, and industry did not implement the selection results of their studies.

Anecdotal information tells of where gains might be made or losses avoided. A few managers emphasize their brilliance by telling how they worked hard to get the right person on the machine and it really paid off. Less frequently visible are the four "false-starts" of a month each before someone was found who could make the machine produce. Not many like to talk about the "new" operator who tore out the final drives and caused a $30,000 repair. Some managers know of operators who consistently have machine damage and maintenance three or four times above the average. A few managers use measures to minimize the loss of production from the operator who failed to improve on the job. Long term productivity losses are exchanged for reliable attendance, "hard work" or good maintenance.

Gains from selection and training are a bit like the negative hypotheses of safety. It is difficult to show how the accident that never happened was avoided. As a means of clarifying the parameters of a selection and training decision, estimates of gains from the log loader project are illustrated. The basis for the estimates were logging supervisors, while the associated assumptions are the author's.

Figure 3 shows the cost of training a loader operator to be $12,000, most of which is the first time development cost spread over a relatively small number of trainees. The pattern of gains from training is derived from the cumulative difference of two learning curves. One learning curve is from an operator trained in the traditional fashion while the other is from an operator receiving designed training. The slope of gains is characteristic and does not continue upwards but levels out recognizing that training differences may not continue forever (Garland, 1990a.).

[PLACE FIGURE 3 HERE]

If the gains from selection were incorporated as a fixed amount at the beginning of training, about half the cost of training could be justified based on earlier estimates. In addition, if selection could eliminate the "false-starts" of operators who make little improvement in a months' time, then another quarter of the training cost could be justified. In total, a designed selection program could save about three-fourths the cost of training in this example.

Figure 3 incorporates the job leaving characteristics of the industry as well and yet the training cost is recouped by day 76 of training (Garland, 1990b.). Sensitivity analysis can also show the effects of harvest system costs, timber size, and so forth, but the conclusion here is that training certainly pays. Selection also pays but the potential is less demonstrable.

FUTURE DEVELOPMENTS

Without doubt, the future of harvesting in western North America will involve more mechanization. Issues of short wood versus log length systems, use of optimal bucking techniques, environmental impacts and so forth remain to be resolved. Selection will need to be tied to recruitment issues for machine operators. Synthetic validity (selection results extended to similar jobs) based on the log loader project can shed light on operator abilities needed to be successful machine operators. Selection through training will also occur.

Machine operator training will likely increase but the organizational form and degree of cooperation among contractor firms, associations, educational institutions, industry, and government agencies remains unclear. My current work involves development of a "training shell" for mechanized harvesting operators where training outlines are generalized with options for specific training needs based on the owner's machine configuration and operating conditions. The training shell will be supported by plastic-coated training cards for the operators to serve as reminders of principles and concepts.

The largest question unanswered is whether individual firm owners will recognize the potential gains from selecting and training their machine operators.

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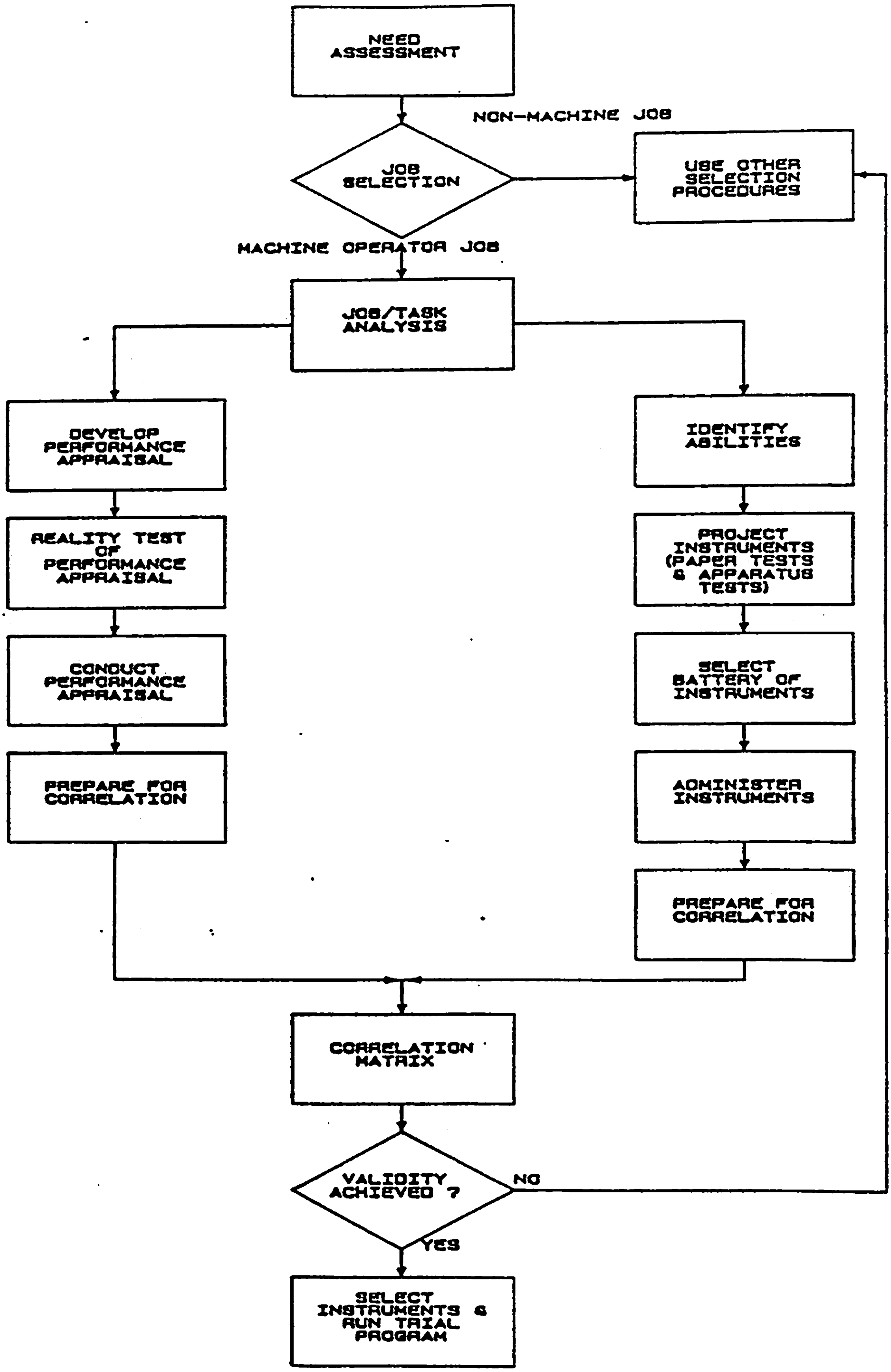

Figure 1. Flowchart of a Selection/Validation Effort.

(After Garland, 1985)

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

Figure 2. Sample Performance Check Behaviors.

(After Garland, 1987)

SELECTION AND TRAINING OF LOADER OPERATORS

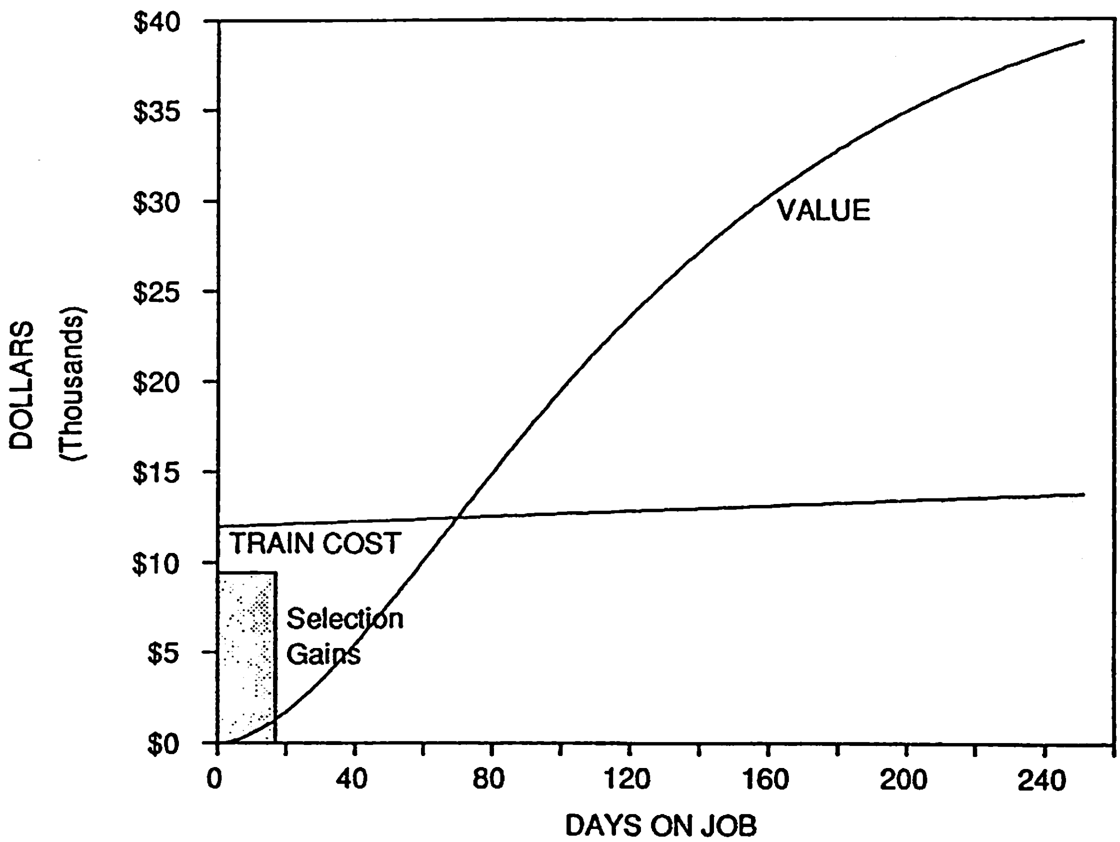

Figure 3. Gains and costs of loader operator selection and training.
(After Garland 1990)

POSTERS

FELLING AND SKIDDING COST ESTIMATES FOR THINNINGS TO REDUCE GYPSY MOTH IMPACTS

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ABSTRACT

The gypsy moth is a serious threat to the hardwood forests of the eastern United States. Although chemical treatments currently exist which can be used to help control the impacts of the moth, silvicultural control measures are just now being proposed and tested. Felling and skidding cost estimates for harvesting merchantable timber under two such proposed silvicultural thinning treatments are reported. Costs for felling the nonmerchantable component of the thinnings in order to achieve treatment objectives are also discussed.

Keywords:
Harvesting costs, productivity, gypsy moth.

INTRODUCTION

The gypsy moth, *Lymantria dispar* Linnaeus, is one of the most notorious pests of hardwood trees in the eastern United States. In 1990 alone defoliation was estimated at 7.4 million acres of forest land in the Northeastern states. In an attempt to minimize defoliation damage, a number of control measures have been implemented. Among these are monitoring population levels, maintaining the health and vigor of trees, discouraging gypsy moth survival, and treating with a variety of insecticides to kill larvae and protect tree foliage (McManus *et al.* 1989). Aerial application of pesticides are the current most commonly used control method used on forested lands, where cost and labor prohibit individual tree treatments.

A variety of interrelated factors determine the vulnerability of forest stands to defoliation. Three of the most important include the abundance of preferred food species, site and stand factors, and tree health and vigor. Stands that are predominately oak, the favored food species of the moth, that are under other stress factors often incur repeated severe defoliations. Silvicultural treatments that modify these vulnerability factors can be applied to forested stands as an alternative technique in the fight to control gypsy moths. Guidelines for applying silvicultural treatments to reduce defoliation and minimize losses have been proposed by the U.S. Forest Service (Gottschalk, 1986).

Two forms of silvicultural thinnings, designed to manipulate species composition and stand structure, have been recommended to reduce the severity of moth damage. In stands dominated by oaks (50 percent or more of the basal area is in oak species) the goal is to reduce the mortality that would occur from defoliation by using "presalvage thinnings" to remove highly vulnerable trees that are likely to die due to stresses caused by defoliation. Presalvage thinning concentrates on reducing stand vulnerability. In mixed stands (less than 50 percent of the basal area in oaks), the goal is to prevent the spread and establishment of the moth and reduce defoliation potential by removing the most susceptible trees, a process referred to as "sanitation thinning" (Smith 1986). The primary objective of sanitation thinnings is to reduce stand susceptibility. The effectiveness of the two thinning treatments are currently being evaluated on gypsy moth threatened stands in West Virginia.

STUDY OBJECTIVES

In conjunction with a larger study, an investigation was undertaken to determine productivity and costs associated with harvesting timber under the proposed presalvage and sanitation thinning treatments. Continuous time and motion studies and modeling techniques were used to develop productivity models from which felling and skidding cost estimates could be made. In addition to this, an analysis was also performed which takes into consideration the costs of felling the nonmerchantable timber necessary to fulfill the treatment prescriptions following a commercial sawtimber harvest. Determining the cost of the additional work required to fell the residual marked stems is an important component in determining the economic feasibility of their application. This paper provides stump to landing harvesting productivity and cost estimates, and discusses the economic and silvicultural implications of applying an additional cultural treatment to the nonmerchantable component of the stand as a separate treatment following a commercial logging operation.

STUDY AREA

The study took place on the West Virginia University

Experimental Forest, Monongalia and Preston Counties, West Virginia. Six stands of mixed Appalachian hardwoods, each receiving one of the two thinning treatments were included in the study. Stands ranged in size from 22.6 to 31.2 acres for a total treated area of 165.6 acres. Three stands were marked for thinning according to the presalvage prescription, while the remaining three were marked according to the sanitation prescription. Initial attributes for each stand are given in Table 1.

METHODS

Productivity and Cost Calculations

Felling. Productivity rates and man hours required to fell both the merchantable and nonmerchantable timber were estimated using Sarles (1984) equations. The equations yield estimates of productive felling times exclusive of delay elements, based on volume and spacing between successively felled trees. Estimates of scheduled felling times to be used in the cost analysis were then calculated by factoring in a saw utilization rate of 60 percent which agrees with previously reported rates in the literature (Sarles et al. 1984, Jones 1983, Miller 1984, Werblow and Cubbage 1986). By applying the values from these equations to the number of stems, volume to be felled, and average distances between felled trees, an estimate of the number of scheduled and productive hours needed for felling the merchantable and nonmerchantable timber in each stand could be calculated.

