Harvesting logistics: From woods to markets

Proceedings
July 1998

Papers for this proceedings were presented at the 1998 COFE conference on "Harvesting logistics: From woods to markets", held in Portland, OR, July 20-23, 1998. Printed directly from author-prepared copies, these papers are without technical review. Individual authors assume responsibility for views expressed.

Peter Schiess
Finn Krogstad
Editors

Council on Forest Engineering

The 1998 symposium was hosted by the PNW region through the Washington State Department of Natural Resources (DNR), the University of Washington Forest Engineering Program (UW), IUFRO Section 3.06.00, Forest operations under mountainous conditions, and the forest industries of the PNW.

The symposium was structured around four days of technical sessions and field trips that provided the opportunity to view and discuss issues relating to the harvest, transport and manufacturing of timber and wood products.

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Determining Time as a Cost in Constructing Waterbars on Forest Sites in Vermont

Daphne Hewitt
Neil Huyler
Peter Hannah
Chris LeDoux

Abstract

Waterbars and other BMPs add a significant cost to a harvest. Costs of $15 to $20 per individual waterbar have been cited in literature. In this study, the time required to construct each of 191 waterbars on nine forest sites in Vermont was measured using a hand held 8mm video recorder. Stepwise regression was used to identify the impact of soil drainage, gradient, waterbar width and depth, stoniness of soil, machine horsepower, forester involvement and planned road on time taken to complete construction. Construction time varied from 25 seconds to 9 minutes 53 seconds, with a mean time of 2 minutes and 19 seconds. The model predicted a mean time of 2 minutes and 29 seconds. The dimensions of the waterbar had the greatest effect on time, and the horsepower of the machine used appeared to override moderate site conditions. This model accounted for only 21% of this variation, and there are evidently other factors influencing construction time that are not readily identifiable. Operator experience and construction method may be among the important factors. Using current machine rates of $65 per hour, average construction cost per waterbar is $2.68. This study provides the first field measurements of time required to install a waterbar, and methods used here may serve as a basis for planning future cost studies.

Keywords

water quality, forest practices, regulations, time studies, BMP's, cost, waterbars, acceptable management practices.

Introduction

Concern for quality of water in streams, rivers and lakes throughout the nation has increased in the past decade. Degradation of water quality occurs either directly from a point source such as an industrial plant, or indirectly from a non-point source such as land management activities. Since the early 1970s, individual states have thus taken measures to minimize the non-point pollution potential of forest management activities.

Water quality control programs, usually defined as Best or Acceptable Management Practices (BMPs or AMPs) are now implemented to some degree in all states (Cubbage, 1995; Ice et al., 1997; Vermont Department of Forests, Parks and Recreation AMP's, 1987). These practices may be voluntary or mandatory, and include activities that can be incorporated during the harvest to reduce runoff and soil erosion. Studies have shown that BMPs are among the most effective practices to reduce non-point source pollution during harvesting, but there is an added cost to implement them (Irland and Connors, 1994; Kochenderfer et al., 1997). Estimates of average total costs for combined BMP practices have been assessed through surveys and interviews, and range from around $8 per acre in lowland areas, to around $30 per acre in the mountains (Cubbage and Lickwar, 1991; Shaffer et al., 1997).

In studies of unit costs for individual BMPs investigators found waterbars cost from $15 to $20 each, based on loggers' estimates of the time involved in their installation (Cubbage and Lickwar, 1991; Lickwar et al., 1992; Shaffer et al., 1997). Dollar values however, are subject to inflation and cannot be meaningfully applied to different situations in the future. In Vermont, skid trail drainage structures (waterbars, broad based dips and culverts combined) have been estimated at $18.51 per acre, based on literature and interviews with loggers (Huyler and LeDoux,1995).

Because of the time value of money, a measure of average time to construct an individual waterbar or other control measure would be a useful expression of the cost. There is virtually no published data on the time taken to install waterbars. A literature review by MacMath (1994) highlights the need to better assess actual construction costs through direct field observation. Information thus derived would enable loggers and landowners to better assess the cost of AMPs, and to factor them into harvest plans using appropriate dollar rates.

The principle objective of this study was to measure the time required to install individual waterbars on skid trails and truck roads on typical logging sites in Vermont. A further objective was to develop a table for determining cost of waterbar construction that an operator or forester could use when estimating operation costs on a timber sale. The hypothesis in this study is that by using regression methods, a model could be developed to predict construction time from quantifiable site variables.

Methods

Site Selection

During the summer of 1997, nine harvesting sites in Vermont were identified by contacting foresters and loggers involved with active jobs. Site visits were made when operators planned to construct waterbars. Measurements were usually made at the end of a job or section of a job, as roads and skid trails were closed up. While temporary waterbars may be installed at any time, those waterbars put in at closure are constructed with long term durability in mind, and thus likely to cost more.

Site selection was also based on logistic feasibility, and representation of typical situations encountered in Vermont. A range of slopes was desired and this was taken into account during site selection. The nine sites ultimately selected were primarily located in central Vermont. Soil conditions did vary between sites, but most soils were well drained.

Data Collection

At each site, time to construct each waterbar was recorded using an 8mm hand held video recorder with a built in clock that recorded time in minutes and seconds. The operator was followed throughout the entire process of putting in waterbars. Construction time was counted from the moment the machine blade was lowered into position at a waterbar location, to the moment the machine moved to the next location. After the site visit, times were transcribed from the tape and cycle elements identified as: construction time; rest; and travel time between waterbars.

After each waterbar was constructed, microsite variables were measured. Variables selected were based on likelihood of affecting the time taken to construct a waterbar, and ability to be measured easily and reliably in the field (Table 1).

Data Analysis

Mean, minimum and maximum values, standard deviations and distributions were determined for each variable. A natural log (log e) transformation was performed to achieve normal distribution of construction time, width of waterbars, travel time and distance drained by each waterbar.

Waterbars were constructed on eight sites with a bulldozer, and on one site with a skidder. A one-way analysis of variance (ANOVA) indicated no significant difference between the two machines used ($P > .05$), and the data was combined for further analysis.

The variables waterbar depth, waterbar width, machine horsepower, slope, forester involvement, stoniness, future use of road and soil drainage were used in a stepwise regression model to evaluate their effect on time.

Results and Discussion

The time in minutes and seconds to construct 191 individual waterbars was measured. Measures on 160 were used in the final statistical analysis. Owing to special features, the remaining 31 waterbars were analyzed separately.

The mean time required to complete an average waterbar was 2 minutes and 19 seconds. Time values ranged from 25 seconds to 9 minutes 53 seconds. Slope of the road above the waterbar ranged from 5 to 25 % (Av. 21%). Waterbars ranged from 7 to 30 inches (Av. 17.3 inches) in depth, and from 10 to 60 feet (Av. 22.4 feet) in width. Foresters were involved in marking the location of the waterbars in 70% of the cases. Future recreation use of the logging road or skid trail was planned in 90% of the cases.

Eight variables were used in a stepwise multiple regression analysis to test their relationship with time required to construct a waterbar, five of which were retained in the final model. The following equation best describes the relationship between time and the independent variables:

$$\text{Log e Time} = 2.82 + 0.56\ (\text{Log e waterbar width})\ (\text{ft}) - 0.01(\text{machine horsepower}) + 0.04\ (\text{waterbar depth})\ (\text{in}) + 0.46\ (\text{future road use}) + 0.22\ (\text{soil drainage}).$$

(R square = 0.21)

The regression equation may be used to calculate predicted time required to install a waterbar when values for other variables in the relationship are known. For example, using mean values of variables for the nine sites in this study, average predicted time can be calculated as:

$$\text{Log e (Time)} = 2.812 + 0.56\ (\text{Log e } 22.4) - 0.01\ (71) + 0.04\ (17.3) + 0.46\ (1) + 0.22\ (0)$$

$$\text{Log e (Time)} = 4.995$$

Time = 2 minutes 29 seconds.

Residuals from the model were plotted against each continuous variable, and homogeneity of variance verified, indicating the model is appropriate. This model however, accounts for only 21% of the variation in construction time. Other factors are obviously influencing the time required to construct a waterbar, which are not easily identified and may not be readily quantifiable. Such factors may include quality of equipment, other site variables, variation between individual operators, and variation in operator experience with waterbar construction. Methods for constructing waterbars are not standardized, and this may affect efficiency and required time.

Results of this study do allow an assessment of the relative impact of the variables measured. Dimensions of the waterbar - width and depth, and machine horsepower had the greatest effect on construction time. Site characteristics such as slope and stoniness of soil, initially expected to be significant, were among the least important.

Table 1. Independent variables recorded on harvest sites in Vermont in the construction of waterbars

Variable	Description
Continuous Variables - measured during construction of waterbar	
Time	Time taken to construct waterbar (seconds)
Slope	% of slope along road above each waterbar from the waterbar ridge above, as appropriate.
Waterbar width	Width of waterbar (feet)
Waterbar depth	Average depth of waterbar (inches). Measured from the top of the mound to the bottom of the ditch at three points along the bar
Horsepower	Horsepower of machine used for construction
Distance drained	Length of road drained by waterbar (feet) along the slope to the bar above or the drainage break, as appropriate
Travel time	Time taken to reach waterbar from bar above (feet)
Categorical Variables - site characteristics	
Stoniness	Stoniness of soil, ordinal value to note if stones, rocks, or ledge comprised>50% of soil at site=1 <50% = 0
Forester	Forester involvement, waterbars marked by a forester = 1, determined by machine operator = 0
Soil drainage	Presence = 1 or absence = 0 of standing water in the immediate area at time of waterbar construction
Future road use	Intended future use of the road, recreation = 1, no future use = 0

The merits of this method of predicting construction time is that it takes into account a number of site and structural variables that can be easily measured in the field. Different values can be substituted in the equation according to each individual situation. It does require the width and depth of the waterbar to be known or estimated beforehand however, and the factors that influence the dimensions are not clear. Loggers may decide on the width of the waterbar according to site and soil conditions, or it may be determined by road width. Depth of the waterbar may be related to soil conditions or future road use. Further examination of the relationship of structural dimensions of the waterbar to site characteristics may clarify this.

The wider and deeper the bars, the longer the time required to construct a waterbar. The number of forward and backward repetitions required to construct each waterbar was not counted during this study, but could be the focus of further time and motion studies.

As machine horsepower increases, the time to construct a waterbar decreases. It appears that the power of the machine might override site characteristics such as stoniness of soil, or steepness of slope. Site conditions in the study were considered to be moderate, and extremely steep or rocky conditions may reduce machine operability and increase the time required to complete construction.

When recreation use of the road is intended, construction time is increased. Operators were observed shaping and packing down the earth mound at the lower end of the waterbar to stabilize it and make it better able to withstand recreation activities, such as mountain bikes and off-road vehicles. Packing the waterbar was not factored into this study, but it is possible that this influences the variation in construction time.

The presence of standing water in the immediate area surrounding the waterbar resulted in a longer time to complete construction of the bar. Operators may take additional time to plan the drainage of a saturated area, efficiency is reduced in wet conditions, or a wider bar may be required to drain the area.

The final answer desired by loggers and harvest planners is the actual dollar cost to construct a waterbar or other AMP measure. In this study, the mean predicted time taken to install waterbars on harvest sites in Vermont is 2 minutes and 29 seconds. If current average contractor charges for bulldozer use are $65.00 per hour, then the average cost per waterbar is $2.68. This is considerably less than the unit costs for waterbars of $15 to $20 cited in other studies (Cubbage and Lickwar, 1991; Lickwar et al., 1992; Woodman and Cubbage, 1993; Shaffer et al., 1997). Past studies relied on logger estimates of the time dedicated to BMP construction whereas this study takes actual field measurements of the construction time required.

This study indicates that the slope of the road does not significantly affect the time required to complete an individual waterbar but does affect the distance required between waterbars. Taking slope and number of waterbars into account, an estimate of the cost of waterbars required per 1,000 feet of logging road can be determined (Table 2).

Time Taken to Travel Between Waterbars

Additional results from data measured in the field may also be significant when considering the total cost of installing drainage structures. In this study, the time taken to travel to each waterbar, and the length of road drained by the bar, was measured. In a stepwise regression analysis the added effect of slope and machine horsepower were tested for impact on travel time. Linear relationships were found, but the regression model accounts for only 15% of the variation in time, so there are clearly other factors influencing time spent travelling between bars.