A machine rate procedure was then used to estimate costs for felling the timber based on the estimated scheduled and operating times. The cost calculation included fixed and operating costs for the chain saw, and labor costs for its operation. Labor costs included a base wage and additional employer contributions for a total cost of $10.25 per scheduled man hour.

Skidding. Skidding of the merchantable timber was performed by three rubber-tired skidders. The skidders included a John Deere 440C[1], a John Deere 440B, and a Franklin 170, all of which were cable machines. Complete time and motion records were kept for the entire skidding operation for each of the three machines. All skidding element times, both productive and nonproductive were recorded by persons stationed both in the woods and at the landing. Additional skidding parameters such as skid distance, number of trees per turn, volume per turn, machine utilization rates, and a number of other variables were recorded and used to develop productivity models on which the skidding cost analysis was based.

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

Table 1. Initial stand attributes.

Stand	Acres	# Trees /acre	BA/ac (ft^2)	BF/acre (Int 1/4")	Pulpwood Cords/ac
		SANITATION THINNINGS			
1	30.2	369	145.8	14,823	13.7
3	31.2	274	143.5	10,540	17.8
6	26.9	295	146.5	13,663	14.3
		PRESALVAGE THINNINGS			
9	22.6	405	143.5	10,062	17.1
11	24.1	391	141.5	10,754	14.9
15	30.6	370	131.0	7,248	17.7

A unit production cost analysis similar to the one presented by Miyata and Steinhilb (1981), was used to estimate costs for skidding the merchantable timber harvested. The procedure calculates production costs per unit volume, with fixed costs based on scheduled machine time and operating costs based on productive time. Equipment costs were calculated using published machine rates and cost factors (Anonymous 1981, Brinker et al. 1989, Miyata 1980, Werblow and Cubbage 1986) altered to fit the needs of this study where necessary to determine hourly machine costs, both fixed and operating, for each of the three skidders. Labor rates for skidding totaled $13.91 per scheduled machine hour. By applying these machine and labor rates to the estimate of scheduled and productive machine hours from the productivity models, the costs of skidding the merchantable timber could be estimated for each machine on each stand.

RESULTS

Felling and Skidding Merchantable Timber

Costs to fell the merchantable sawtimber were calculated based on total estimated volumes skidded in each stand. All logs skidded to the landing were measured for large and small end diameter and length. Smalian's formula was then used to estimate cubic foot volumes which were used in Sarles (1984) equations to calculate felling times and production rates. Estimates of total cost were then computed by using the machine rate procedure. Felling costs were similar for both thinning treatments and averaged $2.51 and $2.63 per cunit of wood felled for the sanitation and presalvage treatments, respectively. A summary of merchantable felling costs by stand is included in Table 2.

Skidding costs were estimated using the appropriate productivity models and machine rates for each machine used on a treatment. With skidding costs expressed as dollars per unit volume skidded, rates are again similar between the two treatments. Using average values from the three stands included in each treatment, costs including labor were estimated at $7.78 and $8.04 per cunit of wood skidded for the presalvage and sanitation treatments, respectively.

Total skidding costs including labor on a treatment basis were determined by summing the skidding costs for each of the machines used on stands in the respective treatments. Total cost for skidding the 31,207 ft^3 of timber harvested under the presalvage thinning treatments was estimated at $2,429.16. Total cost for skidding the 37,397 ft^3 of timber harvested under the sanitation thinning treatments was estimated at $3,007.20.

Table 2. Summary data for felling merchantable timber.

Stand	# Trees	Merch. Vol(ft^3)	Felling Time SMH[a]	Cost/ cunit[b]	Total Cost $
		SANITATION THINNINGS			
1	326	18,168	38.4	2.38	432.39
3	217	9,380	22.5	2.70	253.08
6	208	9,848	22.6	2.58	253.80
		PRESALVAGE THINNINGS			
9	144	5,190	13.6	2.95	152.97
11	367	17,530	38.0	2.44	427.96
15	222	8,487	21.4	2.84	240.86

[a] Scheduled man hours at 60 percent saw utilization rate.
[b] Cunit = 100 cubic feet.

Felling Nonmerchantable Timber

Although demands exist for quality Appalachian hardwood sawtimber stumpage, markets are scarce and at times nonexistent for pulpwood. The scarcity of pulpwood markets in the mountain region make thinnings economically infeasible, or at best marginal (Sarles *et al.* 1984). Consequently, many logging contractors working in stands marked for thinning simply cut and utilize the sawtimber, while the marked poletimber is left standing. Although this practice may be the most economical from a loggers point of view, the pulpwood component of a thinning must be dealt with if the silvicultural treatments are to be successful.

The logging contractor harvesting the timber in this investigation was strictly a sawtimber producer, consequently all of the marked poletimber, in addition to a good deal of the marginal sawtimber in the 12 and 13 inch size classes remained standing once the commercial harvest was complete. In order to fulfill the treatment objectives, a follow-up treatment to fell these remaining stems had to be performed.

In order to more closely approximate the actual cost of this follow-up treatment, one additional cost component must be added. A contractor or consulting forester hired to fell the nonmerchantable stems following the commercial harvest would require a margin of profit for their work. In this discussion a 15 percent margin for profit was included in the costs of felling the nonmerchantable marked timber.

Based on the felling productivity and cost calculation procedure using appropriate values for each stand, the cost to fell the residual timber ranged from a low of $27.17 per acre to a high of $46.02 per acre for the six stands treated (Table 3). Felling costs were similar on a treatment basis, differing by only 8.6 percent, and averaged $37.88 and $34.88 per acre for the presalvage and sanitation treatments, respectively.

Table 3. Summary data for felling nonmerchantable timber.

Stand	# Trees /acre	Avg DBH	Felling Time SMH[a]	Cost/ Acre	Total cost
		SANITATION THINNINGS			
1	50.5	8.2	75.2	32.21	972.74
3	63.6	8.7	99.4	41.23	1286.42
6	44.8	9.0	63.4	30.51	820.68
		PRESALVAGE THINNINGS			
9	72.1	8.5	80.4	46.02	1040.02
11	41.7	8.4	50.6	27.17	654.68
15	64.1	8.2	95.1	40.23	1231.00

[a] Scheduled man hours at 60 percent saw utilization rate.

DISCUSSION

When a timber buyer bids on a timber sale the costs for felling and skidding are calculated into the gross stumpage value that a landowner receives for the rights to harvest the timber. Because the contractor harvesting the timber in this study was not responsible for felling the nonmerchantable stems as part of the commercial harvest, the cost of felling these trees can be charged against the gross stumpage value in order to arrive at a net sale value. Gross stumpage values by stand were determined using the average value for the sale as a whole. The cost to fell the residual marked stems was then subtracted from this value to arrive at a net stumpage value on a stand basis. Gross and net stumpage values on a treatment basis are calculated in a similar fashion. Gross stumpage value, merchantable felling costs, skidding costs, nonmerchantable felling costs, and net stumpage values by stand and treatment are given in Table 4.

As can be seen in Table 4, gross stumpage values can be significantly reduced as a result of having to fell the nonmerchantable timber. Percent decreases in gross stumpage value ranged from a low of 17.1 percent to a high of 91.6 percent for stands 11 and 9, respectively. The differences in gross and net value change are primarily a function of the amount and value of the merchantable timber which offsets the nonmerchantable felling costs. Based on treatment averages, percent decreases in gross stumpage values were again quite similar, and averaged 37.7 and 42.9 percent for the sanitation and presalvage treatments, respectively

Additional costs of applying these types of silvicultural thinnings not accounted for in this analysis can include such things as the initial timber cruise, marking stand boundaries, timber marking according to the treatment prescription, and sale administration. These costs may significantly decrease

Table 4. Cost summary by stand and treatment[a].

Stand	Gross Stumpage Value	Felling Cost	Skidding Cost	Nonmerch. Felling Cost	Net Stumpage Value[b]
			SANITATION THINNINGS		
1	3974.10	432.39	1496.28	972.74	3001.36
3	2051.81	253.08	731.74	1286.42	765.39
6	2154.64	253.80	779.18	820.68	1333.96
Total	8180.55	939.27	3007.20	3079.84	5100.71
			PRESALVAGE THINNINGS		
9	1135.08	152.97	408.51	1040.02	95.06
11	3829.26	427.96	1349.37	654.68	3174.58
15	1855.12	240.86	671.28	1231.00	624.12
Total	6819.46	821.79	2429.16	2925.70	3893.76

[a] All values in dollars.
[b] Includes labor and 15 percent margin for profit.

the net revenue that a forest landowner receives from a sale. The complexity of the marking criteria for both treatments necessitates qualified foresters do the timber marking, which can add further to the costs. Although, these additional costs were not included in the analysis, one must realize that they exist and may significantly influence the economic feasibility of applying such treatments.

Whether or not forest landowners are willing to accept the reduced revenues resulting from the costs of felling the nonmerchantable timber, in return for a healthier more moth resistant stand is hard to predict. Some individuals may simply want the highest short term return and harvest only the merchantable timber, while others may see the long-term benefits of the silvicultural treatments outweighing the short-term losses.

CONCLUSIONS

Eliminating gypsy moth damage completely is unlikely by any control method, but we may, through a variety of techniques such as silvicultural thinnings, increase our ability to manage populations at tolerable levels. The felling and skidding cost estimators reported may be used along with personal experience as baseline cost estimates to help determine appropriate stumpage values on which a timber sale bid is based. The productivity and cost estimators for both the skidding of merchantable timber and felling of the nonmerchantable stems can also be used by those individuals responsible for marking stands under these types of thinnings. By using this type of information, timber sales can be designed whereby the value of the merchantable timber marked will at least cover the costs of applying the additional cultural treatment to the nonmerchantable component of the stand in order to achieve the treatment objectives.

When applying silvicultural thinnings that include working in the nonmerchantable portion of the stand, it is important to understand that the cultural work necessary to reach the treatment objectives come as a liability in terms of revenue. If costs to fell the residual trees is too high then the prescription must be modified to reduce the cost, or alternative control measures must be used. Although the results of this case study suggest that both thinning treatments are economically feasible and can be applied without an out of pocket expense to the landowner, only time and additional research will indicate whether or not they are effective in controlling gypsy moths.

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THE MONOCABLE CONVEYER SYSTEM FOR THINNING OPERATIONS

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ABSTRACT

Harvesting small, low-value trees and forest residues on steep slopes is presently limited because of the lack of technically sound, economically efficient, and environmentally acceptable equipment and systems in the Pacific Northwest and other mountainous areas in North America. To solve some of these problems, research was conducted to investigate the applicability of a monocable conveyer system. This paper describes the design, unique features, and operational characteristics of the monocable conveyer system and presents the results from the field study.

Keywords:
Low-value trees, thinning, steep slope, forest residues.

INTRODUCTION

Predicted wood consumption in the United States is expected to increase from 370 million cubic meters in 1977 to 820 million cubic meters in the year 2030. Most of the projected increase is for pulpwood that is expected to account for over fifty percent of the total wood products demand in 2030 (USDA Forest Service, 1980).

There are about 9.7 million ha of forestland in Western Washington and Oregon. Over half of these forests are pole-timber stands. Except for stands over 100 years old, the largest age class in this area is the 10-to-30 year's age class (Oliver, 1991). Recently, many researchers have suggested thinning and pruning as desirable silvicultural treatments for young stands in this area (Bergstrom, 1986; Cahill et al, 1986, Fight et al, 1986; 1987a, b; 1988; Oliver, 1986, 1987, 1988, 1990; Oliver and Larson, 1990). Thinning with the proper timing and tree selection have impacts on present and future timber supply by increasing value of the final crop.

In addition to these small, low-value trees to be thinned, some 14 million tons of logging residues in pieces four inches and larger in diameter annually remain in the forests of the United States (Grantham, 1974; Cramer, 1974). If we can recover and use these vast quantities of small, low-value trees through thinning operations and forest residues, the following benefits could be expected (Erickson, 1976; Leicht, 1979; Oliver, 1991; and Tillman, 1978 and 1985; Walbridge et al 1981.)

- Additional fiber supplies to meet the increasing demands for wood fiber.
- Improvement of timber stands, through precommercial (3-6 m in height and 5 to 10 cm in diameter; 10 to 15 years stand) and commercial (25-35 year old; average 18-23 cm in diameter breast height, dbh) thinning operations, which will provide better quality of timber for future harvests.
- Reduction of fire, insect, and other environmental problems.
- Reduced reliance on petroleum imports. Smith and Tillman, 1986, reported the residual wood fuel market is now valued at $4 billion dollars per year, which is about equal to all the plywood produced by the forest industries in the United States. Grantham and Howard (1980) reported the energy potential of the 94 million cubic meters of logging residues of pieces 10 cm and larger in diameter annually remaining in the forests of the United States to be roughly equivalent to 100 million barrels of oil.
- Improvement of aesthetics and future management capability for regeneration, soil and water quality, fish and wildlife, and air quality.

One of the factors limiting the thinning of young stands and the recovery of logging residues is the lack of technically sound, economically efficient, and environmentally acceptable harvesting equipment and systems to transport the materials to landings in adverse sites. Thus, this study aims to reduce the cost of thinning and recovery operations. This research was supported by USDA Competitive Grant NO. 87-FSTY-9-0251.

A review of over 400 publications on various harvesting machines and systems within and outside the United States suggested a unique concept of cable system called a monocable system. The monocable system uses an endless loop of cable (9-12 mm diameter) that runs through a series of open-sided blocks. These blocks hang from support trees by tree-protecting straps. The trees are selected to support both the cable and logs over critical area such as slope breaks, fragile soil, and streams. The endless cable is normally driven by a capstan winch. Logs are attached to the slowly moving monocable by tying or hooking chokers. Consequently, the logs travel continuously from the hitching locations to the landing.

Because of its potential in the United States, the monocable system was studied on various terrain conditions (Miyata et al 1986 and 1988.) Topography includes; (1) relatively flat (0-20%) and dry with minor obstacles on the floor, Medford, Oregon; (2) steep (0-65%) and rugged site with heavy logging slashes (obstacles) on the floor, Snoqualimie, Washington; (3) smooth grade of 45-55%, Leavenworth, Washington; and (4) both sides of a ravine (0-25%, London. These actual field experiments found that the monocable system has the following operational characteristics;

- Low initial and operating cost,
- Low fuel consumption because of the use of a small engine (5-20hp, 0.76-3.03 l per hour),
- Capability of 1,000 m or more yarding distance,
- Not limited by degree of ground slope,
- Capability to meet silvicultural considerations in selective thinning operations without damaging future crop trees,
- Flexibilities for the changing geometry of topography and terrain,
- Capable of both uphill and downhill yarding,
- Capable of direct truck loading and sorting operations at landing,
- Capable of transporting logs above sensitive streams.

Because of its strength, price, and suitability, the baling twine chokers were used to transport small logs (90-140 kg) or logging slashes on steep, difficult sites in an environmentally acceptable manner. When the yarding distance becomes longer, the baling twine has to pass through a larger number of the blocks to reach the landing. Yarding distance alone did not damage the twine, but abrasion and compression between the monocable and the block sheave and the log weight caused wear. After passing 13 or 14 blocks, the twine became weaker and started to drop one or two logs per one hundred logs. Yarding operation was limited by the strength of baling twine, not the capability of the monocable system. Therefore, the objective of this study was to determine the capability of the monocable system to transport the materials from stumps to the landing.

FIELD TEST

In the summer of 1989, the monocable system using the cable- choker hooks, made of steel wire 3 mm diameter (breaking strength - 1,400 kg) was tested to study the capability of the system. It is also called the Miyawaki conveyer system. The cable-choker is attached to the monocable with a clip (Figure 1). Because of clips on the monocable, the cable is driven by three drive wheels (not a capstan) powered by a 7-hp gasoline engine (Figure 2.) When the logs reach the landing, the hook is hit with a stick to drop the logs to the ground. A unique method is used to connect the cables. Six different lengths of cable-60 m, 24 m, 12 m, 8 m, 2 m, and 1 m-are used. Each cable has an eye at both ends; thus, if 635 m of cable are needed for a harvesting operation, then ten 60 m, one 24 m, and one 12 m of cable will be connected with mollies. A set, which consists of a winch, 46 zigzag blocks, 650 m of 9 mm cable and necessary attachments, of the monocable conveyer system is about $14,000. The machine rate is presented in the Appendix for interested readers. Figure 2 presents the monocable conveyer system equipped with three drive wheels.

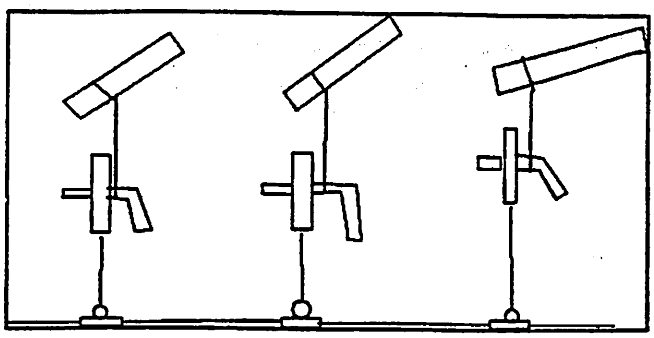

Figure 1. Cable choker with a clip.

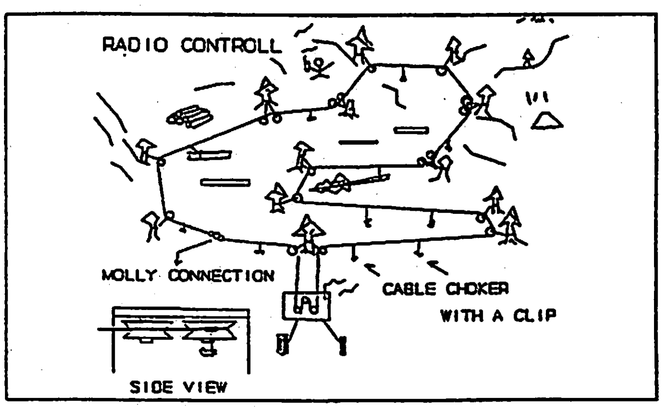

Figure 2. Monocable Conveyer System.

A field experiment was conducted in Clatskanie, Oregon. The ground was flat and dry with no underbrush or obstacles on the ground. A total of 23 whole cotton wood trees were yarded with the monocable system. The average diameter breast height (dbh), height and weight of the trees yarded are listed as follows:

dbh: 13.8 cm ± 6.2 cm;
minimum, 5.8, maximum 27.4 cm.
Height: 13.3 m ± 3.0 m;
minimum, 7.1, maximum, 17.8 m.
Weight: 164.1 kg ± 178.7 kg;
minimum, 13, maximum, 635 kg.

When yarding large heavy trees such as those with dbh, 27.4 cm; weight, 635 kg; height, 17.7 m and dbh, 26.2 cm; weight, 544 kg; height, 17.8 m, the cable speed was slowed from 20 m to 9 m per min. Tension was 272 kg at the outhaul side of the winch and the longest span was 12.2 m. Total cable length was 145 m. When yarding the tree with dbh, 26.2 cm; height, 17.8 m; and weight, 544 kg, it required 340 kg to lift the end of the tree and 590 kg. to start it moving. Because of heavy limbs and branches, the butt was in the air. The monocable was mainly applying a horizontal force to yard the tree. Yarding multiple trees on multiple spans appeared to be easier than a single heavy tree on the entire system. For example: Yarding one tree on the first span, next tree on the second span, and third tree on the third span is smoother than a heavy tree alone on the system. When heavy logs are yarded, the weight distribution on multiple spans should be considered. The winch with a 7-hp engine performed perfectly during the test where whole trees were attached to the monocable one after another.

DISCUSSION AND FUTURE RESEARCH

The amount of precommercial and commercial thinning in young growth stands will continue to increase in the Pacific Northwest and other mountainous areas of North America. Vast quantities of forest residues will continue to be left in the forest floor. The need for more economically efficient and environmentally acceptable equipment and systems for harvesting low-value, small materials will also increase. This field test demonstrated that the monocable system with a 7 hp engine is not only able to transport short logs such as firewood and pulpwood, but also trees with limbs and branches without bucking at the stump. The monocable system with a 6-20 hp engine is capable to yard 635 kg or heavier log to more than 1,000 m if it is laid out correctly. The longer yarding distance of the monocable system reduces the high cost of roadbuilding ($20,000 to $500,000 per km). Future recommended research to maximize the capability of the monocable system concepts include:

- Development of the methods for handling heavier logs at stump and at landing.
- Development of inexpensive support posts for clearcutting operations.
- Mobilization of the winch.
- Development of a mathematical model to depict the relation between tension and multiple payloads (dynamic).
- Two-end suspension methods.
- Development of automatic devices to disconnect the choker hook for tree drive wheel systems.
- Optimization models for layout, work procedures, and the balance of crews.

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APPENDIX

MACHINE RATE

1. Machine Rate - A winch (6-10 hp)	
A. Initial investment (P)	$5,220.00
B. Salvage value (S) (20% of P)	1,044.00
C. Estimated life (N) 5 years	
D. Operating hours (900 hr) per year (H)	
E. Average value of yearly investment (AVI)	$3,549.60
AVI = [(P-S)(N+1)]/2N + S	
F. Depreciation (P-S)/N	$ 835.20
G. Interest(12%)+insurance (3%) +taxes(3%) = 18% of AVI 18% of AVI	$ 638.93
FIXED COST PER YEAR	$1,474.13/yr
FIXED COST PER HOUR (F)	$ 1.64/H
H. Maintenance and repair: 90% x (P-S)/(NxH)	$ 0.84/H
I. Fuel (0.3 gal./H x $1.00/gallon)	$ 0.30/H
J. Oil and lubricants (15% of fuel cost)	$ 0.05/H
OPERATING COST PER HOUR (O)	$ 1.19/H
HOURLY MACHINE RATE (MR) = F + O =	$ 2.83/H
2. Attachment Cost**	
A. Cable 3,000 ft	$ 0.91/H
B. Hooks and Wire	$ 0.17/H
C. Blocks	$ 0.77/H
D. Rope	$ 0.01/H
HOURLY ATTACHMENT RATE (AR) =	$ 1.86/H
3. TOTAL HOURLY MACHINE RATE (TM) = MR + AR =	$ 4.69/H

* This machine rate was used for 1991, since the money rate between Japanese "Yen" and US "dollar" fluctuates a few times a day. We could purchase the monocable system (1 set) $8,000 in 1986, because of the rate (200 Yen = one US dollar). In 1988, the purchased price changed because of the change in rate (116 Yen = one US dollar). In 1991, the rate is fluctuating between 120 Yen and 160 Yen.

** Attachment cost; based on Umeda et al, 1982.

HAZARDS ON THE FELLING ESCAPE PATH

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ABSTRACT
Many fellers apparently have acted safely and yet were badly injured in a felling accident. A safe feller selects a direction of fall, puts in a notch cut to direct the tree, a back cut to fell the tree, and retreats on an escape path as the tree falls. But even when observing these recommended safe practices, a feller on the escape path is still at risk! There are three types of accidents that can injure or kill a feller on the escape path: broken limbs or tops, butt rebound, and being struck from behind. This paper describes these three types of accidents, the hazardous stand conditions associated with them, and procedures for avoiding them.

Keywords:
Forest engineering, forest operations, logging safety, chainsaw felling, timber production

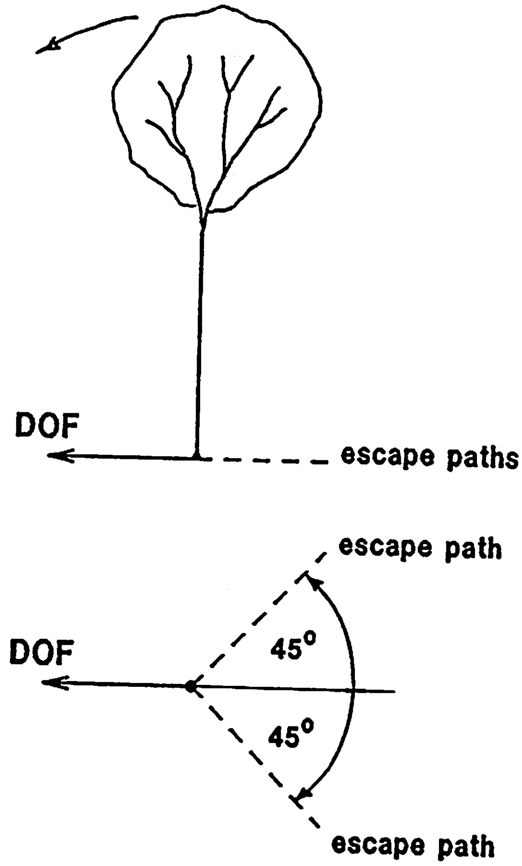

Figure 1. Direction of fall (DOF) and escape paths.

Many fellers apparently have acted safely and yet were badly injured in a felling accident. A safe feller selects a direction of fall, puts in a notch cut to direct the tree, a back cut to fell the tree, and retreats on an escape path as the tree falls. The escape path is also called a retreat path. The escape path extends diagonally behind the stump and the direction of fall at approximately a 45 degree angle (Figure 1). But even when observing these recommended safe practices, a feller on the escape path is still at risk! There are three types of accidents that can injure or kill a feller on the escape path: broken limbs or tops, butt rebound, and being struck from behind. The first two are the result of the falling tree hitting another tree. The third is the result of the falling tree pulling over a tree or breaking a limb from a tree behind the direction of fall. This paper describes these three types of accidents, the hazardous stand conditions associated with them, and procedures for avoiding them.

Broken limbs or tops. In a broken limbs or tops accident, as the tree falls it hits another tree, breaking limbs or tops that are thrown back at the feller. In one fatal accident, a 28-inch-dbh, 95-foot red oak was felled into a forked black cherry tree, a second black cherry tree, a shagbark hickory, and a red oak (Figure 2). While the crown of the falling red oak hit all of these trees, the principal impact was with the forked black cherry tree. The forked black cherry was 23 inches dbh; it forked into two stems at 6 feet that were 13.8 and 14.0 inches in diameter, respectively. The height of the black cherry tree, corresponding to the 14.0-inch-diameter stem, was 86 feet. The forked black cherry was 45 feet in front of the red oak. As the red oak fell, its branches bent back the black cherry stems, breaking the 13.8-inch stem into three pieces. The 14.0-inch black cherry stem sprang forward, breaking out the top 25 feet which hit and fatally injured the feller. The top, which measured 4.3 inches in diameter at the base and weighed approximately 50 pounds, flew 65 feet, hitting the feller who was standing 20 feet behind the red oak stump (Peters 1991).

In a similar accident, a 70-foot-tall falling tree hit a 40-foot-tall tree that was 30 feet away. The top 15 feet of the hit tree was broken out and thrown back, hitting and fatally injuring the feller, who was standing 10 feet behind the stump of the felled tree (OSHA 1988). Large-diameter trees with large crowns often are involved in these accidents, with oak the most common species. Dead or rotten limbs also are a factor.

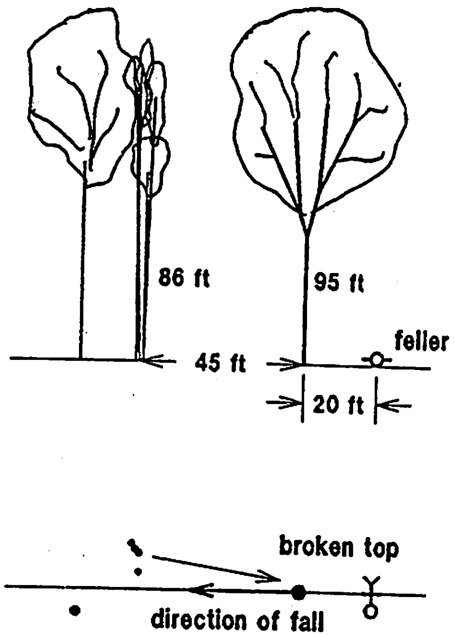

Figure 2. Geometry of a broken top fatal accident.