From the regression model, it takes around 1 minute to travel 100 feet during waterbar construction. In this study, the average distance between waterbars was 73 feet, requiring 44 seconds travel time. At $65 per hour, it would cost an operator $0.79 to travel to a waterbar, thus including travel time increases average cost of construction from $2.68, a total cost of $3.47 per waterbar (Table 3).

Table 2. Costs to install waterbars based on the spacing recommendations in the AMP guidelines for maintaining water quality on logging jobs in Vermont, using calculated cost of $2.68 per waterbar

Road grade (%)	Distance between waterbars (ft)	# waterbars per 1,000 feet of road	Cost of waterbar installation per 1,000 ft. of road ($)
1	400	2.5	6.70
2	250	4.0	10.72
5	135	7.4	19.83
10	80	12.5	33.50
15	60	16.7	44.76
20	45	22.2	59.50
25	40	25.0	67.00
30	35	28.6	76.65
40	30	33.3	89.24

Special-Case Waterbars

A number of the waterbars observed were made to meet recreational or aesthetic requirements and were not included in the main analysis. At one site, the landowner planned extreme recreation use of the road while maintaining aesthetic quality. The average time to construct these waterbars was 19 minutes and 27 seconds. More time is required to shape and pack the waterbar to meet the landowner's standards.

In another group of waterbars, logs were incorporated into the structure as reinforcement. This involved felling, de-limbing and dragging a tree across the road, and packing earth around it to form the mound of the waterbar. The average time to construct these waterbars was 16 minutes and 2 seconds. The additional activities required to build waterbars of this type add significantly to the time taken to complete construction.

These special cases represent the extremes in costs to construct a waterbar to meet aesthetic or long-term functional requirements. A landowner can potentially expect to pay more, possibly reflected in a slightly lower price paid for the timber removed.

Conclusions

This study shows that on average it takes around 2 minutes and 19 seconds and costs $2.68 to install a waterbar on harvest sites in Vermont. Horsepower of the machine used, and dimensions of the waterbar are the most significant variables affecting construction time. Other factors that may influence construction time but are not readily quantifiable include daily variation in human response, operator experience with the equipment used, operator efficiency, and possibly other site characteristics. The data indicates that the methods chosen by the logger for installing waterbars may be highly significant.

Motion studies could be used to break down waterbar construction into its component activities, thus potentially enabling a standard method to be identified. Time and motion studies together comprise the most accurate methods for assessing the time required to complete a task such as waterbar construction.

Table 3. Combined costs of waterbar installation and time to travel to bar, using calculated cost of $2.86 per waterbar*

Distance between waterbars (ft)	Predicted time to travel between bars (minutes/seconds)	Additional cost per bar for travel time ($)	Combined installation and travel cost per bar ($)	# Waterbars per 1,000 ft of road	Combined total cost per 1,000 ft of logging road ($)
400	4.1 min	4.41	7.09	2.5	17.73
250	2.55 min	2.76	5.44	4.0	21.76
135	1.38 min	1.49	4.17	7.4	30.86
80	48.89 sec	0.88	3.56	12.5	44.50
60	36.67 sec	0.66	3.34	16.7	55.78
45	27.50 sec	0.49	3.17	22.2	70.37
40	24.48 sec	0.44	3.12	25.0	78.00
35	21.39 sec	0.38	3.06	28.6	87.52
30	18.34 sec	0.33	3.01	33.3	100.23

* The number of waterbars per 1,000 ft of road follows the spacing recommendations in the AMP guidelines.

Measuring the time taken to construct a waterbar allows appropriate dollar costs to be applied for economic analysis at any time in the future. Past studies have expressed AMP costs on a per acre basis. Expressing costs of waterbars per unit road length instead of per acre may be a more accurate assessment for each site.

This study provides the first field measurement of time required to install waterbars. Further studies could refine the methods used here to obtain more accurate estimates of construction time for waterbars on harvest sites.

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Author Affiliation

Daphne Hewitt, graduate student, University of Vermont, School of Natural Resources, Burlington, Vermont.

Neil K. Huyler, research forester, USDA Forest Service, Northeastern Research Station, Burlington, Vermont.

Peter Hannah, professor of forestry, University of Vermont, School of Natural Resources, Burlington, Vermont.

Chris LeDoux, supervisory industrial engineer, USDA Forest Service, Northeastern Research Station in Morgantown, West Virginia.

A Method for Visual Assessment of Soil Disturbance Following Forest Operations

Michael A. Thompson
James A. Mattson

Abstract

A method to visually assess soil disturbance resulting from forest operations was developed. The method relies on three levels of assessment (with an associated height or depth measurement for some disturbance categories) and is considered an improvement over currently used methods. The first level of assessment defines what is visible on the soil surface (e.g. litter, slash, rock, etc.). The second level of assessment attempts to answer the question "What happened here? (e.g. undisturbed, trafficked, etc.). The third level of assessment attempts to identify larger features of the site (e.g. road, landing, stream, etc.). Associated measurements include depths of rutting or gouging and heights of mounding or covering. The system provides flexibility in assessment and analysis, allowing for categories to be combined to align with most other systems. Commonality of assessment practices is considered important to long-term and widespread usefulness of site disturbance information.

Keywords

evaluation methods, site disturbance, soil displacement, forest operations

Introduction

Active management of forest ecosystems normally requires physical manipulation of the vegetation and/or soil on the site. This work, commonly referred to as forest operations, is often performed by heavy equipment to ease the physical strain on workers, improve productivity of the work, and lower costs of treatment. Heavy equipment operating on the site will have varying levels of impacts on the soil and remaining vegetation. Some of these impacts are an integral part of what the machine is designed to do when fulfilling the treatment objective while many are an unavoidable result of operation.

For example, a scalping implement is designed to expose mineral soil for planting or seeding. While scalping, the carrier machine may be compacting the soil, crushing low vegetation, rutting the soil, dotting the site with oil and gas spills, and releasing products of combustion into the atmosphere. The most severe impact (scalping) is desirable, at least to the point that it doesn't create undue erosion. Compacting soil and crushing low vegetation are usually considered a negative impact, but may actually improve the performance of desirable regeneration in the scalps by reducing competition with other undesirable vegetation. Soil rutting, also considered a negative impact, can improve growth on some sites by storing water on dry sites or by providing drainage on wet sites. Fuel spills and air pollution from equipment are always considered negative effects.

Therefore, a possible framework within which to think of the effects of forest operations on the site is; 1) are the effects intended or unintended relative to the objective of operation?; and 2) are the effects desirable or undesirable relative to the objectives for managing the site? Desirable effects should be maximized while undesirable effects should be minimized. Whether or not an effect is deemed desirable or undesirable will depend on many factors, of which site characteristics and management objectives are especially important.

Assessing the effects of forest operations on the site is an important first step in evaluating the significance of impacts on the health of the forest ecosystem. Some effects can be determined visually while others cannot. The purpose of this paper is to present a method we developed to assess site effects (does not include damage to the remaining vegetation) from forest operations that can be reasonably ascertained visually. The method can be used with both line transect or point sampling techniques.

Visual Methods for Site Disturbance Assessment

A good methodology for visually assessing the effects of forest operations on the site is critical to properly assessing their extent and importance. A good evaluation system or method has the following attributes (Thompson et al. 1997):

Accurate - The system should provide an accurate description of the physical effects that actually occurred as a result of the forest operation.

Consistent - Measurements should be objective so that they can be consistently and repeatedly applied by different observers.

Easy to apply - The system should be reasonably fast and easy to apply to minimize the cost of data gathering.

Provides useful information - It should provide useful and appropriate information for developing a clear picture of direct and possible indirect effects.

Statistically valid - It should provide methods and measurements that are statistically valid.

Visual methods for assessing site disturbance rely on the ability of the observer to visually evaluate disturbance categories along a line or at a point. Systems used to evaluate disturbance are many and varied. Dyrness (1965) used the following:

Undisturbed - Litter in place, no evidence of compaction.
Slightly disturbed - Three conditions fit this class:
  a. Litter removed and undisturbed mineral soil exposed;
  b. Mineral soil and litter intimately mixed, with about 50 percent of each;
  c. Pure mineral soil deposited on top of litter and slash to a depth of 2 inches.
Deeply disturbed - Surface soil removed and the subsoil exposed; the soil surface is very seldom covered by litter or slash.
Compacted - Obvious compaction due to the passage of a log or mobile equipment.

A number of other researchers have either used this scheme or expanded on it slightly. Bockheim et al. (1975), Miller and Sirois (1986), Sidle and Laurent (1986), Reisinger et al. (1992), and Aust et al. (1993) all generally followed these categories.

Martin (1988) expanded the classification to ten categories as follows:

- Undisturbed - No visual disturbance of any type.
- Depressed - Forest floor not disturbed laterally, but depressed by equipment or by a falling tree.
- Organic scarification - Forest floor disturbed laterally, but no evidence of compression by wheels, tracks, or falling trees.
- Mineral scarification - Removal of the organic horizons but no disruption of the mineral soil.
- Organic mounds - Mounds of soil, still covered by organic material.
- Mineral mounds - Mounds of mineral or organic soil covered by mineral soil deposits.
- Organic ruts - Shallow wheel or track ruts within the organic horizons or deep compression ruts still lined with organic soil.
- Mineral ruts - Wheel or track ruts in mineral soil.
- Dead wood - Stumps or logs in contact with the soil, or slash too dense to allow for evaluation.
- Rock - Bare rocks larger than 10cm.

Turcotte and Smith (1991) used a similar scheme of nine categories, but grouped the categories into 4 consolidated categories as follows:

- Slash
- Intact forest floor
  - Undisturbed
  - Organic mound
  - Organic rut
- Bare mineral soil
  - Mineral scarified
  - Mineral mixed
  - Mineral mound
  - Mixed side rut
- Mineral ruts

McMahon (1995a) used a detailed classification scheme, distinguishing between fifteen disturbance types grouped into five classes as follows:

- Undisturbed
- Shallow disturbance.
  - Litter in place
  - Litter removed, topsoil intact
  - Litter and topsoil removed
  - Topsoil deposited on litter
- Deep disturbance.
  - Topsoil removed, subsoil exposed
  - Erosion feature
  - Subsoil puddling
  - Rut 5 to 15 cm deep
  - Rut 16 to 30 cm deep
  - Rut >30 cm deep
  - Subsoil/baserock deposit
- Slash cover
  - 10 to 30 cm deep
  - >30 cm deep
- Non-soil

The classification systems presented here serve to illustrate the amount of variation that exists between systems in common use. Many other classification schemes not presented here have also been used. The system used to classify disturbances will ultimately determine whether or not the results will be comparable to other results. Therefore, to ensure comparability of results, a standard classification system is needed for documenting soil disturbance due to forest operations.

In a previous paper (Thompson et al. 1997), we recommended the use of a disturbance classification system similar to that used by Martin (1988). After more deliberation and field trials, we have developed a somewhat different system that we feel is an improvement over other methods currently used. The method consists of three levels of assessment that answer three main questions. These are:

1) What is visible on the soil surface?
2) What happened here?
3) Is this part of a larger feature in the landscape?

Each question corresponds to an evaluation column in the scheme as shown in Table 1:

Table 1. Site disturbance assessment system

Visible Layer	Evaluation	Feature
Litter	Undisturbed	Main Trail
Organic Soil	Trafficked	Secondary Trail
Mineral Soil	Scarified	Skyline Corridor
Muck	Gouged-depth	Landing Area
Slash	Rutted-depth	Decking Area
Stump	Mounded-height	Service Area
Rock	Covered-height	Road
Water	Unknown	Stream, Pond, Marsh

Visible Layer

The visible layer defines what is on the soil surface at that point. Litter is the largely undecomposed organic debris, such as leaves, twigs, and other plant remains, that covers most forest soils. Organic soil is defined as the uppermost soil layer just below the litter containing largely decomposed organic matter (humus and O horizons) and is generally darker in color than the mineral soil below. Mineral soil is defined as the soil layer just below the organic soil composed of material of predominantly mineral origin (A and B horizons). If litter, organic soil, or mineral soil are mixed, the point is classified as the predominant component of the mix. Muck is completely saturated richly organic soil. Slash is woody debris covering the soil surface that is too thick to allow classification of what happened to the soil at that point. A slash designation is only used if the observer cannot see the soil surface beneath the slash to evaluate it. Stumps are only classified as stumps when remaining in place. If a stump has been uprooted from the ground and the soil surface cannot be evaluated beneath it, it should be classified as slash. Rocks and stumps are usually considered undisturbed because driving or dragging things over them does not affect site quality in general. Water should only be recognized if it is a permanent or semi-permanent feature of the landscape (i.e. vernal pond, intermittent stream, etc.). Occasional puddles should not be considered water. Different layers should only be recognized if measuring 30 cm across or larger. Measurements should be taken to the nearest 10 cm along transects (if used) and to the nearest 3 cm for a height or depth measurement.