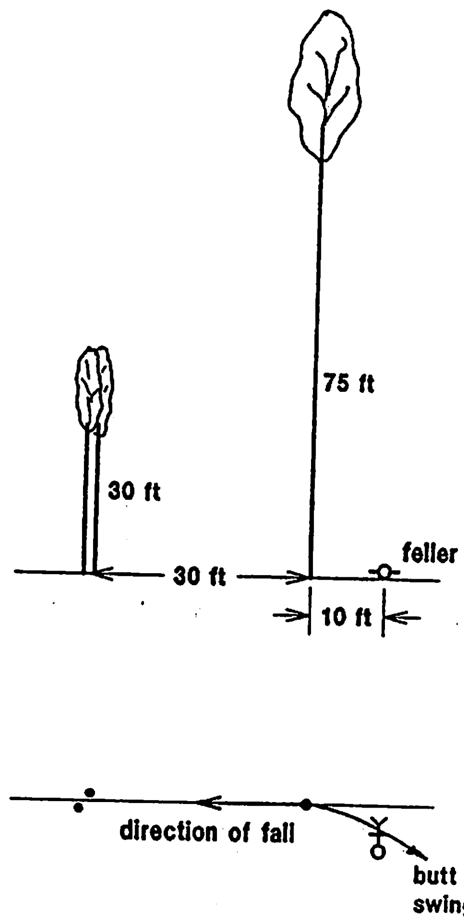

Figure 3. Geometry of a hypothetical butt rebound accident.

Butt rebound. As the tree falls, the bole, at approximately midheight of the felled tree, strikes the top of the crown of another tree or trees and slides back or rebounds at the feller. As the butt rebounds, the butt may be swung sideways by the action of two branches or stems pinching the bole of the felled tree. A hypothetical example is shown in Figure 3. The dimensions shown in the figure are typical for this type of accident, but do not represent an actual case. In reported fatal accidents, the felled tree was either a pine or fir (Peters 1990). In various incidents, the hit trees were an oak (two incidents), a black gum, a forked sapling, two trees (one incident), and two snags (one incident).

A feller should anticipate this hazard when falling a tree with a small crown whose bole will hit the top of another tree or trees. The forked sapling involved in one fatal accident was only 20 feet tall, indicating that the hit tree does not have to be large. The direction of butt swing can be predicted from the geometry if the tree falls between two trees or branches. The swinging action of the bole hitting between two branches or stems can be illustrated by dropping a pencil on an open upright scissor. Being able to predict direction of butt swing may be useful to a feller when selecting an escape path.

Struck from behind. As the tree falls, it interferes with a tree behind the direction of fall and either pulls the tree over onto the feller or breaks off limbs that strike the feller (Figure 4). Interference between crowns could be a result of a dense timber stand or a vine growing in the canopy. Other factors in these accidents are shallow-rooted species and rotten or dead limbs.

How can a safe feller avoid these accidents? The first step is to **recognize the hazard.** Merely retreating on the selected escape path as the tree falls is not sufficient to guarantee safety. Three types of accidents can injure or kill a feller on an escape path: broken limbs or tops, butt rebound, and being struck from behind. Second, the feller **should determine which type of accident** is most likely to occur. For example, if a large red oak is to be felled in a partial cut, a butt rebound accident is less likely than broken limbs or tops, or a "struck from behind" accident. Recognizing the possible accident type often will suggest the appropriate evasive action. Third, the feller should **choose the safer of the two escape paths.** Local ground slope will affect this decision. Brier patches or vines may have an influence. When the hazard of butt rebound is noted, the

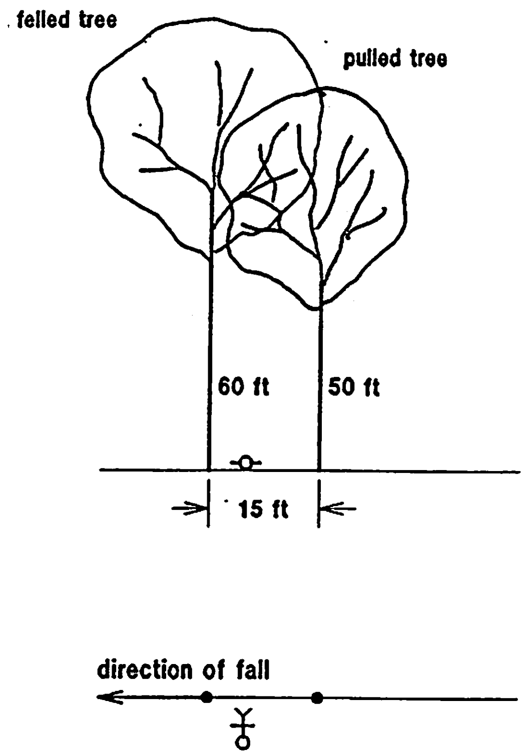

Figure 4. Geometry of a hypothetical struck from behind accident.

expected direction of butt swing also could influence the choice. The feller should have a safe location identified that is accessible from the escape path. Standing trees in the area may afford a safe location to head for. Fourth, as the tree falls, the feller should retreat quickly on the escape path to the predetermined safe location. There is a tendency for the feller --particularly a nonprofessional-- to stand and watch as the tree falls. According to one report, 80 percent of all felling injuries occur within 10 feet of the felled tree stump, suggesting that staying in the felling area too long is a major concern (Kessler 1990).

Assume that the feller has assessed the risk associated with felling the tree in a specific direction of fall and finds it unacceptable. One option in this situation is to change the direction of fall. Another is to change the order of fall by felling the potential hit tree first and eliminating the possibility of injury from broken limbs or tops and butt rebound.

A proposed OSHA safety standard (1989) states, "A retreat path shall be planned and cleared as necessary, before the cut is started. When feasible, the retreat path shall extend back and diagonally to the rear of the expected felling line." This proposed OSHA rule has been a recommended practice for years. However, as discussed in this paper, it is far from a guarantee of safety. I recommend this proposal be amended as follows, "A retreat path shall be planned and cleared as necessary, before the cut is started. Where feasible, the retreat path shall extend back and diagonally to the rear of the expected felling line. Specific hazards that should be evaluated when selecting the retreat path are butt rebound, broken limbs or tops, and trees from behind being pulled over by the felled tree." The failure to determine all of the potential hazards when felling trees can cause unnecessary fatalities and serious injuries. Fellers should be made aware of all the potential hazards associated with their work and be given sound recommendations on how to avoid these hazards.

ACKNOWLEDGMENTS

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THE PRACTICAL VALUE OF HELIPACE

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ABSTRACT

Helipace is a personal computer program that helps the harvest planner and timber appraiser estimate helicopter logging production data and stump-to-truck costs. It is patterned after procedures used by Northwest helicopter industry representatives.

The program user inputs conditions for a specific stand of timber, and for a log landing to which the timber might be yarded. The locations of the stand and landing are established by measuring coordinates from an arbitrary x-axis and y-axis. A z-coordinate is determined by using ground elevation. The user can run as many alternatives as needed for any timber stand (or unit), depending on the number of landings and other variables available that effect the outcome.

Helicopter production elements and costs that remain constant from sale-to-sale are stored in the program, including hourly costs for equipment and labour. By adding stand and landing data, the total estimated stump-to-truck cost is calculated.

Helipace is an excellent tool for harvest planning and timber appraisal. There are no physical limitations to Helipace, such as distance, elevation, slash removal, etc., which are found in other commonly used methods. The method it uses to appraise slash removal (i.e. yarding unutilized material) is easily understood and appears feasible. Cost per thousand board feet or cubic feet is the program's main output, thereby providing reliable cost estimates and cost differences among alternatives.

Keywords:
Program, Helicopter logging, Production, Cost estimation.

A CASE STUDY

Suppose your deceased uncle left you 80 acres of forest land. You would likely be most grateful, and would likely assume that this would mean a substantial increase in your personal wealth. Indeed it could! But before assuming anything, perhaps an investigation is in order. You are a forester with a lot of experience in this type of work. But you are very busy at this time, so you engage a consulting forester residing in the areas where this generous gift is located - many miles from your residence and workplace.

A couple weeks later your consulting forester sends a topographic map of the area and the following report:

Report No. One

> The company records show the property to be exactly 80 acres with no improvements. Its assessed value is for land only, and amounts to $200 per acre. Timber value is taxed at the time of harvest (i.e. 5 percent of net stumpage).
>
> The ground is steep and rough for the most part.
>
> Conifer forest covers all of the property, comprised mostly of mature and over mature Douglas-fir and Western hemlock.
>
> The property is surrounded by National Forest that is designated Wilderness.
>
> The only access to the property is by trail. The nearest road is about 1.0 mile to the east. Road construction is difficult and expensive (about $30 000 per mile). Road building is not permitted in Wilderness, which means the property in landlocked. There may be an opportunity to extend an existing road another 0.4 of a mile to the edge of the Wilderness.

This isn't great news, and your thoughts about your generous uncle may have taken a dramatic change. You wonder if he even liked you. Or maybe he wanted to test your capabilities to deal with tough situations.

You give your consulting forester a call to thank her for the investigative work and to ask, "Where do we go from here?" In response she asks, "What would you like to get from this property?"

After a few thoughtful moments, you offer the following guidelines:

- Maintain a vigorous forest environment.
- Harvest some timber now if possible, when the market is good.
- Visit the property occasionally.
- Harvest more timber in 10 years for the children's university expenses, or sell the property in 10 years for this purpose.

Your consultant then asks for more time - to cruise the timber and to look into harvest opportunities. You authorize her to do this.

A month later you receive a second report with the following information:

TIMBER CRUISE SUMMARY:

Species	Net Volume	Ave DBH	Ave AGE	Ave Mill Value
Douglas-fir	1,000 MBF	36 in	250 yrs	400 Per M
Western hemlock	1,700 MBF	24 in	140 yrs	250 Per M
TOTAL/AVE	2,800 MBF	27 in	165 yrs	309 Per M

HARVEST INFORMATION:

Forest Service will issue a conditional permit to helicopter log.

Forest Service will issue a permanent R/W to build 0.4 Miles of road.

There are 3 possible helicopter landing locations (as shown), one of which requires construction of 0.4 miles of new road at an estimated cost of $12,000.

RECOMMENDATIONS:

1. Harvest about 1,200 MBF now; estimated Revenue = $66,000
2. Harvest about 1,200 MBF in 10 years; est. Revenue = $59,700 (discounted)
3. Obtain Forest Service Permit to Helicopter Log.
4. Obtain Forest Service Permanent R/W to build 0.4 miles of road to Land. No. 2.
5. Partial cut the entire 80 acres, to remove high risk Douglas-fir and to thin Western hemlock; clearcutting or heavy partial cutting would be incompatible with the integrity of the surrounding forest.
6. Remove about 10 tons per acre of Logging Slash to protect residual stand from wildfire and to prepare open areas for natural seeding.

HARVEST ANALYSIS DATA (Attached):

WILD SALE ANALYSIS MAP
HELIPACE PROGRAM - WILD SALE ANALYSIS - PAGES 1 & 2
WILD SALE NETWORK ANALYSIS
WILD SALE NETWORK DATA & RESULTS

BILL FOR SERVICES (enclosed for services rendered to date - $1,920). For services to complete the first timber harvest, which include acquiring the needed logging permits and right-of-way, preparing the first timber sale, soliciting for bids, executing the contract, and administering the road construction and logging, the consulting fee will be 15 percent of the gross stumpage (approximately $12,000).

Well, maybe this isn't such a bad deal after all. So you find a time soon to visit the area. Your first objectives are to meet with your consultant and to visit your property with her. After a vigorous hike in and look around, you feel really good about everything that has transpired. You are awed by you responsibility to care for this land, and inspired to manage it wisely. Being a forest landowner can surely give you a very special feeling about many things.

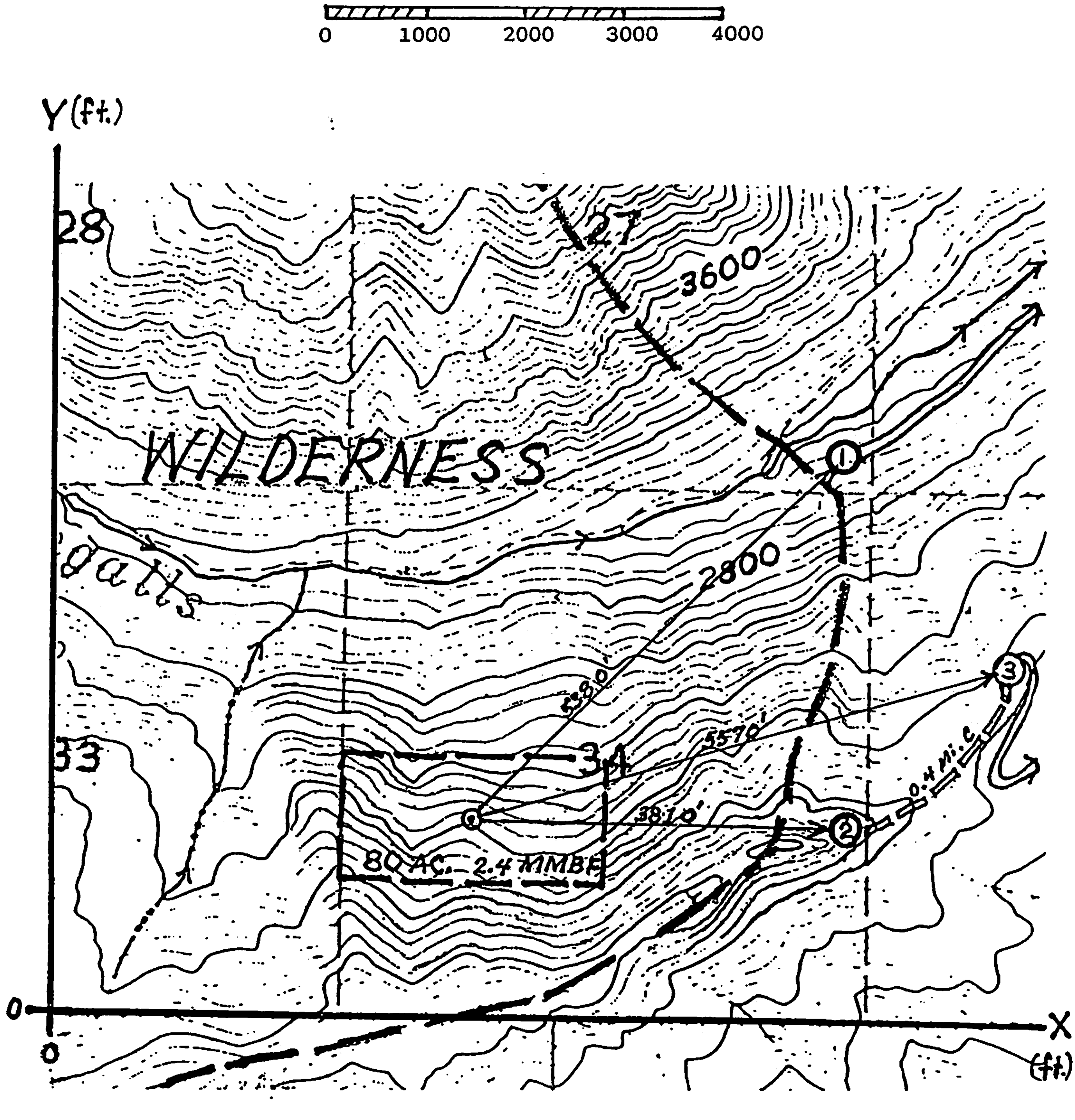
While in the area you visit the Forest Service and a few other agencies to verify some of the work your consultant has done, and to check-out her reputation as a consulting forester. She appears to be a well-respected professional and seems to know her job well.

You are especially impressed with her knowledge of helicopter logging and her use of the software programs Helipace and Network II. Her use of these programs identified important production data and estimated costs needed to do this rather unique analysis. She recognized also the need to analyze both harvest entries because of the effect of road construction on both entries.

Your consulting forester has demonstrated the value of keeping-up with today's technology. Having been in this field of forestry (i.e. logging engineering) for many years, you appreciate the complexity of doing analyses like these. You also realize that having sale areas with several units would not be much more difficult and this one unit sale if you have computer tools like Helipace and Network II to do the analysis.

WILD SALE ANALYSIS MAP

Scale: Feet



HELIPACE PROGRAM - WILD SALE ANALYSIS - PAGE 1 OF 2

Unit 1 ALTERNATIVE DETAIL Part 1 — Project File WILD — PROGRAM USER INPUT (*)

	ALT 1		ALT 2		ALT 3	
Sale*	WILD		WILD		WILD	
Acres*	80		80		80	
Unit Centroid Coordinates: x*	+	4220	+	4220	+	4220
y*	+	1960	+	1960	+	1960
z*		3920		3920		3920
Log Landing [LL]*	1		2		3	
Log Landing Coordinates: x*	+	7900	+	7960	+	9550
y*	+	5620	+	1920	+	3560
z*		2500		4640		4080
Unit/LL Elev Change	-1420		+ 720		+ 160	
Mean Flight Path Length FT	5381		3809		5567	
Include Service Flight Time?	(optional)					
Service Landing						
Service Landing Coord: x	+	0	+	0	+	0
y	+	0	+	0	+	0
z		0		0		0
LL to SL Flight Path FT	0		0		0	
SL to Unit Flight Path FT	0		0		0	
Prescription*	OR/CT		OR/CT		OR/CT	
Utilization Standards	16/9/50/24/ 8/N		16/9/50/24/ 8/N		16/9/50/24/ 8/N	
Minimum DBH*	16		16		16	
Minimum Top DIB*	9		9		9	
Minimum Piece Size BF*	50		50		50	
Preferred Length FT*	24		24		24	
Shortest Acceptable Lngth FT*	8		8		8	
Yard Unmerchantble Material?*	N		N		N	
Add Weight% for Intended YUM*	0		0		0	
Add Wt% for Unintended YUM*	8		8		8	
VOLUME & WEIGHT						
Gross Scale MBF/acre	20.0		20.0		20.0	
Defect%*	25		25		25	
Net Scale MBF/acre*	15.0		15.0		15.0	
Totl Weight to yard lbs/acre	176087		176087		176087	
Includes YUM Weight lbs/acre	14087		14087		14087	
Cut Trees/acre*	14.6		14.6		14.6	
TreeAvg: Gross Scale BF/tree	1370		1370		1370	
lbs/tree	12061		12061		12061	
Avg DBH*	30		30		30	
Avg Height*	96		96		96	

	ALT 4		ALT 5		ALT 6	
Sale*	WILD/YUM		WILD/YUM		WILD/YUM	
Acres*	80		80		80	
Unit Centroid Coordinates: x*	+	4220	+	4220	+	4220
y*	+	1960	+	1960	+	1960
z*		3920		3920		3920
Log Landing [LL]*	1		2		3	
Log Landing Coordinates: x*	+	7900	+	7960	+	9550
y*	+	5620	+	1920	+	3560
z*		2500		4640		4080
Unit/LL Elev Change	-1420		+ 720		+ 160	
Mean Flight Path Length FT	5381		3809		5567	
Include Service Flight Time?						
Service Landing						
Service Landing Coord: x	+	0	+	0	+	0
y	+	0	+	0	+	0
z		0		0		0
LL to SL Flight Path FT						
SL to Unit Flight Path FT						
Prescription*	YARD UNUTILIZED MATERIAL		YARD UNUTILIZED MATERIAL		YARD UNUTILIZED MATERIAL	
Utilization Standards	16/9/50/24/ 8/Y		16/9/50/24/ 8/Y		16/9/50/24/ 8/Y	
Minimum DBH*	16		16		16	
Minimum Top DIB*	9		9		9	
Minimum Piece Size BF*	50		50		50	
Preferred Length FT*	24		24		24	
Shortest Acceptable Lngth FT*	8		8		8	
Yard Unmerchantble Material?*	Y		Y		Y	
Add Weight% for Intended YUM*	10		10		10	
Add Wt% for Unintended YUM*	8		8		8	
VOLUME & WEIGHT						
Gross Scale MBF/acre	20.0		20.0		20.0	
Defect%*	25		25		25	
Net Scale MBF/acre*	15.0		15.0		15.0	
Totl Weight to yard lbs/acre	195652		195652		195652	
Includes YUM Weight lbs/acre	33652		33652		33652	
Cut Trees/acre*	14.6		14.6		14.6	
TreeAvg: Gross Scale BF/tree	1370		1370		1370	
lbs/tree	13401		13401		13401	
Avg DBH*	30		30		30	
Avg Height*	96		96		96	

HELIPACE PROGRAM - WILD SALE ANALYSIS - PAGE 2 OF 2

Unit 1 ALTERNATIVE DETAIL Part 2

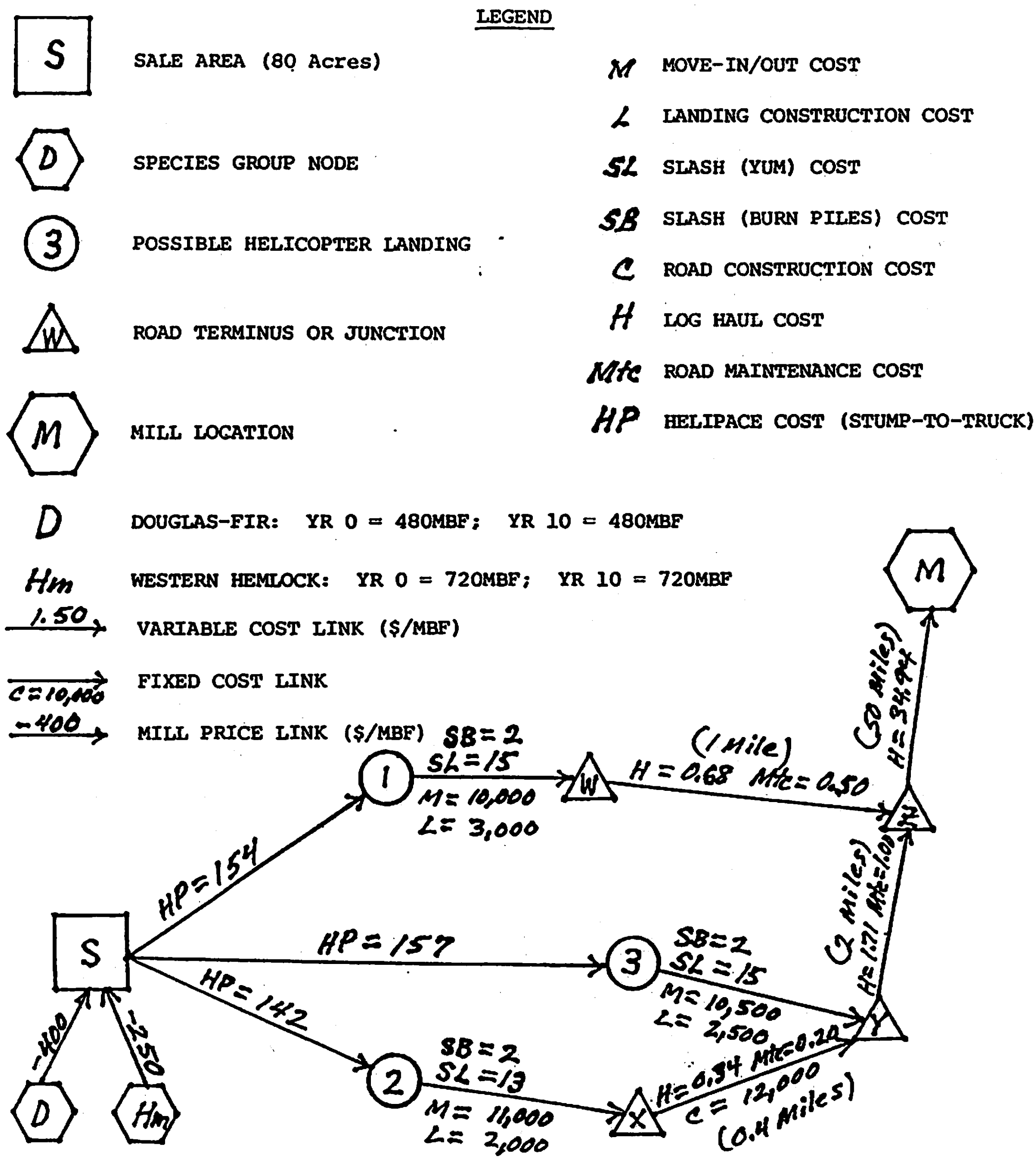
Project File WILD

PROGRAM USER INPUT(*)

PAYLOAD Aircraft*	S-64	ALT 1 LAND 1	S-64	ALT 2 LAND 2	S-64	ALT 3 LAND 3	S-64	ALT 4 LAND 1 YUM	S-64	ALT 5 LAND 2 YUM	S-64	ALT 6 LAND 3 YUM
Target Load: Unobstructed	15236		14779		15138		15236		14779		15138	
Obstructed	12188		11823		12110		12188		11823		12110	
% of Butt Logs to be Ripped*	(not available yet-est cost=$30/mbf ripped as per Jim Neal,12/90)								0		0	
%Remaining Canopy Closure*	30		30		30		30		30		30	
Weight Proportions: Unobstrd	.97		.97		.97		.97		.97		.97	
Obstructed	.03		.03		.03		.03		.03		.03	
Avg Available Load: Unobstrd	15236 -	0	14779 -	0	15138 -	0	15236 -	0	14779 -	0	15138 -	0
Obstructed	11945 -	0	11587 -	0	11868 -	0	11945 -	0	11587 -	0	11868 -	0
Load Factors: Unobstructed*	1.00 -	.00	1.00 -	.00	1.00 -	.00	1.00 -	.00	1.00 -	.00	1.00 -	.00
Obstructed*	.98 -	.00	.98 -	.00	.98 -	.00	.98 -	.00	.98 -	.00	.98 -	.00
Number of Turns: Unobstructd	897 -	0	925 -	0	903 -	0	997 -	0	1027 -	0	1003 -	0
Obstructed	35 -	0	36 -	0	36 -	0	39 -	0	41 -	0	40 -	0
Mean Load	15111 -	0	14658 -	0	15014 -	0	15111 -	0	14658 -	0	15014 -	0
Plausibility Test Trees/Turn	1.25		1.22		1.24		1.13		1.09		1.12	
TURN TIMES												
Add Min/Unobstructed Turn*	.10		.10		.10		.10		.10		.10	
Unobstructed Min/Turn*	3.20		2.80		3.24		3.20		2.80		3.24	
Add Search Min/Obstrctd Turn	.15		.15		.15		.15		.15		.15	
Obstructed Min/Turn	3.75		3.35		3.79		3.75		3.35		3.79	
Mean Min/Turn	3.22 -	.00	2.82 -	.00	3.26 -	.00	3.22 -	.00	2.82 -	.00	3.26 -	.00
Mean Turns/Effective Hour	18.66 -	.00	21.25 -	.00	18.39 -	.00	18.66 -	.00	21.25 -	.00	18.39 -	.00
Effective Yarding Hours/Day	7.0		7.0		7.0		7.0		7.0		7.0	
Yarding Workdays	7.1 -	.0	6.5 -	.0	7.3 -	.0	7.9 -	.0	7.2 -	.0	8.1 -	.0
Total Payunits: NetMerch MBF	1200.0		1200.0		1200.0		1200.0		1200.0		1200.0	
Pounds/Net BF	10.8		10.8		10.8		10.8		10.8		10.8	
Production Rate GrossMBF/Day	224.1 -	.0	247.7 -	.0	219.5 -	.0	201.7 -	.0	222.9 -	.0	197.6 -	.0
Aircraft Fixed $/Day	7,500		7,500		7,500		7,500		7,500		7,500	
Aircraft Variable $/Day	10,500		10,500		10,500		10,500		10,500		10,500	
Yarding System $/Day	18,000		18,000		18,000		18,000		18,000		18,000	
Aux Support Aircraft $/Day	1,000 -	0	1,000 -	0	1,000 -	0	1,000 -	0	1,000 -	0	1,000 -	0
Sawyers	11 -	0	12 -	0	11 -	0	10 -	0	11 -	0	10 -	0
Rigging & Landing Crew	9 -	0	9 -	0	9 -	0	9 -	0	9 -	0	9 -	0
Loaders with Operators	1 -	0	1 -	0	1 -	0	1 -	0	1 -	0	1 -	0
Additional Ripping $/Day	0 -	0	0 -	0	0 -	0	0 -	0	0 -	0	0 -	0
Support System $/Day	6,900-	0	7,200-	0	6,900-	0	6,600-	0	6,900-	0	6,600-	0
Miscellaneous Costs $/NetMBF	6.25		6.25		6.25		6.25		6.25		6.25	
Production Cost $/Net MBF (STUMP-TO-TRUCK)	154 -	0	142 -	0	157 -	0	169 -	0	155 -	0	172 -	0