Evaluation

This column is an evaluation of what happened to the soil surface at the point in question. Undisturbed means nothing happened. Trafficked means there is evidence that the tires or tracks of a machine passed over the soil surface. Scarified means there is evidence that something was dragged across the soil surface with no associated trafficking. Gouged means there is evidence the soil layers were gouged by something other than the tires or tracks of a passing machine. Rutted means there is evidence of ruts caused by the passage of tires or tracks of a machine. Mounded implies disturbance of the original soil layers into a mound and is normally found adjacent to ruts. Covered implies no disturbance of the original soil layers, only a fresh layer of disturbed soil on top (normally found adjacent to a gouge). Unknown is a designation that should only be used in conjunction with slash because this is the only case where the observer will not be able to evaluate the soil surface. The only other evaluation that should be used with slash is trafficked if there is clear evidence that the slash over the soil surface had been trafficked. The hole left by an uprooted stump should be considered a gouge.

Feature

This is a less important part of the classification scheme used to evaluate larger features in the landscape and their relative abundance. Any major feature of interest on the site could be added to this list, or this column could be disregarded.

Discussion

The system we have proposed for classifying site disturbance from forest operations has several advantages. We feel that the system provides an appropriate classification for the full range of visible site effects. We feel the system will be easy to reproduce by different observers because the evaluations of what remains on the soil surface and what happened to produce these effects are separated and less subjective than some other systems in use. The system can be used with any of the commonly used sampling methods, such as classifying single points (e.g. Dyrness 1965), the small area around a point (e.g. Gingras 1994), the lengths of intersecting line segments (e.g. Howes et al. 1983), or the intersecting area a fixed distance to both sides of a transect (McNeel and Ballard 1992). We feel this system provides good flexibility by combining a high level of detail with ease of use and reproducibility.

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Predictors of bearing capacity of forest access roads with peat subgrades, under changing weather conditions

M. J. O'Mahony
A. Ueberschaer
P. M. O. Owende
S. M. Ward

Abstract

Forest access roads with peat subgrades are extraordinarily weak, hence, exhibit fast and severe deterioration on overloading, leading to expensive repair and maintenance. Consequently, there is a need to develop methods with which pavement strengths may be predicted to allow strategic control of the axle loads of timber haulage vehicles. This paper evaluates the significance of depth of peat in the pavement subgrade as a potential approach to resolution of this problem. Results of investigations on a typical peat-based road located in County Mayo, in the West of Ireland, are presented.

Pavement strength was assessed on the basis of deflections measured by a Benkelman beam, in three series of experiments that were also designed to evaluate possible influence of weather conditions. The results were subsequently analyzed in linear and non-linear (quadratic) regression and correlation analyses. It was found that the correlation was mainly quadratic, and pavement surface deflection is expected to increase with depth of peat in the subgrade at a reducing rate and getting to a constant at specific depths of peat, which is in agreement with the theory of pavement loading by wheeled traffic. Measured deflections were in the 0.5-10 mm range, and were lower for frozen pavements. The predicted maximum in the regression models was evaluated to be 7 mm for specific depths of 2400 mm and 2700 mm. Corresponding coefficients of determination varied from 0.63 to 0.66, indicating that the significant source of variation (63%-66%) was the inherent thickness of peat in the subgrade.

Depth of underlying peat can therefore be used to set load restrictions, or axle load limits for logging operations through such pavements. The measured deflection suggest that the commonly used deflection and strain based empirical strength indices are not always applicable for pavements with peat subgrades. However, there was also evidence to suggest the existence of a 'critical' depth of peat, which may limit deflection to rationalize their use. Unfortunately, this depth was influenced by the prevailing moisture regime. There is need therefore, to develop independent

indices for weak flexible pavement such as those with peat and other soft soil subgrades.

Introduction

Over one-seventh of the land-surface in the Republic of Ireland is covered by Peat (Gallagher, 1982), a non-homogeneous deposit of partially decomposed vegetable matter saturated with water (Galvin, 1976). The organic nature and high degree of dispersion characterize peat as having elastic-viscous-plastic properties. As a system with highly mobile components (water and dispersed solids), a peat bed is very sensitive to mechanical pressure, leading to a reduction in the water potential and deformation (Solopov *et al.*, 1968). Its deformation modulus decreases with water content, and increases with the degree of decomposition. Consequently, there are variations in deformability, bearing capacity and stability of peat soil foundations under varying weather conditions and time frames. These present a considerable challenge to the maintenance of serviceability of roads constructed over peat.

There are about 92000 km of public roads in the Republic of Ireland, twelve per cent of which are laid over peat subgrades. In respect to strength, a strong sub-grade has a California Bearing Ration (CBR) of 15-30% (County and City Engineers Association, 1988). Roads with peat subgrades have CBR of 2 to 4%, which indicates their inherent weakness. Such roads may loose their shape during usage, and with cumulative repairs, they are eventually unable to bear loads commensurate with their design capacities (Hampson, 1993). Excavation to more stable materials such as rock, gravel or clay is therefore usually recommended when the peat layer is deeper than 1500 mm (Department of Environment, 1978). However, in many cases this is deemed impractical and uneconomical, and the recommendation is observed only when constructing major National Roads or other critical structures. Minor roads often are laid directly upon peat because of restricted financial budgets, an option that is recompensed with extremely poor performance, and can at worst cause total subsidence of the roads (Gallagher, 1982).

Forests in the Republic of Ireland are predominantly established on peat soils, which are unsuitable for the production of agricultural crops. Access roads with peat subgrades therefore, have to be used in general forest management and during logging operations. Haulage of large loads of timber and the movement of other heavy machinery peculiar to forestry operations lead to their rapid deterioration. This imposes expensive repair and maintenance costs, hence, makes transportation a costly factor in the overall timber production process (COFORD, 1994), while the local road users are also aggravated. Consequently, a simple and effective assessment of their future serviceability, for routing timber extraction and related forestry operations, facilitates a rational approach to minimizing the damage.

Any pavement maintenance policy should have a model of the relationship between pavement life, as indicated by some measure or rating of its structural condition, and applied loads (De Pont and Pidwerbesky, 1994). An accepted method of assessing pavement strength (Kennedy and Lister, 1978; Hunter, 1994), is the measurement of its transient deflections under a standard load. The technique allows identification of weak sections of a road network, to enable restoration before the structural integrity is seriously impaired.
The objective of this study was therefore to investigate the significance of the depth of peat as a potential predictor of bearing capacity of pavements with peat subgrades, and the influence of weather conditions on the magnitude of transient deflection.

Methodology

Site description and experimental layout

The 4.2 km long experimental road, was located in County Mayo on the West of the Republic of Ireland, running between Longitude 9° 35' W and Longitude 9° 50' W and adjacent Latitude 53° 45' N. The section considered was flat over a distance of 700 m on the 110 m contour, gradually ascending to 220 m over 1600 m, then following the 220 m and 240 m contours over 1900 m.

The road consisted of a crushed limestone base of thickness varying between 150-220 mm and sealed with 5 mm thick bitumen layer, a sub-base of sandy gravel of thickness between 220-300 mm, and a subgrade of blanket peat (850-2750 mm) and clay (O'Mahony and Owende, 1998). Based on the constituents, it was classified as a flexible pavement (Croney and Croney, 1991). It provided the only access to the adjoining forests, hence, it was assumed that the entire stretch had been exposed to similar traffic. After its initial construction in the later half of 19th century, the road had been strengthened in some sections and also resurfaced in patches, after damage had been incurred from haulage of timber in 1989 and 1996.

From the history of the experimental road, visual pavement characteristics and road drainage conditions varied over the selected section. Depths of the strata of the underlying peat and conditions of the road drainage also varied considerably over its 4.2 km length. Six separate blocks considered as independently homogeneous and including sections with and without evidence of previous repair or restoration, were selected and marked out. The experimental section was marked at 100 m intervals, and at every 10 m within each block for data-points. Details of the experimental pavement are provided in Table 1.

Table 1: Details of the experimental road (O'Mahony and Owende, 1998). The moisture content (MC), shear strength, and penetration resistance of the subgrade were measured in the first series of experiments

Block	MC, %d.b.	Shear Strength, kPa	CI, kPa	Depth of road layers, mm		
				Base	Sub-base	Peat subgrade
A	590	7-30	280	220	300	1570-2100
B	625	17-38	280	200	300	1200-2750
C	340	22-29	400	160	220	0-1250
D	550	17	200	150	250	1000-1900
E	550	17	200	150	250	1100-1700
F	340	21-29	420	160	220	0-1000

Equipment description, test procedures and data analysis

Pavement construction was verified by digging trenches at four different locations across the experimental road. Depth of peat was further measured at every data-point by probing the adjacent road embankment using a steel rod. The extent of cracking as a pavement condition was assessed by visual inspection, and classified according to Kennedy *et al.* (1978). The width of pavement and the embankment, depth of the drainage ditches and the level of water in them at respective data-points were also measured. Rut depth, which represents the permanent deflection of the road pavement, was measured using a 2 m straight bar placed transversely to the wheel-track. Rut depth was then measured using a calibrated wedge.

Pavement deflection was measured using a Benkelman beam (Kennedy *et al.*, 1978). Characteristics of the experimental truck that was used to impose deflections on the pavement are presented in Table 2.

Table 2: Vehicle specifications for pavement deflection measurement.

Specification	Recommended[†]	This study
Vehicle weight		
Rear axle load, kN	62.3	62.2
(kg)	(6 350)	(6 340)
Tire:		
Size (width x Ørim)	7.50×20 or 8.25×20 or 9.00×20	9.00×20
Inflation pressure, kPa	590	590

[†] Kennedy *et al.* (1978)

Measurements were taken on three different occasions to investigate the influence of weather. Initial measurements were taken in January of 1997, and subsequent measurements in March and July of 1997.

Correlation between measured deflection and depth of peat in the subgrade for the three series of experiments was investigated by simple linear and non-linear (quadratic) regression analyses. This was based on a hypothesis that depth of peat has a significant influence on the bearing capacity of pavements with peat subgrade. Lines of best fit for 95% confidence intervals were established.

Record of weather conditions

Weather data (Table 3), including amount of rainfall and temperatures over fourteen days prior to and during the days of measurement, was obtained from the Irish Meteorological Service. The temperature at the surface of the experimental pavement was also recorded.

Table 3: Weather conditions over two weeks prior to (Pre-test average) and during the experiments

	Pre-test average	Test Series 1 (January)	Pre-test average	Test Series 2 (March)	Pre-test average	Test series 3 (July)
Temperature, °C:						
Air	2	1	10	11	12	14
Soil (top 100mm)	2	2	10	11	11	16
Surface		-2		11		21
Rainfall, mm:	19	1	25	4	47	1
Days with < 0.05mm	10		2		4	

Results and Discussion

Pavement deflection

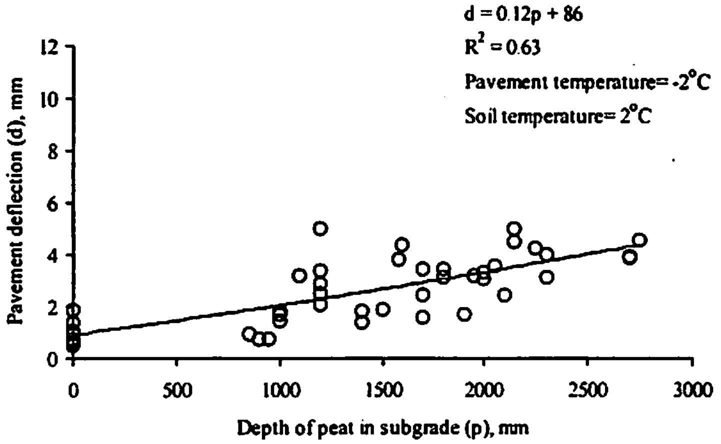
The results of the deflection measurement are presented as scatter plots in Figure 1. Deflection of the pavement surface almost doubled in March compared to January. It ranged from 1.78 mm to 3.36 mm, corresponding to increases of between 48% and 98%. The differences between the deflection data of March and July were statistically insignificant, ranging from 50-590 μm, equivalent to increase of between 1.4 % to 8.3%.