WILD SALE NETWORK ANALYSIS

Network II PC Program by Sessions



WILD SALE NETWORK DATA & RESULTS

ACTIVITY OR COST ELEMENT	MEASURMENT UNITS	YARD TO LANDING NO. 1	YARD TO LANDING NO. 2	YARD TO LANDING NO. 3
NET VOLUME TO HARVEST				
Douglas-fir @$400/M Year 0	MBF	480	480	480
West.hemlock @$250/M Year 0	MBF	720	720	720
Douglas-fir @$400/M Year 10	MBF	480	480	480
West.hemlock @$250/M Year 10	MBF	720	720	720
TOTAL VOL HARV (10 YR PERIOD)	MBF	2,400	2,400	2,400
ROAD CONSTRUCTION	MILES	0	0.4	0
ROAD CONSTRUCTION COST	$$$	0	12,000	0
LANDING CONSTRUCTION COSTS	$$$	3,000	2,000	2,500
MOVE-IN & MOVE-OUT COSTS	$$$	10,000	11,000	10,500
HELIPACE COST (STUMP-TO-TRUCK)	$/MBF	$154.00	$142.00	$157.00
SLASH TREATMENT - YUM	TONS/ACRE	9.8	9.8	9.8
(Data from Helipace Analysis)	$/ACRE	225	195	225
	$/MBF	$15.00	$13.00	$15.00
BURN YUM LANDING PILES	$/MBF	$2.00	$2.00	$2.00
WASH STATE HAUL: CLASS A MILES @ $.475		50.0	50.0	50.0
CLASS B MILES @ $.676		1.0	0.0	0.0
CLASS C MILES @ $.855		0.0	2.4	2.0
HAUL (incl.$11.19/M Basic Charge)	$/MBF	$35.62	$36.99	$36.65
ROAD MAINTENANCE @$0.50/M/Mile	MILES	1.0	2.4	2.0
	$/MBF	$0.50	$1.20	$1.00
NETWORK II RESULTS (DISCOUNTED @ 4%)				
REVENUE	$/MBF	$259.63	$259.63	$259.63
VARIABLE COSTS	$/MBF	$173.46	$163.47	$177.26
FIXED COSTS	$/MBF	$5.42	$10.42	$5.42
P & R (12% OF COSTS)	$/MBF	$21.47	$20.87	$21.92
GROSS STUMPAGE	$/MBF	$59.28	$64.87	$55.03
CONSULTING FEES (15% OF STPG)	$/MBF	$8.89	$9.73	$8.25
NET STUMPAGE BEFORE EXCISE TAX	$/MBF	$50.39	$55.14	$46.77
NET STUMPAGE BEFORE EXCISE TAX		$120,940	$132,341	$112,258
STATE EXCISE TAX @ 5%		$6,047	$6,617	$5,613
NET STUMPAGE		$114,893	$125,724	$106,645

INTERDISCIPLINARY RESEARCH CAN PROVIDE INFORMATION FOR THE HARVESTING CHALLENGES OF THE 1990's

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ABSTRACT

Management of our complex forest ecosystems in the economic and political climate of the 1990's is a challenge for planners, managers, and loggers. A multifunctional approach --using the research results of other disciplines and considering all forest uses and values-- can improve the effectiveness of forest operations research. Since harvesting cost and revenue are closely related to changing stand attributes, harvest models must be linked with dynamic growth and yield models to accurately assess the impact of site and stand attributes on logging cost and stand management. Future harvesting plans must incorporate all forest values and uses as well as environmental impacts on soils, wildlife, and water quality. Future logging plans must bring together the volumes of research results from other disciplines in a decisionmaking model. The application of a model called MANAGE to integrate harvesting with the many uses of the forest is described.

Keywords:
Logging cost, wildlife, integration, models.

INTRODUCTION

The public has discovered that America's forests not only produce high-quality wood products but also are superb places in which to hike, hunt and fish, camp, and enjoy the outdoors. As public values change, so does the management of these forests. Changing values have resulted in new laws on land use and resource management. These new laws pose new challenges for forest planners, managers, and loggers, and will affect how millions of acres of commercially forested land will be managed.

The challenge for forest managers is to respond to and even anticipate changes in the social context for managing public forests while maintaining a sense of the long-term needs for wood products. To do this successfully requires comprehensive analyses that integrate logging technology, silvicultural treatments, economics, wildlife requirements, and other management considerations in the decisionmaking process. Rigorous financial analysis must be conducted so that tradeoff values of alternative forest management objectives are understood and planned for. Models such as TEAMS (Covington et al. 1988), FORPLAN (Sedjo 1987), and ECOSIM (Rogers et al. 1984) are examples of models that evaluate alternatives for large blocks of forested land.

Stand-growth simulators for forests in the Northeast include NE-TWIGS (Hilt and Teck 1988), SILVAH (Marquis 1986), OAKSIM (Hilt 1985a, b) FIBER (Solomon et al. 1987), and GRO2 (Sendak 1985). These models differ in forest-type application and in method of growth projection. Although some provide economic analysis for various silvicultural treatments, none have detailed logging-cost data and analysis options. MANAGE[1] (LeDoux 1986) is one of the few models applicable to forest conditions in the Northeast that estimates harvesting costs for cable and ground-based logging technology.

METHODS

In this paper we describe the use of the computer program MANAGE to evaluate the impact of four forest management scenarios on logging cost and net returns. Written in FORTRAN 77, MANAGE integrates harvesting technology, silvicultural treatments, market price, and economic concerns over the life of a stand. The simulation is a combination of discrete and stochastic subroutines. Individual subroutines model harvesting activities, silvicultural treatments, growth projections, market prices, and discounted present net-worth (PNW) economic analysis. The model can be used to evaluate alternative management strategies and to develop optimal management guidelines for eastern hardwoods.

Initial Conditions

The stand table used to initiate the simulations was published by Schnur (1937) for even-aged upland oak forests (Table 1). The table represents projected conditions by site index and age for a fully stocked upland oak stand. The initial tree list was input into MANAGE to project growth

[1] The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a government-produced computer program.

Table 1. Initial attributes of timber stand.

Site index	Mean dbh	Vol./ acre	Age	No. trees/ acre	species components: Red maple	White ash	White oak	Red oak	Hickory
	Inches	ft^3	years		---------- Percent				----------
80	8.9	2612	50	249	5.0	6.0	38.0	46.0	6.0

and yield for each management scenario. The stand was assumed to be on moderate terrain and ground-based logging technology was used for both the thinnings and final harvests. The costs and benefits by management scenario were simulated and summarized on a discounted cash-flow basis.

LOGGING TECHNOLOGY

A skidder cost equation for a John Deere 540B[2] rubber-tired skidder was used to estimate skidding cost (LeDoux 1988). The 540B is a medium-size machine capable of skidding small and large logs (Figure 1). Skidding and other harvesting and transportation costs were estimated using EASTCOST (LeDoux 1988). EASTCOST is a microcomputer program that can estimate stump-to-mill costs of ground-based and cable logging systems for eastern hardwoods. The streams of costs and benefits were summarized by management objective. The delivered product prices used (Table 2) were obtained from Coastal Lumber Company, Hopwood, PA and from Forest Product Price Bulletins (Ohio Agric. Res. Serv., 1989; Penn State Univ., 1989; Tenn. Div. For., 1989).

Figure 1. The John Deere 540B Skidder.

Management Objectives

For comparison purposes and to illustrate the use of an integrated model to evaluate alternative management objectives, we considered four scenarios. One was to not harvest the stand; the second was to harvest the stand using the culmination of mean annual increment as the decision criteria; the third was to provide substantial periodic volumes and cash flows through a combination of heavy thinnings and a delayed final harvest; and the fourth was to manage the stand to provide as much hard mast as possible for squirrels, turkey, deer, and bear, and to provide scenic beauty with large trees openly spaced within the stand (Ribe 1991) beginning at age 50.

In each case, the assumption is that the land owner or firm chose to manage the stand in this manner. Our intent is not to suggest the best management practices or guidelines, but to show the kinds of information that can be produced when evaluating or comparing scenarios. We report stand parameters such as dbh, volume yield, tree size, and present net worth so that tradeoffs can be visualized or computed and to show how the stands would develop for each scenario.

RESULTS

For management option 1, the stand was projected to its optimal economic rotation so that the maximum present net worth could be compared with other scenarios. This scenario would yield trees that average 14.2 inches dbh, yield a cubic-foot volume of 5,324/acre, have an average tree volume of 30 ft^3, and a present net worth of $504/acre with an optimal economic rotation of 100 years.

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

Table 2. Delivered prices for sawlogs and fuelwood/pulpwood by species (Doyle rule).

Species	Large high-quality sawlogs[a]	Medium-size quality sawlogs[b]	Small low-grade sawlogs[c]	Fuelwood/ pulpwood[d]
	---------- Dollars/Mbf		-------	Dollars/cord
Red maple	210	160	80	30
White ash	500	300	100	30
White oak	500	300	100	30
Red oak	600	350	100	30
Hickory	210	160	100	30

[a]Minimum small end diameter $\geq$ 13 inches; length $\geq$ 10 feet.
[b]Minimum small end diameter $\geq$ 11 inches; length $\geq$ 8 feet.
[c]Minimum small end diameter $\geq$ 10 inches; length $\geq$ 8 feet.
[d]89 ft^3/cord, minimum small end diameter $\geq$ 4.0 inches that will not make large, medium, or small sawlogs.

When using culmination of mean annual increment as the decision criteria, option 2, the stand would reach rotation age at 80 years (Figure 2), produce trees that average 12.18 inches dbh; yield a volume/acre of 4,482 ft^3, and have a present net worth of $365/acre. The average tree would contain about 21 ft^3.

Option 3, to provide periodic volume and cash flows through a series of thinnings, was accomplished by scheduling commercial thinnings at ages 65 and 100 with a final harvest at optimal rotation age of 150 years. This objective produced trees that averaged 13.89, 14.85, and 18.33 inches dbh at age 65, 100, and 150, respectively; volume yields were 2,000, 2,792, and 2,674 ft^3/acre at age 65, 100, and 150.

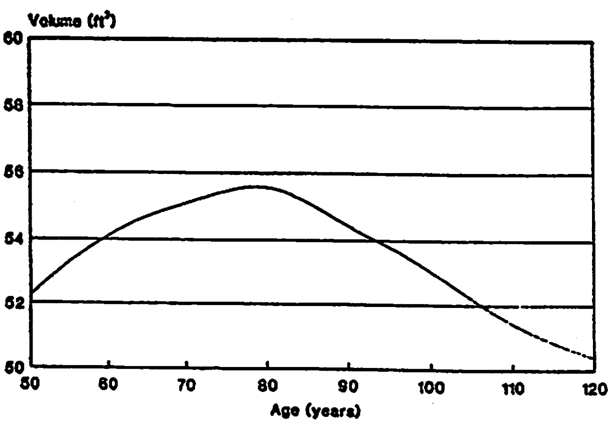

Figure 2. Mean annual increment for scenario 2.

Present net worths were $91.48 and $124.34, and $46.17/acre at ages 65, 100, and 150.

Option 4, to provide mast for wildlife and scenic beauty, was accomplished by removing smaller diameter trees in favor of those that would produce hard mast. The larger trees were left to increase and maintain the scenic beauty of the stand. The thinning at age 50 removed trees that averaged 6.63 inches dbh, leaving trees that averaged 10.53 inches dbh. The thinning at age 50 removed 613 ft^3/acre resulting in a present net worth of $-418.57/acre. The residual stand was projected to its optimal economic rotation for comparison purposes. The optimal rotation would be at age 100 years, yielding 4,955 ft^3/acre with trees that averaged 17.10 inches dbh. The average tree size would be 45 ft^3. However, trees that are 24 inches dbh and larger could be produced at a stand age of 165. The results for all management objectives are summarized in Figures 3-6.

CONSIDERATIONS FOR MANAGERS

Although the objective of management option 4 is partially to produce mast for squirrels, deer, turkey, and bear, there is no guarantee that mast will be produced or that the desired wildlife species will be present or even use the area: mast production or wildlife use are variables that cannot be accurately predicted. However, if through management we can provide healthy forests/ecosystems, then the chances of a given objective meeting with success are increased.

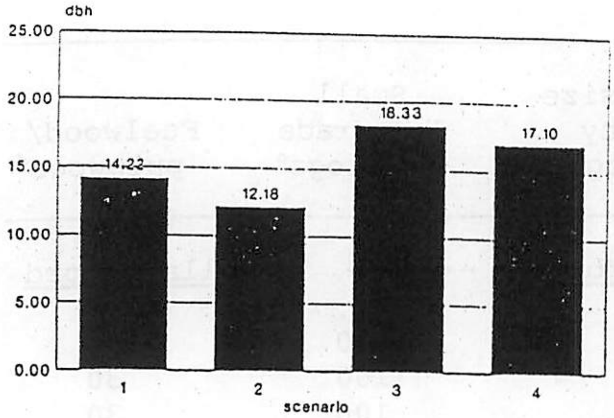

Figure 3. Average dbh at rotation age by management scenario.

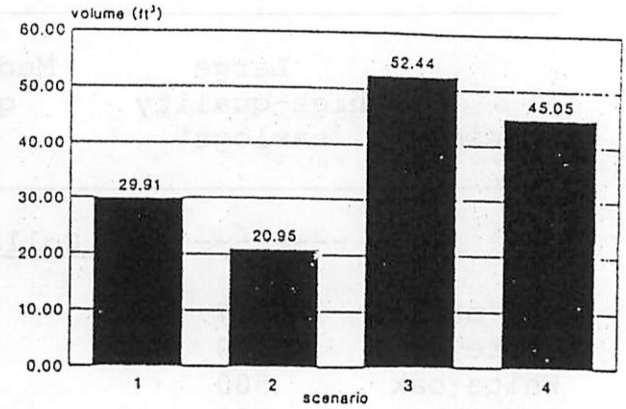

Figure 6. Average tree volume at rotation age by management scenario.