Effect of depth of peat in subgrade

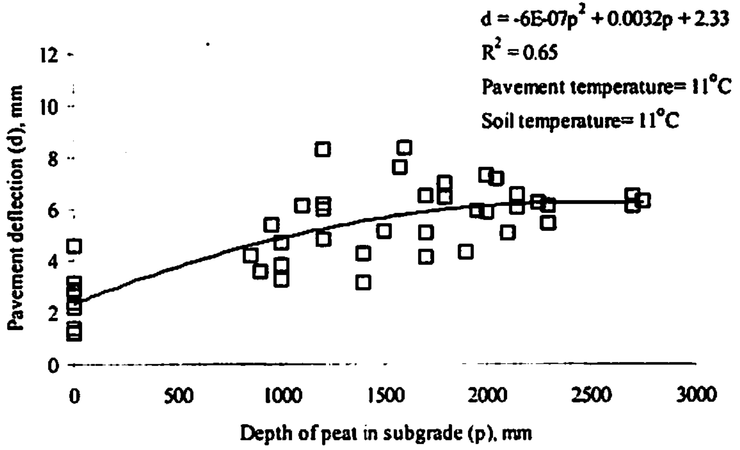
Regression curves and results of correlation for pavement deflection versus depth of peat in the subgrade are presented in Figure 1. Data for January 1997 was best described by a linear response function of deflection with increasing depth of peat in the subgrade (R^2=0.63), hence, higher deflections are expected for thicker depths of peat. Data for March and July 1997, depicted a quadratic response implying that pavement surface deflection is expected to increase with depth of peat in the subgrade at reducing rate, and getting to a constant at specific depths of peat. By differentiation of the response functions, this depth was estimated to be 2700 mm and 2400 mm for March and July respectively, with corresponding maximum deflection of 7 mm in each case. The latter observations are in agreement with theory of pavement loading by wheeled traffic (Douglas, 1987), where maximum stress due to surface loading is expected to reduce with increasing depth below the point of loading, as a quadratic function of depth. The deviation of the January data could be attributed to the frozen pavement surface (-2°C) when the measurements were taken.

For each series of data, significant variation in deflection may be attributed to the depth of peat in the subgrade. For example, the total variation in deflections that could be attributed to the depth of peat in the subgrade, in data for January, March and July 1997 were, 63%, 65% and 66% respectively. Closeness of the coefficients of determination suggests similar variation for independent moisture regimes, also evidenced in Figure 1.

(a) January 1997



(b) March 1997



(c) July 1997

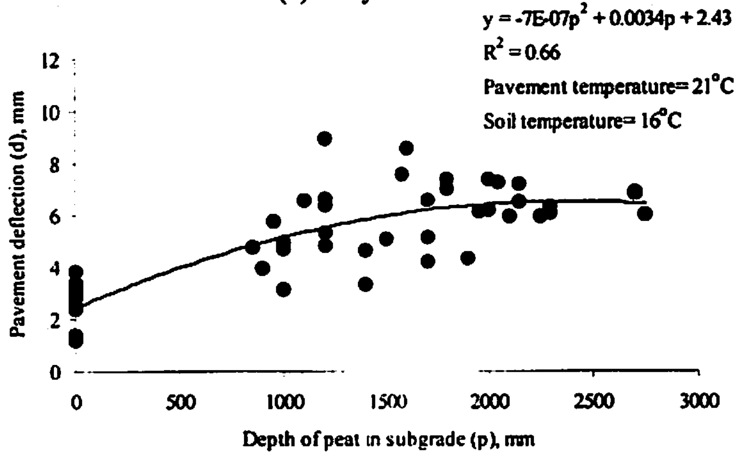


Figure 1: Regression and correlation analyses for deflection measurements for January (a), March (b) and July (c). The estimated maximum deflections for March and July was 7 mm in both cases, and corresponds to a depth of peat in the subgrade of 2700 mm and 2400 mm, respectively.

An earlier study on the same experimental pavement indicated that, for loads up to 10 tonnes per axle on a 'walking-beam' suspension, the deformation of the experimental pavement were predominantly within the elastic range (O'Mahony and Owende, 1998). The study also concluded that fatigue and vibrations rather than deformation or settlement, were important in the degeneration of this road.

Magnitudes of deflection ranging between 0.5- 10 mm were measured in this study. This suggests that the commonly used empirical strength indices (Kennedy and Lister, 1978), which are based on deflections of less than 2 mm may not always be justified for pavements with peat subgrades. However, observing the data for January 1997 (Figure 1a), there is evidence to suggest the existence of a critical depth of peat, which may limit deflection to rationalize their use. Unfortunately, results in this study also suggest that this depth is influenced by the prevailing temperature and moisture conditions. Consequently, there is need to develop independent indices for weak flexible pavement such as those with peat or other soft soil subgrades.

Effect of surface-dressing and partial pavement restoration

The cumulative secondary surface dressing and partial repairs on the experimental road, are evidenced by the thicker pavement base (200 mm) and sub-base (300 mm), for blocks A and B respectively (Table 1). Un-resurfaced sections (blocks C, D, E and F) had base and sub-base thicknesses of 150 mm and 220 mm, respectively. The effects of surface dressing and partial restoration on the strength characteristics of the experimental road, were investigated by comparing data for resurfaced and un-resurfaced sections. The results are presented in Table 4. The resurfaced or restored sections of the pavement had three times higher depth of peat on average (Table 4). The sections also experienced up to double the magnitude of deflection. The implication therefore is that, increasing the thickness of the base and sub-base in itself does not have a significant effect in reducing deflections, hence, roads with peat subgrades are prone to damage.

Effect of weather conditions and other predictors

Although the actual moisture content of the subgrade was not measured, comparison of data from the three experiments, *viz.* January, March and July 1997, indicate higher deflections under wetter weather conditions. For example, the mean pavement deflection for experiments in January (2.7 mm), was lower that for March (5.1 mm) and July (5.4 mm). The precipitation recorded (Table 3) for January, March and July was 19, 25 and 47 mm, respectively. The plots in Figure 1, depicted a similar variation, although January data was best fitted to a linear response function, an anomaly that may be attributed to the frozen pavement surface. For subgrades without peat deposits, the deflection approximately tripled over similar moisture variations (Figure 1). Since the measurements were replicated on exactly the same locations, the observed variations can only be attributed to the change in moisture and temperature condition in the pavement strata.

Table 4: Comparison of surfaced and un-resurfaced sections of experimental pavement. Equal means and unequal variance were assumed in testing the hypothesis that the sections were similar

Section	Depth of peat, mm (Mean ±SE)	Pavement deflection by series, mm (Mean ±SE)		
		January	March	July
Resurfaced	2002 ± 92	3.56 ± 0.18	6.34 ± 0.21	6.60 ± 0.21
Un-resurfaced	774 ± 118	1.84 ± 0.22	4.21 ± 0.35	4.36 ± 0.34

All the differences were significant at $p<0.05$

It is also known (Amaryan, 1993) that pore water pressure influences deformability, bearing capacity and stability of saturated soils such as peat. However, its variation was not recorded in this study, hence, further experiments are necessary to elaborate on this observation.

Other predictors, including the level and size of the drainage ditches, including the volume of flow at the time of measurement, were not significant.

Conclusions

Depth of underlying peat is a reliable predictor of the bearing capacity of roads with peat subgrades. It could therefore be used to set load restrictions, or axle load limits for logging operations through such roads.

There is a critical depth of peat to limit excessive pavement deflection, hence, allow the use of the common serviceability indices for management of pavements with peat subgrades. However, it is affected by temperature, and the prevailing moisture regime in the subgrade. Due to limiting results from this study, a generalization of the impact of weather conditions requires sensitivity analysis for the supportive strata.

Acknowledgement

This study was supported by the National Council for Forest Research and Development (COFORD) and the Irish Forestry Board (*Coillte Teoranta*).

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Authors' Affiliation

Forest Engineering Unit, Department of
Agricultural and Food Engineering,
University College Dublin,
Earlsfort Terrace, Dublin 2,
IRELAND
Tel.: 353 1 7067418
Fax: 353 1 4752119
e-mail: forest.eng@ucd.ie

Traffic Patterns and Site Disturbance

Tim McDonald
Emily Carter
Steve Taylor
John Torbert

Abstract

Traffic patterns of forest harvesting machinery were recorded in two clearcuts using global positioning systems (GPSs) and the results compared to a grid point intersect visual assessment (chain-by-chain grid). Results indicated that grid-based sampling of site disturbance overestimated the amount of disturbed area. Percent of the stand not trafficked for the grid sampling method was half that of the GPS-derived estimate. Grid sampled estimates of skid trail area were twice that of the GPS estimates. Although there were several practical problems with using the GPS systems in a harsh environment, they provided a detailed assessment of the total impact to the sites from mechanized harvesting.

Keywords

site disturbance, harvesting, GPS, traffic

Introduction

Determining impacts from mechanized logging involves the use of a 'damage' classification system to rank the extent of disturbance in a given, typically small, area, plus some form of area-based sampling scheme to apply the classification over an entire stand. In assessing logging damage to soils, the expense in time and resources to perform core sampling over a large area is prohibitive and impact assessments more commonly are based on visual criteria (eg McMahon 1995). Coupling visually-assessed damage classes with actual changes in soil physical properties, however, can be difficult.

There is a need for a reproducible, objective method for assessing impacts from logging machinery. Results obtained from the method should correspond clearly with changes in soil physical properties. McMahon (1997) proposed a method for using global positioning systems (GPS) to transform equipment movement patterns into a map of traffic intensity, or number of passes. This method is both reproducible and objective, and the link back to changes in soil physical property changes has been investigated in a number of studies. This paper reports on a study implementing the methods of McMahon (1997) in tree-length harvesting systems typical of the Southeast. Objectives of the study were to:

1. Test the use of GPS for tracking machine movement of forest harvesting equipment,

2. Investigate the correlation between GPS-derived measures of site disturbance and grid-sampled methods.

Figure 1. Map of site 1 showing the access and in-stand roads, plus the walnut grove inclusions. The unit was about 600 m in length from left to right.

Materials and Methods

Two sites were selected for the study. Both were loblolly pine plantations on Gwinnett series soils in Lee County, AL. Site 1 was 25.6 ha in size and included two walnut groves that were not harvested. Site 2 was 16.4 ha. Weather during the harvest was generally wet. The logging contractor used one feller buncher (HydroAx 511E), two skidders (Timberjack 450B and 460C), and two loaders (Prentice 270 with CTR delimber/slasher). No delimbing gate was used. Skidder turns were pulled to a single landing on site 1, with one loader installed on either side of a woods road at the top of a hill (see figure 1). On site 2, both loaders operated from the same deck until the upper section of the stand was felled, then one was moved into the stand (see figure 2).

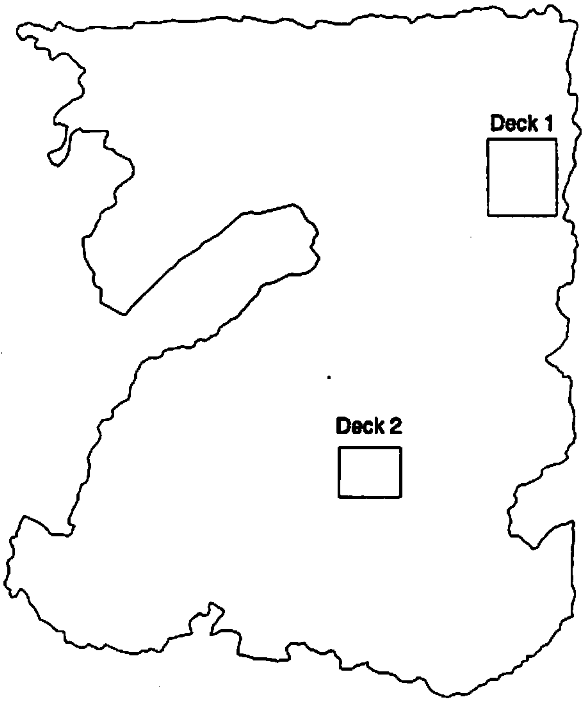

Figure 2. Map of site 2 showing logging decks. The stand was approximately 300 m in length from left to right.