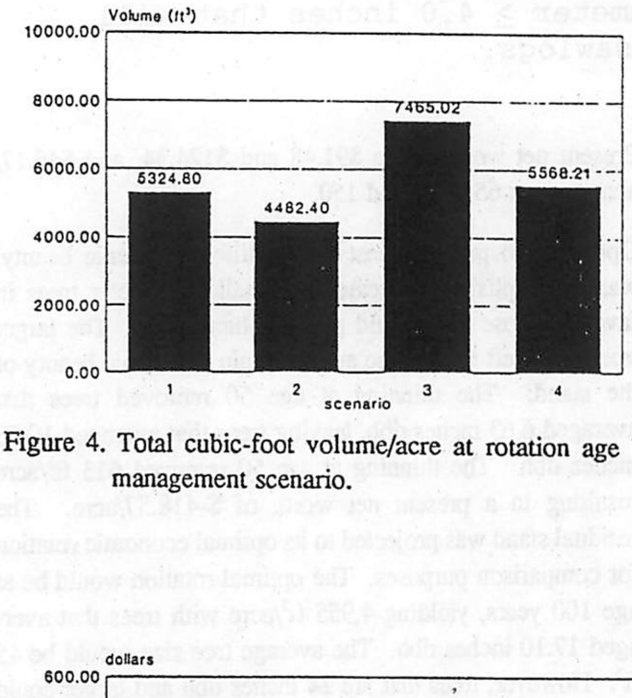

Figure 4. Total cubic-foot volume/acre at rotation age by management scenario.

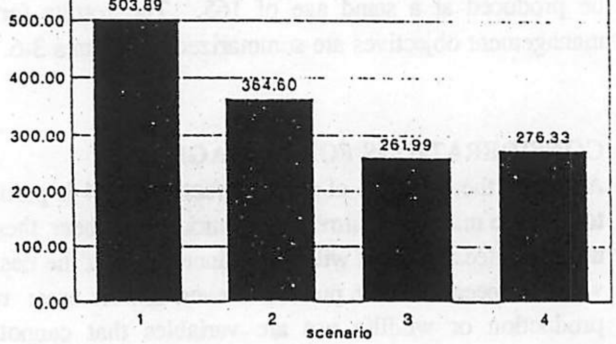

Figure 5. Cumulative present net worth by management scenario.

By evaluating alternative scenarios, loggers and logging planners can gain insight into the size and volume of wood flows created by various objectives. Analyses such as this also allow loggers to see project logging costs accurately. As forest-land owners and users specify management scenarios for whatever reasons that require logging, loggers and planners will need to know the types of products and values involved. Integrative models can provide them with information on tree and stand parameters necessary to harvest stands in the 1990's and beyond.

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REGIONAL REPORTS

SOUTHERN REGIONAL REPORT

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INTRODUCTION

The recent recession has reduced the demand for pulpwood and sawtimber in the South and forced most logging contractors to be very careful about new purchases or expansions. In addition, the usually unpredictable southern weather has thrown a lot of people for a few loops recently.

HEAVY SPRING RAINS

Many parts of the mid-South are experiencing their wettest spring in decades, limiting the access of logging operations to stands ready for harvest. This situation has become so severe in some areas that paper mills have been forced to temporarily close. Several cities in Louisiana, Arkansas, and Mississippi had received rainfall equal to their annual averages by the end of May. The situation is similar but not quite as severe in the southeastern states. Logging access is limited, but mills have yet to be forced to close.

LOGGER ASSOCIATIONS

Over the past two years, logging contractors have become increasingly interested in forming professional associations. The Mississippi Loggers Association formed in May 1989 to seek insurance reform and in many ways has been the role model for other southern logging groups. In early 1990 the Southeastern Wood Producers Association was formed. This group is based in Hilliard, Florida and claims members in both Florida and Georgia. In March 1991, the Arkansas Timber Producers Association was organized. All of these new associations were created in large part due to frustration with the rapidly increasing cost of workers compensation insurance.

While logger associations are common in other regions of the USA, they relatively new to the South. Many state forestry associations in the South did not actively address logging issues, tending to focus instead on landowner issues. However, other state forestry associations, including those in Virginia, South Carolina, Alabama, and Georgia, have active committees who address logging issues. Rumors abound that logger associations will soon be created in other southern states.

WORKERS COMPENSATION INSURANCE

The cost of workers compensation insurance continues to be concern of logging contractors in the South. The mechanized logging code (2719) created in Mississippi in May 1989 is still the only such code allowed in southern states. Several discussions have taken place during the past year in Florida and Georgia with state insurance departments and the National Council on Compensation Insurance (NCCI) about creating this mechanized code in other states. About half of the southern states still have two workers compensation insurance codes for logging: 2705 -- Pulpwood Logging, and 2702 -- Logging and Lumbering, Not Otherwise Classified. The other states either never used a pulpwood code or eliminated it in the mid-1970's. In most states which still have two codes, discussions are underway about either combining the two codes into a single logging code or replacing the obsolete pulpwood logging code with one for mechanized logging. During the next 12 months, additional states are likely to either adopt a mechanized code or convert to a single logging code.

WETLANDS

Industry continues to closely follow the growing number of restrictions concerning wetland areas. The Wetland Delineation Manual published by the Environmental Protection Agency last year has been revised and a draft of this revision has recently been released. There is a great deal of concern over the economic impacts of increased wetland protection on local economies and governments. This has led to the introduction of several bills in Congress which would require that economic impacts of wetland protection or designation be considered in future actions.

CLEARCUTTING ON NATIONAL FORESTS

One of the largest controversies during the past year has involved a decision made by U.S. Forest Service Chief Dale Robertson to eliminate the use of clearcutting on the Ouachita National Forest in Arkansas and Oklahoma. This decision was made after a "walk in the woods" with Senator David Pryor (D-Ark) last summer during a visit to the forest. Industry groups were outraged at the action which ignored several legislative acts governing development of forest management plans for federal lands. This decision was later reversed by the Assistant Secretary of Agriculture, but environmental groups and the media in Arkansas are still opposing clearcutting on this forest. The Ouachita is the largest national forest in the South, covering over 2 million acres.

SOUTHERN REGIONAL COFE

The second annual meeting of the Southern Region of the Council on Forest Engineering (SR.COFE) was held March 5-7 in Macon, Georgia to discuss "Advances in In-Woods Processing". Members and attendees gathered on Tuesday night for a social sponsored by Southland Machinery in Milner, Georgia. A full-day field trip took place on Wednesday. The group visited two highly mechanized whole-tree chipping operations producing debarked chips from sand pine and a highly mechanized roundwood operations using a CTR mechanical delimber. The final stop of the afternoon was Dry Branch Kaolin Corporation who hosted the group for a tour of their kaolin strip mining operations. Kaolin is a fine clay used to coat paper and for a variety of other uses. A half-day technical session on Thursday concluded the meeting. Proceedings are available for $10 from Ben Jackson, Cooperative Extension Service, P.O. Box 1209, Tifton, GA 31793. Tom Reisinger of Virginia Tech was elected Chairman of SR.COFE for 1992.

NORTHEAST REGIONAL REPORT

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INTRODUCTION

The most significant issue affecting forest engineers in the northeast, over the past year, was the economy. Additionally, the ongoing problem with regulation of timber harvesting continued to be of concern to forest engineers in the region.

Regional Economy

The recession of 1991 was first felt in the Northeast in 1990. Generally, the forest products industry was spared the worst of the recession; but, it did have its impact on the industry in the region.

Northeastern USA. While the downturn in the national economy has affected the entire forest industry in the northeast USA, these impacts vary. The pulp and paper segment has had to reduce hiring temporarily, but otherwise is hopeful for the future. While the industry in the region is not operating at capacity, it is able to still make a profit. This is due mainly to the major capital projects completed in the early 1980's that increased production efficiencies. Stumpage prices for pulpwood, over the last year have generally stayed constant or declined slightly.

On the other hand, the lumber segment of the industry was significantly impacted. This is, in part, due to the direct linkage between the performance of the industry (even the hardwood segment) and the health of the housing industry. Production is down from last year and stumpage rates for sawlogs have dropped significantly. However, there were some bright spots. The demand for high quality hardwoods (e.g. red oak, white oak, and white ash) was such that premiums were still paid. While the recent decline in interest rates gives some hope for an improvement in the fourth quarter of 1991, there is some concern that the recent cutting bans in the northwest will short circuit any housing recovery.

Eastern Canada. The attitude in eastern Canada, over the past year, was slightly more pessimistic. Pulp and paper companies felt the full effect of the "recession." Most mills were not working at capacity and newsprint prices continued their downward trend. The increased demand for recycled papers and the relative distances between markets and Canadian mills will probably continue to exacerbate the economic problems faced by the Canadian pulp and paper industry. However, the recent decline in interest rates may help the Canadian housing market, and hence, the Canadian lumber industry.

Timber Harvesting Regulation

The past year has seen a mixed response to environmental regulation. On one hand, broad-based environmental initiatives were defeated in a number of states. In many cases these defeats were more a result of public dissatisfaction with the tax cost of the programs rather than disagreement with the goals of the programs. However, local regulations affecting timber harvesting have continued to proliferate.

New regulations dealing with licensing in Maine will have a direct impact on forest engineers. Under the new licensing requirements, foresters (and forest engineers) will have to pass a written examination and work under the direct supervision of a licensed forester for two years before being licensed.

Forest Engineering Education

In the educational arena, the past year was characterized by relatively constant enrollments and continued work an a diverse range of research projects.

University of New Brunswick. The past year was very active for the only school in Canada offering a fully accredited degree in Forest Engineering. Student enrollments continued at about 100 students. Additionally, the University of New Brunswick signed academic agreements with two universities in the People's Republic of China to facilitate research and the exchange of graduate students and faculty.

University of Maine. At the University of Maine forest engineering enrollments remained relatively constant at about 60 students. Research activities, over the past year, have concentrated on: (1) the development of interfaces between expert systems, mathematical programming, and simulation and animation; (2) extensions to road location theory to account for biometric considerations; and (3) use of GIS in truck routing algorithms.

State University of New York. At the SUNY College of Environmental Science and Forestry, enrollments in forest engineering increased slightly over past years. At the College, research efforts have concentrated on: (1) use of GIS in predicting the impacts of timber harvesting on wildlife habitat; (2) use of remote sensing technologies to assess land cover; (3) long term site and soils impacts of partial cutting.

NORTHEAST REGIONAL COFE

The Northeast Regional Council on Forest Engineering (NER.COFE) continued to be active in 1991. Tom Corcoran, University of Maine, continues to serve as Executive Chair and John Scales, International Paper, serves as Chair-Elect.

A two-day meeting/workshop on "Effective Forest Operational Planning" was held on March 4-5 in Orono, Maine. Fifty-one people were registered for the meeting. Topics discussed at the meeting/workshop included: the need for proper soils identification in forest operational planning, the need for proper fuel and lubrication selection in forest operational planning, and the use of mobile rock crushers for forest roads.

The next meeting of NER.COFE will be held in March of 1992. Further details about this meeting will be forthcoming in the fall of 1991.

LAKE REGION REPORT

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INTRODUCTION

This paper outlines some of the recent developments influencing harvesting in Ontario, Minnesota, Wisconsin and Michigan. A survey of Lake States contractors was also made to obtain information of logging systems employed and contractor concerns. Table 1 presents total net growths and removals in the region.

Table 1. Harvesting and net growth statistics for the Lake region.

Prov./State	Removals, million cord	Removals, million m3	Net growth, million cord	Net growth, million m3
Ontario	13.1	29.3	19.6	44.0
Minnesota	3.4	7.6	4.5	10.1
Wisconsin	4.4	9.8	7.6	17.0
Michigan	5.1	11.4	7.3	16.3
Total	12.9	28.8	19.4	43.4
Overall total	26.0	58.1	40.0	87.4

ONTARIO

The forest industry in Ontario is reeling from the recession. Most pulp and paper mills are taking down-time. In addition the Abitibi Thunder Bay newsprint mill has been shut down for an indefinite period; poor profitability and quality were said to be the major reasons. The employee buy-out proposal for Spruce Falls Power and Paper has yet to be successful and the mill is facing serious cutbacks. The lumber industry is suffering from the 15% export tax and there have been a number of closures.

Another major factor beginning to affect forestry, and expected to have a major impact when completed, is the Class Environmental Assessment for Timber Management on Crown Lands in Ontario. This hearing began in May 1988, and is expected to continue for another 12-18 months. An independent audit of forest regeneration on Crown lands has also begun, with the full support of the industry.

Some of the guidelines currently affecting forest harvesting are the Environmental Protection Act, Environmental Guidelines for Access Roads and Water Crossings, Timber Management Guidelines for Protection of Tourism Values, and a number of guidelines for the protection and provision of habitat for moose, fish, bald eagle, golden eagle, peregrine falcon, waterfowl, wetland birds, heronries, cavity nesting birds, warblers, bats, deer, furbearers and woodland caribou.

The main harvesting system used employs feller bunchers, with stroke-delimbers and slashers (>75%). Almost all mechanized delimbing occurs at roadside. However, there is ever-increasing pressure to delimb in the stump area to keep the slash on-site. The major new equipment of interest are the chain flail-delimber-debarker-chippers. Canadian Pacific Forest Products is currently using four Peterson Pacific DDC-5000's with chip quality comparable to woodroom chips. Boise Cascade is testing a Morbark Model 23 Flail Chiparvester, with mixed chip quality results.

LAKE STATES

In Minnesota, a Generic Environmental Impact Statement (GEIS) on Timber Harvesting and Management is being prepared for the Minnesota Environmental Quality Board by Jaakko Pöyry, Inc. Another development has been an initiative to reduce logging worker compensation rates. The program involves a fixed fee paid per cord by the industry. This fee is returned to contractors participating in the program. The program entails both courses and site inspections. It is expected compensation rates will be immediately reduced from 47% down to 42%. A co-operative effort between the Minnesota Dept. of Natural Resources, USDA National Forests, County Land Commissioners, forest industry, Minnesota Pollution Control Agency, Minnesota Timber Producers Association and University of Minnesota has resulted in a set of forestry operations standards, entitled Water Quality in Forest Management "Best Management Practices in Minnesota." These standards are currently being implemented in the field.

In Wisconsin, a court action initiated by Native Americans for general timber gathering rights was not successful. There is no word whether the decision will be appealed.