Machine position data were collected using 3 GPS receivers: 2 Trimble ProXR, and 1 Trimble GeoExplorer. From previous studies it was known that the GeoExplorer system did not operate well within canopy conditions, and it was therefore decided to track the feller buncher with one of the ProXR systems. This proved to be a mistake from a practical perspective. Although there was a protective bar running across the front of the feller buncher cab that screened the ProXR antenna from being swept off by branches, it was lost about 4 days into the study. This incident, plus the loss of a second antenna because of a burst hydraulic line severing the cable, resulted in a significant loss of data for Site 1. The area in figure 1 marked 'Complete Coverage' was the only portion of the stand where we felt reasonably confident that a full complement of traffic data had been collected. For the remainder of the study deployment of the GPS receivers was: GeoExplorer on the feller buncher with the much lower-profile antenna duct taped to the cab, and the ProXRs with magnetic mounts on the skidders. No antennas were lost after adopting this strategy. This was not to say that data collection went without problems. Without someone on the site continuously, it was difficult to catch problems with the systems (dead batteries, or more commonly the feller buncher operator arriving late for work), resulting in further losses of GPS data coverage.

Positional data collected from the GPSs were differentially corrected then exported to a GIS. The data from the GeoExplorer required significant editing to eliminate errant points. These points tended to be from one to several sequential instances of the path being shifted by up to several hundred meters. Elimination of these points reduced the amount of data collected from the GeoExplorer by about 10 percent. Data from the ProXR systems was much less prone to these types of errors.

After correcting the data, it was transformed from a vector sequence of points to a raster map of number of passes using a custom software package (McDonald and others 1998). These maps were then imported into the GIS and registered with stand boundary coverages.

Table 1. Visual features recorded in site disturbance assessment.

Soil Disturbance	Traffic Type	Ruts
A - litter in place	Deck	< 2"
B - Mineral soil visible	Skid Trail Primary	> 2"
C - Mineral soil only	Skid Trail Secondary	
D - Mineral soil and litter mixed	Non-trail Trafficked	
Non-soil or slash	Untrafficked	

Following harvest, site disturbance was measured using a visual inspection method. Visual characteristics of ground condition were evaluated on a chain-by-chain grid. Characteristics noted are shown in table 1. Disturbance was classified using the rules shown in table 2.

Table 2. Disturbance class definitions.

Traffic Type	Soil Disturbance	Ruts	Disturbance Class
Untrafficked	all	all	Untrafficked
Skid Trail - primary	all	all	Skid Trail
Skid Trail - secondary	all	all	Skid Trail
Deck	all	all	Deck
No-trail Trafficked	A	< 2"	Slightly Disturbed
	A	> 2"	Disturbed
	B - D	all	Disturbed
Non-soil Slash	-	-	Indeterminate

Results and Discussion

Figures 3 and 4 show maps of traffic intensity for the two study sites. Complete data (feller buncher plus skidder) was only available for a small area of site 1, as marked in figure 1. More complete coverage was available for site 2 as a whole, but again, feller buncher data was missing for the extreme north end of the stand, as well as the extreme southeast corner. Data for both sites was analyzed on a total stand basis, and using reduced areas corresponding to our best estimate of the portions of the stand with complete position data coverage.

Table 3 is a summary of the percent of area in varying traffic intensity categories for both sites, as recorded, and for the regions of the site where we felt confident that complete data coverage was obtained. For site 1, where numerous problems were encountered keeping the GPS equipment on the machines, slightly more than half of the area was left untrafficked. For the portion of site 1 with complete GPS data coverage, the area remaining untrafficked was 37.6 percent. For the entire area of site 2, the portion not trafficked was 37.1 percent. For the portion of site 2 where GPS data were complete, the area not trafficked was 26 percent. The true value for area not trafficked on these sites was probably somewhere between the

'Site 1 - complete data' and 'Site 2 - complete data' estimates, about one third of the stand.

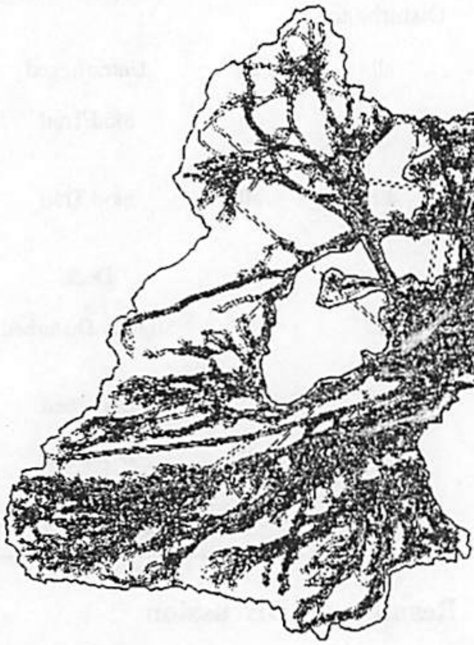

Figure 3. Traffic patterns as measured using the GPS on site 1.

Figure 4. Traffic patterns as measured using the GPS on site 2.

Table 3. Percent of stand area as a function of number of passes.

# of Passes	Site 1 - partial data	Site 1 - complete data	Site 2 - reduced data	Site 2 - complete data
0	52.3	37.6	37.1	26.0
1	14.5	18.3	15.7	16.1
2	8.9	12.4	11.2	12.7
3	5.7	8.4	8.1	9.6
4-10	12.4	17.4	20.2	25.2
11-20	3.0	3.5	4.3	5.6
21-50	2.0	1.7	2.4	3.5
51+	1.2	0.7	0.9	1.3

Of the two thirds of the stand trafficked, about 26 percent was hit once, and 62 percent 2 to 10 times. On average, only about 8 percent of the entire stand was trafficked more than 10 times.

Table 4 presents a summary of the visual stand disturbance assessment. The results were very different from the GPS-derived data for the untrafficked class. The visual assessment found only about 10 percent of the stand had been left untouched, versus about one third for the GPS. Comparing the other classes to GPS data was more difficult. If we assumed 1 to 3 passes was slightly disturbed, the GPS and visual site disturbance data were comparable, both between 35 and 40 percent of the total area. If 4 to 20 passes were considered disturbed, then results were also comparable, with the visual assessment giving slightly higher estimates. If more than 20 passes was considered skid trails, then the GPS-derived estimate was much lower than the grid sampling method - 5 percent versus 20 percent.

Table 4. Summary of percent of stand area in each disturbance category based on the grid sampling method.

Disturbance Class	Site 1	Site 2
Untrafficked	11	8
Slightly Disturbed	35	40
Moderately Disturbed	25	29
Skid Trail	18	12
Landing	2	5
Indeterminate	10	6

These results suggested that the visual disturbance assessment method used in this study overestimated the degree of impact of harvesting machine traffic, for the conditions and systems tested. It was possible that the spatial resolution of the visual assessment was unsuited to the conditions. McMahon (1995) suggested a much higher sampling rate for the greatest accuracy, perhaps on a 3 m spacing within transects 10 m apart. It was also possible that true point estimates of disturbance were not made, perhaps being biased by nearby conditions. From figures 3 and 4 it was clear that the presence or absence of traffic varied on the order of a meter or less in regions far removed from the logging decks. It was conceivable that the sampler could have been interpreting what was happening in a large enough region around the grid point that traffic disturbance was assumed where there was none. It was also possible that the GPS-derived maps were wrong, and further research is needed to verify their accuracy.

The GPS data provided a means of calculating the relative contribution of each machine to total site disturbance. For example, for the 'Site 2 - complete data' portion of the stand, of the 74 percent of the total area trafficked, 32 percent was from the feller buncher alone, 28 percent from the skidder alone, and 40 percent from both machines. About 40 percent of the area trafficked by the feller buncher alone was a single pass, versus 31 percent for the skidder. This type of information could be of importance in measuring site disturbance if there was a difference in degree of impact associated with machine type.

Summary and Conclusions

Site disturbance estimates were made on two clearcut sites using two procedures - mapping traffic intensity with GPS, and by visual inspection. Traffic mapping using GPS was complicated by the need for high levels of supervision of the process, and by the use of equipment adapted more for field use than for mounting on machinery in a harsh environment. Results showed that, for the stand types and harvest systems tested, GPS-based and visual assessments of site disturbance differed by a factor of two in the amount of area found not trafficked during clearcutting, and the area of decks and skid trails. Assuming that the GPS estimates were accurate, about one third of the stand remained untrafficked after clearcutting with conventional tree-length harvest systems.

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Analysis of Work-Related Injuries on Mechanized Logging Operations in the Piedmont and Coastal Plain Regions of the South

Robert M. Shaffer
Jason S. Milburn

Abstract

A random sample of injuries to employees of mechanized logging operations in the piedmont and coastal plain regions of the South was taken from the 1997 claim records of three cooperating Workers' Compensation Insurance carriers. Additional information on equipment, labor and operations for each firm reporting a sample injury was also provided. The sample data was entered into a database management program for sorting and analysis. Results include the percentage of injuries incurred by job function, task being performed when the injuries occurred, nature and cause of the injuries, and injury total cost. Comparisons are made between fully mechanized and partially mechanized (manual delimbing), large and small, and piedmont and coastal plain operations.

Keywords

logging, safety

Introduction

Logging is an extremely dangerous occupation. U.S. Labor Department statistics show that logging industry employees incur job-related injuries at a rate 26% higher then the industrial average and fatalities at a rate 19 times greater (BLS 1997). Because of the high accident and injury rate, Workers' Compensation Insurance (WCI) premium rates for logging firms are among the highest for any industry.

Safety training can help to reduce logging injuries and fatalities. However, many of the current logger safety training programs in the South are based on the analysis of summarized injury data from a wide range of logging systems and operating conditions. The resulting safety training programs are then often conducted on a state or region-wide "one-size-fits-all" basis. For example, analysis of annual summarized publicly available WCI statewide logging injury data from Virginia typically shows that well over 60 % of the reported injuries are chainsaw-related (Shaffer 1993), supporting the conclusion that chainsaw safety should be the emphasis of logger safety training across the state. However, many logging operations in the piedmont and most in the coastal plain regions of the state are fully mechanized -- that is, all felling, delimbing, and bucking are performed by a machine with an operator in a protected, enclosed cab. Will these logging firms gain the greatest benefit from chainsaw safety training programs, or would another training focus provide greater benefit?

Careful analysis of logging injury data for specific logging systems and operating conditions could facilitate the development of "targeted" safety training programs that could emphasize the causes and types of accidents and injuries most likely to occur on those operations. Thus, the objective of this study was to determine the most frequent causes and types of injuries specifically for "mechanized" logging operations (primary felling is performed mechanically) in the piedmont and coastal plain regions of the South. This type of logging system (feller-buncher/grapple skidder) produces more than 60 % of the wood harvested in this region (Porter, 1993).

The combination of data necessary to conduct this study is available only through certain Workers' Comp. insurance firms and is generally proprietary. Fortunately, three major firms providing WCI to loggers in the South agreed to cooperate in the study.

Study Methods

The three cooperating insurance firms agreed to provide their WCI logging injury claim records for 1997. From this population of approximately 2,000 logging injuries reported by mechanized logging operations in eight southern states, a "blended" random sample of 300 injuries was selected for analysis. For each sample claim, information was recorded on:

1. Age and experience of the injured worker.
2. Injured worker's primary job (skidder operator, truck driver, etc.).
3. Task the worker was performing when the injury occurred.
4. Location of the accident (woods, log deck, shop, etc.).
5. Time of day and day of week the injury occurred.
6. Nature of the injury (laceration, fracture, sprain, etc.).
7. Body part injured (ankle, back, eye, etc.).
8. Cause of injury (fall, struck by, motor vehicle accident, etc.).
9. Object involved in injury (chainsaw, loader, log, etc.).
10. Total cost of the injury.

Operational "demographic" information was also recorded for the logging firm employing each injured worker. This included:

1. Location of the operation (piedmont or coastal plain).
2. Number of skidders.
3. Method of mechanical felling (high-speed disc sawhead, shear, bar & chain sawhead).
4. Method of delimbing (manual chainsaw, delimbing gate, pull-through delimber, stroke delimber).
5. Type of wood produced (tree-length, cut-to-length, chips).
6. Number of logging crews operated by the firm.
7. Total number of logging workers employed by the firm.

The injury and demographic information was categorized and entered into a computer database management program for sorting and statistical analysis.

Results

The deck hand (delimber/topper) was the *crew member most frequently injured* (34 % of sample injuries), followed by the truck driver (24%), skidder operator (11%), and loader operator (8%). Forty percent of the sample injuries occurred to workers with less than one year's experience on that job.

The *job function being performed* most frequently when the injury occurred was delimbing/topping (24%); followed by maintenance/repair (19%); operating equipment, including a truck (15%); and mounting/ dismounting equipment (9%). The injury occurred most frequently on the log deck (41%), followed by the woods (29%) and the shop (11%).

Fifty percent of the injuries were "struck by" various objects, including a falling tree or limb (15%), a moving log (14%), a truck (11%) or a chainsaw (11%). Falls accounted for 21% of the injuries, and motor vehicle accidents 10%. The most frequent *nature of the injury* was a laceration (29%), followed by a sprain (23%), a contusion (23%), and a fracture (18%).

Sixty-four percent of the injuries cost less than $5,000 for medical care, lost wages and rehabilitation. Twenty-four percent had a total cost from $5,000 to $20,000, while 12% cost more than $20,000. Median total cost for the 300 sample injuries was $1,200. Mean cost was $10,920, ranging from a low of $0 to a high of $660,000. Fifty-four percent of the most costly injuries ($20,000+) were the result of a worker being "struck by" a tree, limb, or log.

When the data were sorted by "fully mechanized" (delimbing/topping performed mechanically) and "partially mechanized" (delimbing/topping performed manually with chainsaws) operations, differences in the injured worker's primary job and the task he was performing were observed (Table 1). As you would expect, deck hands performing manual chainsaw delimbing and topping are by far the most frequently injured employees on partially mechanized operations (51%). Even on fully mechanized operations, the landing worker or other crew member required to manually delimb, top, or fell the occasional "oversize" or "inaccessible" tree accounts for a substantial percentage of injuries (24%). However, on fully mechanized operations, equipment operators and truck drivers are injured with nearly equal frequency, often while performing equipment maintenance and repair (24%) or mounting/dismounting their machine (10%).

Table 1. Logging injury statistics for "fully" and "partially" mechanized operations.

Injury Statistic	**Fully Mechanized (n=213)**	**Partially Mechanized (n=87)**
Crew member injured	**(% of injuries)**	
Deck hand	26%	51%
Equipment operator	32	22
Truck driver	26	18
Task being performed		
Delimbing/topping	17%	38%
Maintenance/repair	24	7
Felling	7	11
Mounting/dismounting equipment	10	9

Sorting by piedmont and coastal plain operations did not produce any significant differences in injury statistics. Sorting by the number of crew members on the operation revealed one interesting difference: Truck drivers were injured more frequently on "large" operations with 10 or more employees (31% of injuries) than on "small" operations with 5 or fewer workers (17%), while equipment operators were injured more frequently on small operations (41%) than on large ones (21%).

Finally, injury statistics by the worker's primary job for all operations are as follows:

1. *Skidder operators* incurred 11% of the sample injuries. The injuries primarily occurred while they were operating the skidder (27%), performing maintenance or repair (21%),

manually felling or delimbing a tree (21%), or mounting/dismounting their machine (18%).

2. *Loader operators* incurred 8% of the injuries. They occurred primarily when mounting or dismounting the loader (42%) or performing maintenance (33%).
3. *Truck drivers* incurred 24% of the injuries. These injuries primarily occurred while the driver was operating the truck (35%), performing maintenance (14%), trimming the load (10%), or mounting/dismounting the truck (8%).
4. *Feller-buncher operators* incurred 7% of the injuries, primarily during maintenance (30%), operating (20%), or dismounting (15%).
5. *Deck hands* incurred 34% of the injuries. They primarily occurred while the worker was manually delimbing and topping (61%) or felling (14%) trees. Fifteen percent of the injuries to deck hands occurred while they were walking or resting.
6. *Supervisors* incurred 6% of the sample injuries, primarily while performing equipment maintenance or repair (45%) or felling/delimbing a tree with a chainsaw (22%).

Conclusions

The study results support the following conclusions regarding injuries to workers on mechanized (feller-buncher/grapple skidder) logging operations in the piedmont and coastal plain regions of the South:

1. A worker performing equipment maintenance or repair or a worker felling or delimbing a tree not processed by the feller-buncher or delimbing device sustains the greatest risk of injury on a fully mechanized operation.
2. Mechanization of the delimbing function will dramatically reduce (but not completely eliminate) the most costly injuries, those where a worker on the ground is "struck by" a tree, limb, or log.
3. An alarming number of injuries occur when equipment operators are simply climbing into or getting out of their machines. Eliminating this easily preventable accident would reduce injuries to equipment operators by 24%.

Acknowledgments

Partial funding for this study was provided by the American Pulpwood Association's Timber Harvesting and Transportation Safety (THATS) Foundation. Significant in-kind project support was provided by members of APA's Southwide Safety Committee.

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Authors' Affiliation

Robert M. Shaffer is Professor of Forestry Operations and Timber Harvesting Extension Specialist, and Jason S. Milburn is Graduate Research Assistant in the College of Forestry and Wildlife Resources at Virginia Tech, Blacksburg, Virginia.

Comparison of Forwarder CTL and Skyline Yarder CTL Systems in a Natural, Eastern Oregon Stand

Erik S. Drews
Bruce R. Hartsough
James A. Doyal
Loren D. Kellogg

Abstract

Two harvesting systems were compared for reducing fuel loadings in overstocked conifer stands; forest managers also set a high priority on minimizing soil disturbance. Both systems employed cut-to-length (CTL) harvesters. One used a forwarder and the other a small skyline yarder. Both systems produced very similar and acceptable results in terms of fuels reduction and soil disturbance, but at different stump-to-mill costs: $42/green ton for the forwarder versus $72/green ton for the yarder.

Keywords

fuels reduction, cut-to-length, CTL, single-grip harvester, forwarder, cable yarder, skyline, forest harvesting.

Introduction

Many forested areas in the Blue Mountains of eastern Oregon have heavy fuel accumulations due to insect attacks and suppression of fire. Forest managers recognize the need to decrease these high levels of fuels, but are also seeking to reduce the detrimental impacts to the soil and the residual stand associated with traditional harvesting practices. In this region, the traditional harvesting method for small diameter material includes mechanized felling and bunching followed by whole-tree skidding. In thinning operations, whole-tree skidding has been associated with high levels of residual stand damage and soil disturbance, including compaction or displacement of soil on 15 to 20% of the harvested area (Burry 1998). Previous research has shown that reduced impacts can be achieved by using a skyline cut-to-length (CTL) system (Brown and Kellogg 1996, Kellogg and Brown 1995). However, ground-based equipment provides a lower-cost alternative to skyline yarding, where conditions allow ground-based operations and if the environmental impacts are within acceptable limits.

To compare ground-based and skyline systems, the Limber Jim Fuels Reduction Project was conducted on the Wallowa-Whitman National

Forest. As a fuels reduction project, the overall management objectives were to reduce crown fire potential, meet soil protection standards, and pay for the operations with harvested products (McIver 1998). Because of concerns about sedimentation in salmon-bearing streams, minimization of soil disturbance was also a key objective.

As a research project, Limber Jim's overall objective was to provide forest managers with information on the cost and environmental tradeoffs between the ground-based and skyline systems. It was an interdisciplinary research effort that included studies of harvest operations and their effects on residual stands, soils, soil biota and wildlife habitat (McIver 1998).

Site Description and Treatment Prescription

The Limber Jim study area was located on the La Grande Ranger District of the Wallowa-Whitman National Forest in the Blue Mountains of northeastern Oregon. Six harvest units were located on a ridge separating the Upper Grande Ronde drainage and the La Grande municipal watershed. Soils ranged from shallow scabs to deep volcanic ash. The slopes were relatively flat, averaging 12% or less on all units, although some subunits had slopes of up to 25%.

Some stands were mixed conifer with the primary species including grand fir (Abies grandis), western larch (Larix occidentalis) and Douglas-fir (Pseudotsuga menziesii var. glauca), while others were primarily lodgepole pine (Pinus contorta). Insect attacks by the mountain pine beetle (Dendroctonus ponderosae) and the western spruce budworm had severely damaged many of the stands, resulting in high percentages of standing dead or down trees. The Limber Jim units had some of the highest fuel loadings in the local area; fuel accumulations of up to 80 tons per acre were measured.

The primary goal was to reduce fuel loadings by half. Although treatment prescriptions varied somewhat from unit to unit, all standing dead and down trees in the 4" to 15" DBH range were to be removed, along with some live trees in the same diameter range. Live trees were either leave-tree marked or cut-tree marked, depending on the unit. Since most of the removals were dead and/or small, the primary product was chips for oriented strandboard. Some sawlogs were produced from the larger green trees.

Harvesting Systems

The study units were not steep enough to require a skyline system. However, compared to the traditional whole-tree skidding, the skyline CTL system was viewed the benchmark for a low-impact system. A forwarder CTL system was selected as the ground-based system. It was expected to cost less than the skyline system, and have less impact than whole-tree skidding. It was not clear how the impacts would compare with those of the skyline system.

Both systems used the same single-grip harvester for in-woods processing (felling, delimbing, and bucking). The main difference between the two systems was the means by which the logs were transported to the landing: one used a forwarder and the other used a skyline yarder. Both of these systems were expected to result in less soil disturbance than with whole-tree skidding, due to a) the mat of slash deposited on the trails by the harvesters and b) full or one-end suspension of the logs by the forwarder and yarder.

Layout. The Forest Service Sale Administrator and the loggers located landings and planned the general layout of the harvester trails and yarding corridors. The Forest Service required harvesting trails to be spaced at approximately 60 feet on center. On the forwarder units, the harvester operators located trails as they worked. For the skyline units the logger premarked the skyline corridors (at approximately 150-foot intervals) and the trees to be used for intermediate supports and guyline anchors. Between the designated skyline corridors, the harvester operators located the intermediate trails as they worked.

Harvesting. The two harvesters used with both systems were 1991 Hitachi 200LC excavators fitted with 1992 Keto 500 harvesting heads. They worked in very similar manners with both systems, but with some minor differences. On the forwarder units, logs were cut to 16-foot lengths and placed where convenient on either side of the trail. On the skyline units the logs were cut to longer lengths (averaging 23 feet) and placed in choker-sized bunches that were angled towards the skyline corridor.

Forwarding and Yarding. The forwarder system involved only one machine – a 12-ton 1996 Valmet 646 – and the operator. The skyline system was a six-man, two-machine operation. Equipment included a recent model Diamond D210 3-drum swing yarder with an Eaglet motorized slackpulling carriage, and a John Deere 690 knuckleboom loader. The crew included the yarder and loader operators, a chaser, rigging slinger, choker setter, and a hooktender who prerigged corridors.

Both systems either built log decks or fed logs hot to the chipper, depending on whether the chipper was at the site.

Chipping. A Morbark 27-inch disk chipper processed the smaller logs from both systems. It sorted and decked the occasional sawlog as it worked. Since the chipper was working in several units, it was frequently shuttled between them and therefore processed many of the logs cold. Chipper production was reduced as a result of the half an hour or so lost each time the chipper was moved between units, up to three times per day. However, production was limited to eight truckloads of chips per day by the mill.

Loading. Sawlogs comprised only a small fraction of the tonnage removed, and all sawlogs were loaded from the cold decks left after the chipping operations were completed.

Trucking. The trucking contractor charged a flat rate ($397/load) to haul from the site to the mill (10 off-highway miles and 60 on-highway miles).

The harvest operations occurred between June 1996 and August 1997.

Harvesting Study Objectives and Methods

Objectives for the harvest operations portion of the study included:

1) Measure production rates
2) Determine harvesting costs and revenues
3) Compare harvest systems.

The six harvest units were grouped into three pairs; units in a pair had characteristics that were as similar as possible. Then one unit from each pair was randomly assigned to either the forwarder or the skyline system.

The two systems were studied using a combination of shift-level reports, detailed time/motion studies, and weight and/or volume records of truck loads by product. A stump-to-mill cost was determined by summing together the costs of the operations: layout (skyline system only), harvesting, yarding, chipping (chiplogs), loading (sawlogs), and finally trucking. The cost for each operation was based on operator-reported scheduled hours (SH) of machine operation combined with a cost per SH for each machine. The hourly cost was calculated using the machine rate method. No allowance was made for profit or risk. Assumed purchase prices, lives, labor costs and resulting hourly costs are displayed in Table 1. A cost per ton was calculated for each operation by dividing the operation cost by the total tonnage for all chip loads and sawlog loads. (No shift level data was recorded for sawlog loading, so a typical rate of 30 green tons per SH was assumed.)