In all three states there is active discussion of the effect of harvesting operations and forest management on biotic diversity and wetlands. Active modification of harvesting systems is ongoing to meet the more stringent environmental standards, and to ensure minimum environmental impacts. In addition, private forest owners are becoming increasing reluctant to allow heavier forest machines onto their lands.

The small contractors are in a very difficult situation. To be able to survive in the future there is the need to mechanize. However, it is difficult for the small contractors to afford the new equipment and reach the high annual usage rates required.

LAKE STATES LOGGING SURVEY

A random survey of contractors in Minnesota, Wisconsin and Michigan revealed a wide range of operations in size, equipment employed and harvesting methods. The respondents accounted for 158,395 cords of wood, or about 1.2% of the total volume harvested in the area. The following harvesting statistics were obtained:

I) Harvesting methods
a) clear cutting = 31.1%
b) modified cutting = 41.8%
c) shelterwood = 4.9%
d) thinning = 15.6%
e) selective = 6.6%

II) Average cut area = 44 acres

III) Felling equipment
a) chain saw = 25.8%
b) feller buncher = 67.4%
c) harvester = 6.8%

IV) Off-road transport
a) cable skidder = 22.9%
b) grapple skidder = 66.7%
c) forwarder = 10.4%

V) Delimbing equipment
a) chain saw = 46.3%
b) mechanized = 53.4%
c) no delimbing = 0.3%

VI) Bucking/slashing equipment
a) chain saw = 11.8%
b) mechanized = 87.9%
c) not bucked = 0.3%

VII) Delimbing location
a) cut-over = 94.5%
b) roadside = 5.5%

The major short- and long-term concerns expressed by contractors are listed below:

SHORT-TERM
- high stumpage prices (n=4)
- low prices paid at mill (n=4)
- wood shortages (n=4)
- insect infestation, fires or poor management resulting in reduced timber availability (n=2)
- forests being tied-up for non-timber uses
- high fuel prices
- changing the public's misconception that cutting trees is bad

LONG-TERM
- forests being tied up for non-timber use by various interest groups (especially environmental groups) (n=8)
- high worker's compensation costs (n=4); one suggestion that there should be a governing body to ensure compensation rates paid by the contractors are covered by the industry, and to ensure the loggers are properly trained, equipped and following safety procedures
- high stumpage and low mill prices (n=2)
- lack of spacing in over-dense stands will limit future availability of large size timber
- markets

As can be seen, the major contractor concerns are timber availability (mainly due to pressure for non-timber use of forests), high stumpage rates, low delivered wood prices, and high worker's compensation costs.

WESTERN REGIONAL REPORT

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INTRODUCTION

The past year has been a difficult one for the timber industry with many changes and uncertainty about future directions. Forest engineers and others across the western region were contacted during the preparation of this paper. Their help is greatly appreciated. The most relevant issues are organized into eight main sections that follow.

NORTHERN SPOTTED OWL

In 1990, the U.S. Fish and Wildlife Service listed the northern spotted owl as a threatened species under the Endangered Species Act. One year after the owls listing, the only thing certain is continued uncertainty, chaos, and confusion. Various teams have produced recommendations to protect the owl, and different bills have been proposed. New events are happening each day but there is no permanent plan being followed.

An Interagency Scientific Committee developed the "Jack Ward Thomas Report" setting aside 8 million habitat conservation acres where logging would be restricted. Following the Jack Ward Thomas Report, the U.S. Fish and Wildlife Service announced their recommended logging restrictions on 11.6 million acres (85% of these lands are in Oregon). The 11.6 million acres is equivalent to 40% of all forested land in Oregon, or a strip of timber 6 miles wide from Portland, Oregon to Portland, Maine. Estimated timber and related industry job losses range from 25,000-100,000 throughout the Pacific Northwest. Oregon 1990 statistics show that 39 veneer and sawmill operations closed; 131 mills have permanently closed since 1980.

The Fish and Wildlife Service claims that logging could be allowed in some of the owl habitat areas. However, virtually every timber sale is being appealed to federal courts and stopped. On May 14th, U.S. District Judge William Dwyer placed a temporary injunction that prohibits any new timber sales within owl habitat areas. The Forest Service hopes to offer 1 billion board feet for sale this year outside of owl habitat areas. This compares to 5 billion board feet offered last year and 3.9 billion board feet sold.

The Department of the Interior appointed a 15 member owl recovery team to develop a draft plan by December 1991 and a final plan by the summer of 1992. The team is to produce a permanent plan for the recovery of owl populations in the western United States.

Approximately 3 million acres of state and private land are included in owl habitat areas. Each state has developed radically different approaches in trying to balance private timber operations with protection of the owl. For instance in Washington, the Department of Natural Resources is rejecting or restricting permits to log private land once 60% of suitable old-forest habitat has been logged around owl sites. Habitat circles range from 1.8 miles to 2.2 miles in radius. In Oregon, the Board of Forestry requires private operators to leave 70-acre unlogged areas around owl nests and other sites where owl activity has been documented. In California, the Department of Forestry is turning down all permit applications to log owl habitat areas and is working on developing its own owl habitat conservation plan.

In Canada, the northern spotted owl has been found only in a small portion of forests in southern British Columbia. Set aside preserves have been established in these areas.

TIMBER SUPPLY

The old growth-spotted owl issue is having an obviously significant effect on timber supply in the west. Productive timberlands west of the Cascade Mountains are being drastically withdrawn from harvesting. In the future, eastside harvest levels could be higher than westside. Throughout the western region, harvested tree sizes on all lands are getting smaller. Some private companies are clearcutting small trees at young ages. Federal management calls for high intensity management of non-reserved forest land. Commercial thinning is the last major source of raw material available and could increase significantly in future years.

The source of chips for pulp and paper mills is also changing. Large cull logs from public lands will not be available as old growth harvests decline and requirements to leave large woody debris increases. Sawmill closures will also result in mill residue reductions. We are already seeing a shift to roundwood sources of chips for pulp and paper mills. For instance in Oregon, 25+ chip facilities are supplying pulp mills with approximately 40% roundwood chips. This compares with approximately 12% roundwood chips a year ago. In many areas throughout the west, there is growing interest in chain flail systems.

RULES AND REGULATIONS

The publics concern over the impacts of timber harvesting have increased significantly. Resources other than timber are also being considered more. To deal with these issues, various groups or committees have been formed. For instance in Canada, a committee chaired by Alex Sinclair of FERIC, has developed ground skidding guidelines focused on planning, engineering and administration to minimize soil compaction and degradation impacts from ground vehicles. Also in Washington, the Timber-Fish and Wildlife Agreement has resulted in a very active group of agency and industry representatives to develop and revise regulations for multiple resource management.

In California and Oregon, some major modifications are being considered to existing Forest Practice Rules. Specific issues being reviewed in Oregon include stream classifications and riparian protection guidelines, clearcut size, water quality authority, wildlife habitat, reforestation, written plans, cumulative effects and forest management, land use conversions, scenic values, new studies and smoke management.

Environmental groups are threatening to put forest practice initiatives to the voters if they fail to win stricter limits from lawmakers. California has taken the lead in putting such initiatives to the voters. As a result, timber companies are hiring biologist to examine the resource issues on their lands and propose changes to try and avoid being forced into certain practices. Louisiana Pacific has announced that they will be phasing out clearcutting on 482,000 acres in California by 1994. Sierra Pacific has agreed to limit clearcuts to less than 20 acres.

In other regulation issues, the Washington Department of Natural Resources now only allows 25% of state logs to be exported. Oregon has a total log export restriction from State lands.

In the safety area, Oregon OSHA is proposing to revise its Logging Code. It has been completely reorganized and expanded to cover all forest activities. The new code applies to all employees, both in public and private sectors. Provisions for a formal safety and health program are included in the rules, which outline training requirements and establish safety committees. The revised code is going through a public hearing process during June, 1991.

ALTERNATIVE TO CLEARCUTTING

The new forestry ideas coming out of past ecological studies on the H.J. Andrews Experimental Forest by Jerry Franklin and others are being studied and put into practice in some areas. The U.S. Forest Service describes their New Perspective as the planning and management philosophy designed to reduce polarity among resource users and to restore forest management options. Interdisciplinary teams of researchers are evaluating a wide range of alternatives to clearcutting. In Canada, there is a joint venture between Forestry Canada, Ministry of Forestry, University of British Columbia and FERIC. Other research organizations and universities have similar joint studies underway. There are also some operational trials being conducted with little research design and formal data collection such as on the Blue River Ranger District of the Willamette National Forest, Plum Creek Timber Company in Washington and the City of Seattle Cedar River Watershed.

SALVAGE LOGGING

In parts of the west, severe drought conditions for 5+ years have weakened trees on many sites and made them more vulnerable to insect attacks. This is occurring in California, eastern Oregon and Washington, and in the interior of Canada. The mountain pine beetle has been the biggest culprit in vast areas of overmature lodgepole pine. Other insects include the western pine beetle, Douglas-fir tussock moth, western spruce bud worm and the Douglas-fir beetle. In California, dead and dying trees comprise several times the allowable cut, and most timber sales involve salvage logging. Large fuel build-ups have created some devastating fires.

FOREST RESIDUE MANAGEMENT

In Canada, there are several factors contributing to increased logging residue at the landing or along roads. First, there are more burning restrictions around recreational areas. Second, the licensee now has unlimited liability for fires. Third, there is no tolerance on wood waste left on logging sites. As a result, a greater amount of logging slash is brought to the landing to reduce the need for burning and encourage more complete wood utilization.

Similar situations are occurring in the western region of the U.S. In California, there is still a strong demand for wood fuel at electric generation facilities. Research studies at UC Davis continue to address methods for gathering logging residue. Site preparation money could be used for collecting the residue if other practices such as burning were not required.

The Department of Forest Engineering at Oregon State University and several interested industry representatives are pursuing the organization of a Forest Residue Management Co-operative to provide an efficient and cooperative approach to the investigation of alternative forest residue management techniques.

NEW EQUIPMENT AND LOGGING METHODS

The following small yarders are being introduced in the west:

Skylead C-40-16,000, Enderby, B.C.

40' tower	3 guylines
3/4" skyline, 1700'	116 hp Cummins diesel
1/2" mainline, 2200'	
1/2" haulback, 4500'	

Different carrier options are available: truck, skidder, or tailer. The first yarder was sold in the U.S. to Tim Wozich, Pleasant Hill, Oregon.

Koller 501; Distributed from Portland, OR

33' tower	4 guylines
3/4" skyline, 1640'	112 hp Cummins diesel
1/2" mainline, 1965'	

Trailer mount. The first yarder was sold in the U.S. to Bob Mahon, Corvallis, Oregon. There is also one 3 drum Koller (K 303) working in the Hoquiam, Washington area. The haulback drum has 1850 ft of 3/8 in. haulback.

Thunderbird, Ross Equipment, Eugene, OR

Their small yarder is scheduled to be introduced in August, 1991. The yarder is a self-propelled side mount design.

40' tower (50' option)	7/16" haulback, 4200'
3/4" skyline, 2000'	4 guylines
1/2 mainline, 2200'	176 hp Cummins diesel

The following multispan mechanical slackpulling carriages are being introduced:

Maki (Mini-Mak II), Pierce, Idaho

9 hp gas motor
skyline and mainline radio controlled clamps
weight approx. 1250 lbs
skylines from 1/2" to 1"
mainline less than 3/4"

Eagle (The Eaglet), LaGrande, Oregon

9 hp diesel motor
skyline and mainline radio controlled clamps
weight approx. 1200 lbs
skylines from 3/4" to 7/8"
mainline from 1/2" to 5/8"

Over the past year, there has been a growing interest in mechanized logging systems. In the intermountain region, there is a steady shift toward more Timbco or Timberjack feller-bunchers and stroke boom delimbers. Several Forest Service sales have been sold in Montana and northeast Washington for the harvester-forwarder systems. In Oregon, Valmet and Timberjack-FMG have been conducting field demonstrations of their equipment.

On the west coast of Canada, cable yarding methods are shifting away from short distance grapple logging toward long-line yarding. There is some interest in mechanized tree processing on cable landings. Long span yarding with large mechanical slackpulling carriages is common on the west coast of Oregon and Washington. In the intermountain region, planning for decreased road densities and longer yarding distances is increasing the need for intermediate supports with mobile yarders. Loader logging (shovel logging) is also being practiced to a greater extent. Loaders are typically prebunching logs to skid trails.

FOREST ENGINEERING EDUCATION AND RESEARCH ORGANIZATIONS

Following is a breakdown of Forest Engineering students attending universities in the west.

At each university, there is generally an even spread of Forest Engineering students throughout the 4 year program. Contacts at all universities indicated that 1991 graduating seniors located jobs. Most jobs are with private industry and some jobs are temporary. Consulting firms are hiring some forest engineers to work on Environmental Impact Statement contracts with the U.S. Forest Service. There is a mixture of opinions on long term demand levels for college trained forest engineers. On one hand, there is a need for people with appropriate technical skills to meet future intensive management practices. On the other hand, there is uncertainty about the level of future timber harvesting.

University	Total Students in Forest Engineering Program	1991 Graduating Forest Engineers
Oregon State University[1]	42	10
University of Washington[2]	18	7
University of British Columbia	18	4
University of Idaho	12	1
University of Calif., Davis[3]	12	0
Humboldt State University[4]	15	2

[1] 29 students enrolled in FE graduate program.
[2] Only includes juniors and seniors because students don't declare a major until their 3rd year.
[3] Currently re-evaluating the FE program. Considering a more general title of the overall program and focus more on recruiting Ag Engineering students; FE would still remain an option.
[4] Production option. Reorganizing as College of Natural Resources and Science.

Two significant items regarding research organization are:

(1) Re-organization of the U.S. Forest Service PNW Harvesting Research Group with the Forest Engineering faculty at the University of Washington. This is the Forest Systems Engineering group that is comprised of 3 Forest Service employees and 4 University of Washington employees. Their research focus is on new technologies and new ideas. They work jointly with other groups such as the Long Term Ecological Research Group and the Streamside Research group.

(2) More formalized working relationship between University of British Columbia and FERIC on cooperative projects. There has always been a good working relationship and this has been recently strengthened. FERIC is also linking up operational studies with other general forestry studies (e.g. site impacts) and mill studies.

The next Skyline Symposium will be sponsored by the University of Washington and is planned for December, 1992. This past year there were no Western Regional COFE events.