Table 1. Machine cost assumptions.

Machine	Price ($)	Life (years)	Wages ($/hr)	Total ($/SH)
Harvester	235,000	5	19	114
Forwarder	194,000	5	18	80
Yarder	407,000	5	142	230[1]
Loader	250,000	7	17	73
Chipper	260,000	7	17	93

(1) Total cost for yarding was $303 per scheduled hour, which combined the yarder and the loader costs.

Results and Discussion

Removals

Harvested trees averaged only seven inches in diameter. Based on time-motion studies of the harvesters, the operations removed approximately 55% down, 26% standing dead, and 19% live trees. More than 80% of the trees removed were dead; this and the small average diameter are reflected in the high proportion of chip tons to sawlog tons. Sawlogs represented less than 10% of the total tonnage removed (Table 2).

Table 2. Harvest areas and removals per acre.

	Forwarder	Skyline
Acres	49	42
Removals:		
Trees/acre (approx.)	300	250
Average DBH, in	7	7
Chip green tons/acre	54	42
Sawlog green tons/acre	4	6

On the skyline units, sawlogs represented a greater proportion of the tonnage removed (12% versus 6% for the forwarder), but this was probably due to differences in stand characteristics rather than to system performance.

Stump-to-Mill Cost

Table 3 summarizes the production rates and costs per ton for each operation. The latter were calculated by dividing the total cost of an operation by the total tonnage of chips and sawlogs so that the column could be summed to give total cost per overall ton.

Table 3. Production rates and costs per green ton.

	Forwarder		Skyline	
Operation	Tons/SH	$/ton	Tons/SH	$/ton
Layout				1.38
Harvesting	8.9	12.86	5.9	19.32
Yarding	13.5	5.93	10.3	29.54
Chipping	19.8	4.40	19.8	4.13
Loading	30.0	0.15		0[1]
Trucking		18.15		18.15
Stump-to-Mill		41.49		72.51

(1) Included with yarding cost

As expected the forwarder system had a lower cost – an average of $41 per green ton – than the $73 per green ton for the skyline system.

Layout. The layout cost applied only to skyline units, where skyline corridors must be flagged and guyline and support trees marked before the harvesting can begin. On the forwarder units, the Sale Administrator approved the layout of the harvest trails, but they were not premarked.

Harvesting. Harvesting contributed about a quarter to a third of the total stump-to-mill cost. When processing for the forwarder system the harvester worked in an "ideal" manner placing logs on either side of the machine. The harvesting was slower for the skyline system due to the time spent placing logs in choker-sized bunches and aligning bunches towards the skyline corridor. It cost $19/ton to harvest the skyline units and only $13/ton for the forwarder units.

Forwarding vs. Yarding. The greatest difference in cost was in forwarding versus yarding: $6/ton versus $30/ton. A cost difference was expected due to the greater hourly expense for equipment and labor involved with the skyline system. In addition, the forwarder had a higher production rate, an average of 13.5 tons/SH versus 10.3 tons/SH for the cable yarder.

Chipping. Chipping cost, at $4/ton, accounted for 10% or less of the total cost for either system. The sale purchaser limited production to no more than 8 chip loads per day, which was less than the capacity of the chipper. A lower chipping cost would have resulted if the cost could have been spread over more loads.

Loading. The loading of sawlogs was a very small expense for the sale due to the low proportion of sawlogs. This cost was only $0.15/ton when spread over total tonnage produced on the forwarder units.

Trucking. The trucking cost was $18/ton, representing 44% of the total cost for the forwarder system and 25% for the skyline system.

Unit-to-Unit Comparison

The units represented ranges of stand and terrain conditions, and over these ranges the forwarder system had relatively uniform harvesting costs compared to those for the skyline (Table 4). Between units, the stump-to-mill cost for the forwarder system varied less than 10%, while that for the skyline system varied 30%; the yarding cost for the forwarder units varied 25% while that for the skyline units varied 60%.

Table 4. Forwarding vs. yarding costs by unit.

Unit	Forwarding cost ($/ton)	Yarding cost ($/ton)	Stump-to-Mill cost ($/ton)
4-F	5.47		40.84
4-S		40.95	83.84
11-F	6.20		41.40
11-S		26.93	71.44
16-F	6.99		44.20
16-S		22.13	61.51

Comparing the paired units (Table 5) shows some discrepancies in the pairings and revealed some factors that may have affected the harvesting cost. Units 11-F and 11-S were well-matched units of similar size, shape and slope (flat); these units represented the intermediate values of harvesting cost. Units 4-F and 4-S differed primarily in that the forwarder yarded uphill while the skyline yarded downhill. The 4-F and 4-S units were shorter and wider than 11-F and 11-S. For the forwarder, the shorter yarding distance decreased travel time and cost. For the yarder the lower volume per yarder setup offset the shorter inhaul and outhaul times and may have lead to the higher cost. On units 16-F and 16-S, both systems yarded uphill, and both used trail or corridor patterns that differed from those on the other units. For the forwarder, side-trails were used so that the forwarder traveled straight up and down the steeper (up to 25%) slopes. These side-trails were all yarded downhill. The side-trails and the longer, narrower unit shape increased travel distance and cost for the forwarder. On unit 16-S, the skyline yarded from only one landing and used a radial pattern of corridors. Deflection was adequate on this unit, without intermediate supports. This configuration was the most efficient for the skyline system and yielded the lowest skyline yarding cost, $22/ton. However, this cost was still more than three times the cost of forwarding on unit 16-F. Furthermore, the radial pattern of skyline corridors was inconsistent with the objective of using parallel corridors. A radial pattern of skyline corridors disturbs a larger percentage of the area near the landing.

Table 5. Unit characteristics.

Unit	Area (ac)	Avg./Max Yarding Dist. (ft)	Avg. Slope (%)	Yarding Direction
4-F	18.0	520/780	12	Uphill
4-S	12.5	270/640	12	Downhill
11-F	24.0	720/1070	2	Flat
11-S	23.0	510/1080	2	Flat
16-F	7.0	480/820	12	Uphill[1]
16-S	6.5	400/670	12	Uphill

(1) Included some downhill sections w/slopes of 15-25%.

Gross and Net Revenue

The primary product from the sale was chips for oriented strandboard, with the only other product being sawlogs. Delivered values for chips were $97.50/BDU, equivalent $59 per green ton; sawlogs were worth $425/MBF at the mill, which translated to $86 per green ton. When averaged by the weight fractions of each product, the average gross revenue was about $62 per green ton (Table 6). Subtracting the stump-to-mill costs, the forwarder system gave a net revenue of $19 per ton. In contrast, the skyline lost $10 per ton.

Table 6. Revenue per green ton and per acre.

	Forwarder		Skyline	
	$/ton	$/acre	$/ton	$/acre
Gross Revenue				
Chips	59	3181	59	2512
Sawlogs	86	302	86	500
Total	61	3483	63	3012
Net Rev.	19	1112	-10	-479

Environmental Impacts

Fuels Reduction. An average of 53 tons per acre were removed of which about 80% was down-dead or standing-dead trees. The management objective of reducing the fuels loading by about half was achieved (McIver, 1998).

The two systems achieved similar results in fuels reduction as the same harvester processed logs for both systems. The fuels were reduced in the 4 to 15 inch diameter classes, which were the sizes targeted for removal. An increase of fuels was found in the smaller size class due to the limbs and tops from the in-woods processing. In general these limbs and tops were matted down to knee height or less due to machine and log traffic.

Soil Disturbance (McIver 1998). There was no significant difference in soil disturbance – a combination of compaction and displacement – between the two systems. Only about 7% of the harvested area was significantly disturbed, much less than would be expected with whole-tree skidding. The type of disturbance, however, was different; forwarding tended to produce more compaction, while skyline yarding created more displacement. Both systems yielded visually appealing results.

Comparison of Harvest Systems

Forwarder CTL. Under the circumstances presented at Limber Jim (relatively flat terrain, and small, low-value logs), the forwarder CTL system (single grip harvester and a forwarder) is probably the ideal system. The forwarder used the trails created by the harvester, which allowed the harvester to work efficiently by placing logs on either side of the trail. The forwarder can easily handle small diameter logs, loading several at once. Although it takes somewhat longer to fill the forwarder bunk with smaller logs, the travel time in and out of the woods is unaffected by log size, yielding only a small change in total cycle time. As a forwarder travels methodically along a trail at only walking speeds (3 to 5 mph) it creates minimal soil disturbance.

Skyline CTL System. The conditions on the Limber Jim project were not ideal for a skyline yarder since most units required intermediate supports and the log sizes were very small. Skyline systems are at their best when they can retrieve a full-capacity load (larger, longer logs) on each turn. The harvester worked more slowly on the skyline units due, in part, to the greater attention and effort required to choker-sized bunches of the small logs and to align the logs towards the skyline corridors. Skyline CTL systems can be economically successful, as was shown in the Deerhorn project (McIver 1995; Brown & Kellogg 1996), which had a higher percentage of sawlogs. However, as shown by the Limber Jim project, lower cost systems can meet the management objectives that are commonly associated with skyline systems–low impacts to reserve stands and soils. Conditions that would favor skyline systems over forwarders include steeper slopes, the need to move logs over sensitive areas such as riparian zones, or where longer logs are desired due to value differential.

Forest Management Implications

Specifying Timber Sales. Part of the motivation for the project was to test harvesting equipment not commonly found in this region until recently: small log CTL harvesters, forwarders, and small yarders utilizing intermediate supports. Each of these machines costs hundreds of thousands of dollars, so loggers are necessarily cautious about investing in new equipment unless they can count on a steady stream of work. Thus, if forest managers intend to specify either of these CTL harvest systems in the future, they need to consider the needs of the logger when creating forest management plans.

Forwarders are limited by the log size they can lift and by the log length they can carry, and by the slope on which they can operate, approximately 30% or less in most cases. Where forwarders are not feasible, skyline systems would be warranted. Managers should choose the least-cost harvest system that is feasible and that will meet all the management objectives.

Possible Changes to Harvest Systems. For conditions like those found on the Limber Jim project, there are several changes that may offer economic and/or environmental benefits. These include using: a) a larger forwarder, b) a harvester with a longer reach to increase trail spacing, c) a mobile winch to pre-yard the logs to edge of the skyline corridor, and d) both a forwarder and a skyline to yard the same corridors/trails when on varied terrain (flat and steep).

Summary

The study demonstrated the excellent results that can be achieved by using CTL systems, and it confirmed the major difference in cost between forwarder and skyline systems for log retrieval. By using in-woods processing (i.e., CTL), widely spaced (60 foot) trails, and log suspension (by forwarder or skyline), fuel reduction can be achieved with only minimal soil disturbance. Furthermore, both systems harvested in a "neat" manner that was barely apparent after completion and that required no remediation work–landing cleanup, water bar installation on skid trails, or piling or dispersion of slash. Between the two systems the greatest difference was in the cost of log retrieval, with skyline yarding costing 5 times as much per ton as forwarding.

Acknowledgment

This research was funded in part by the USDA Forest Service Pacific Northwest Research Station under Cooperative Agreement PNW 92-0240.

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Author's Affiliations

Erik S. Drews, Ph.D. Candidate
Biological and Agricultural Engineering
University of California
Davis, California

Bruce R. Hartsough, Professor
Biological and Agricultural Engineering
University of California
Davis, California

James A. Doyal, Research Assistant
Department of Forest Engineering
Oregon State University
Corvallis, Oregon

Loren D. Kellogg, Professor
Department of Forest Engineering
Oregon State University
Corvallis, Oregon

Harvester-Cable Yarder System Evaluation on Slopes - a Central European Study in Thinning Operations

Hans R Heinimann
Rien J.M Visser
Karl Stampfer

Abstract

Innovative locomotion technology makes it possible to apply harvester systems in thinning operations on steep slopes. Converting and bunching by harvester will probably improve productivity of the following cable yarder system. The study aims to investigate the interface effect between harvester and cable-yarder. An observational study in first commercial thinning operations in a forest company in the eastern Austrian Alps was carried out. A Skogsjan 687 harvester was used for felling, processing, and bunching. Extraction was done by a Syncrofalke yarder using automatic carriage control.

The investigation results in two main findings: (1) bunching by harvester increases cable yarding by about 25%, and (2) bringing a second chokerman into action improves yarding productivity in the order of the prebunching effect. Further research needs to refine bunching strategy. The results encourage application of harvester technology in thinning operations on slopes.

Keywords

steep terrain logging, harvester-cable-yarder interface, Skogsjan, Synchrofalke yarder, bunching, productivity study.

Introduction

Harvesting timber on steep slopes is a difficult operation requiring special technology. While the harvester-forwarder system represents the state-of-the-art in trafficable terrain, log extraction on steep slopes has to be achieved by cable or helicopter yarding. Most of the forests of the Central European Alps have been managed for the last two centuries or even longer. Silvicultural treatment therefore requires much selective logging during thinning operations.

Availability of new locomotion technology (self-leveling wheeled platforms, legged platforms) will make it possible to apply harvesters even on slopes. Harvesters do not only improve efficiency, they will influence the following cable yarder productivity by concentrating the logs into bunches. This so-called *bunching effect* is not a

new idea. Keller (1979) and Kellog (1976) investigated it more than 20 years ago. Technical innovation has been leading to sophisticated cable yarding and harvester systems in the meantime. One problem in harvesting system design is to put components together optimizing the relevant interfaces. The investigation aims to quantify the effects of different prebunching strategies on the productivity of a cable yarder system.
First an experimental layout is developed, then data are analyzed by statistical methods. The results indicate the need for future investigations and encourage the application of combined harvester-cable yarder systems on steep slopes.

Methodology

Subject Matter Model

In forest operations a huge amount of productivity studies are available. In all such studies the mean volume per piece is the main source of variation. In most cases the relationship between the productivity and the mean volume per piece is not linear (Häberle 1984). In cable yarder operations productivity decreases with increasing yarding distance. In the study the following productivity hypothesis was used:

$$prod_{yard} = f(pvol^{e}, dist, side, pieces, BUNCH, CHOK, UP)$$

where
$prod_{yard}$ = *system productivity*
$pvol$ = *mean volume per log*
e = *exponent (curvature)*
$dist$ = *yarding distance*
$side$ = *lateral yarding distance*
$pieces$ = *number of logs per load*
$BUNCH$ = *bunching strategy*
$CHOK$ = *choker setting strategy*
UP = *direction of yarding*

The productivity hypothesis is limited to those effects that probably have the biggest influence and that may be measured or evaluated easily.

Study Layout

To analyze the effects of bunching and chokersetting treatment strategies were defined (Table 1).

Tab. 1: *Treatment strategies*

Factor	Level	Treatment Strategy
BUNCH (bunching strategy)	0	no bunching, logs are distributed randomly in the cutting area
	+	normal bunches prepared by harvester
	++	large bunches prepared by harvester
CHOK (choker setting strategy)	1	one chokersetter
	2	two chokersetters

A factorial layout was utilized to investigate the productivity hypothesis. Using the design factors „bunching strategy“ and „choker setting strategy“ a 3x2 - design was used to classify available harvester / cable yarder operations. The layout of cable corridors is presented in table 2. The study layout is unbalanced what is not unusual in productivity studies because the variation of factors is limited under real conditions.

Tab. 2: *Study Layout*

BUNCH	CHOK	cable corridor
0	1	5
0	2	6
+	1	4
+	2	1,3
++	1	-
++	2	2

Study Object

The test area is located in the eastern parts of the Austrian Alps. A small area of forest within the property of the Mayr-Melnhof company served for the investigations.

The forest consists almost exclusively of Norway Spruce (*Picea abies*) with an average diameter at breast height of 21 to 25 centimeters. The average age of the stands is around 75 years. Stand density is characterized by 900 stems per hectare with a basal area of 41 square meters per hectare. The silvicultural treatment was a first commercial thinning operation with an average yield of 120 cubic meters per hectare. About 450 stems per hectare had to be removed corresponding a reduction of the basal stand area 44 per cent.

Six cable corridors were studied according to the experimental layout (Table 2). The length of each corridor was between 120 to 140 meters, and the terrain had a slope angle of 15 to 25 per cent with smooth and firm ground. The corridors were marked out before the arrival of the harvester and the loggers.

A Skogsjan 687XL harvester felled, processed and bunched the trees to be extracted. Experienced loggers did the same work motor-manually in the corresponding corridor. A medium sized truck-mounted cable yarder (Austrian manufactured „Synchrofalke“) accomplished the extracting operation. The „Synchrofalke“ cable yarder consists of a 10 meter tower, hydrostatically driven winches and a computerized carriage control system. This control system is capable of moving the carriage automatically back to the previous load building location in the stand. The choker setter has a radio control device to operate the yarder during the lateral yarding task. The control abilities of the yarder make it possible to operate the whole yarding system with only two crewmen, the first operating the yarder and swinging the logs at the landing using the integrated crane-mounted grapple, the second setting chokers and operating the lateral yarding process. In some of the corridors two chokermen accomplished the load-building task in the stand.

Tab. 3: *Variable Definition for Data Sampling.*

response	cycle	total time for one yarding cycle	minutes
	loadvol	total load volume for each yarding cycle	cubic meters u.b.
	$\text{prod}_{\text{yard}}$	(loadvol/cycle)*60	m^3 per PSH[4]
factor	BUNCH	bunching strategy; factor containing three levels: (0) no bunching, (+) harvester bunching, (++) improved harvester bunching	3 levels
	CHOK	chokersetters; factor of two levels: (0) one person, (+) two persons.	2 levels
	UP	direction of yarding; factor of two levels: (+) uphill, (0) downhill.	2 levels
	BLOCK	identification of yarding corridors	6 levels
covariate	pvol	mean volume per piece per load	cubic meters u.b.
	pieces	number of logs per load	number
	dist	yarding distance per cycle; chord distance between landing and clamping position of the carriage during lateral yarding.	meters
	side	lateral yarding distance per cycle; distance between skyline and timber bundle to yard	meters

Data Sampling

For each of the six study replications the response variables, the factors and the covariates (Table 3) had to be gathered on the yarding-cycle level. There were 225 yarding cycles investigated. Three people recorded the time elements using hand-held computers. Volume information includes the volume of the total load and the number of logs. The mid-diameter and the length of each log allowed the log volume to be calculated. Each log relates to one load cycle which allows the calculation of the response variable *loadvol* and the covariates *pvol* and *pieces* (Table 3).

Yarding covariates (*dist, side*) are available for each yarding cycle. Yarding distance was marked along each cable road before the beginning of the operation. The lateral yarding distance was rounded to the nearest five meters.

Statistical Analysis

In the analysis factors were included using coding procedures that transformed categorical data into metric variables. All the analysis was done using 0/1-coding (treatment coding). Analysis was carried out by regression techniques applying the following strategy:

- fit a model with all covariates and factors of

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[4] PSH Productive System Hour

table 3;

- select a series of sub-models by dropping variables that are not significant;
- choose two-way interactions of the sub-models;
- evaluate non-linearity of the covariates.

Fitting the parameters of regression models was done with linear model fitting procedures of S-Plus (see Venables and Ripley, 1994). Non-linearity of the covariate *pvol* was evaluated using power transformation. The most appropriate transformation was derived iteratively by looking for the exponent that produced maximal partial variance. One problem that may occur in unbalanced designs is the occurrence of model singularities. The analysis was therefore done interactively to find the model that best explains the influence of factors and covariates and that is as simple as possible.

Results and Discussion

Characteristics of the Yarding Cycles

Table 4 shows the characteristics of the investigated yarding cycles. 10 to 25 cycles per productive system hour PSH were run by the cable yarding system. Another interesting finding is the number of logs per cycle. An average of 7.7 pieces is an extremely high value, because the number of pieces is usually lower than five. The extremely small volume per log and the pre-bunching are possible explanations for this finding.

Tab. 4: *Variability of the response variables and the covariates*

variable	mean	0.05 quantile	0.95 quantile
cycle	4.0 min	2.5 min	5.8 min
loadvol	0.90 m^3	0.38 m^3	1.46 m^3
dist	61 m	10 m	130 m
side	9.6 m	0 m	25 m
pieces	7.7	4	14
pvol	0.13 m^3	0.06 m^3	0.24 m^3

Productivity Model

Statistical analysis resulted in productivity model [1].

$$
[1]\ \mathrm{prod}_{yard} = \begin{aligned}[t] & -3.51 + 14.89 \cdot pvol^{0.6} - 1.12 \cdot pieces \\ & -0.045 \cdot dist - 0.12 \cdot side \\ & +10.48 \cdot \left(pvol^{0.6} \cdot pieces\right) \\ & +2.96 \cdot BUNCH1 + 2.48 \cdot BUNCH2 \\ & +2.67 \cdot CHOK + 5.15 \cdot UP \end{aligned}
$$

where $prod_{yard}$ = *system productivity*
$pvol$ = *mean volume per log*
$dist$ = *yarding distance*
$side$ = *lateral yarding distance*
$pieces$ = *number of logs per load*
$BUNCH$ = *bunching strategy*
$CHOK$ = *choker setting strategy*
UP = *direction of yarding*

All two-level factors of Table 1 take on the value of 0 for the „0“-level, and the value of 1 for the „+“-level. *BUNCH* is a three-level factor that is represented by two binary variables *BUNCH1* and *BUNCH2*. For the „-“-level of *BUNCH* both, *BUNCH1* and *BUNCH2* take on the value of 0. The „+“-level is represented by *BUNCH1*=1, and *BUNCH2*=0 whereas *BUNCH1*=0, and *BUNCH2*=1 characterizes the „++“-level. Häberle (1984) proposed to transform *pvol* by raising it to the power of a variable *e* to reproduce the curvature phenomenon of productivity functions. Variation of the exponent *e* from 0.3 to 1.3 results in minimal residual sums of square at a value of *e* equal to 0.6. All further analysis will therefore be done raising *pvol* to the power of 0.6. Model [1] has a standard error of 3.6 and an R squared of 0.74 which is quite satisfactory for productivity studies.

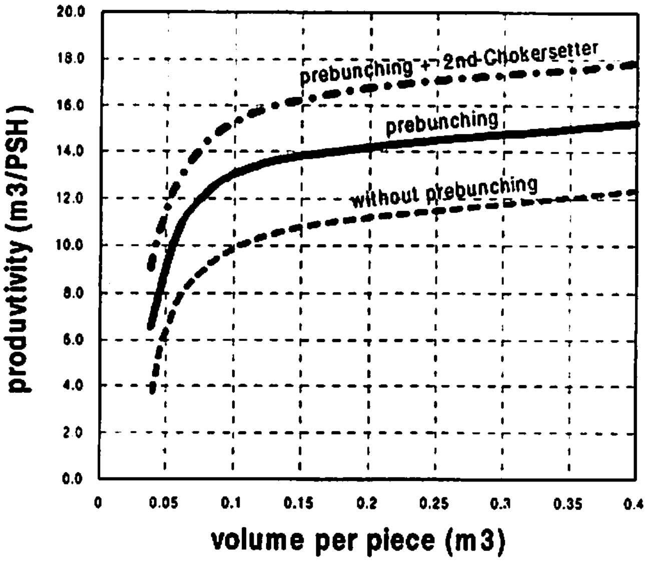

Fig. 1: *Productivity of the Cable Yarder System depending on volume per piece and bunching strategy*

Figure 1 shows the productivity for three treatment strategies. The main effects yarding distance (*dist*), lateral yarding distance (*side*) and load volume (*loadvol*) were set to the mean conditions of the study area (see Table 4). Under similar conditions bunching improves cable yarder productivity by about 27%. Sensitivity analysis indicates that the degree of improvement increases with smaller piece volume to a maximum of about 45%, whereas larger piece volume decreases the improvement only slightly.

The influence of improved harvester bunching („++"-level of the *BUNCH* factor) is of the same order as normal harvester buching („+"-level of the *BUNCH* factor). The fitted coefficients have standard errors of 0.7 and 0.9 respectively which is why the difference is within randomness.

The influence of a second chokersetter (*CHOK*) is significant. It improves the yarder productivity by about 2.7 cubic meters per productive system hour. The effect is similar to the bunching effect. Combining bunching and using two chokersetters results in the highest system productivity (Figure 1). Uphill yarding (*UP*) increases the yarder productivity by about five cubic meters per productive system hour. Estimation of the uphill yarding coefficient is based on only one replication and has to be used with care.

Analysis of variance of model [1] shows that 75% of the total variance may be explained by the factor and covariate effects. The covariates *pvol, pieces* and their interaction explain 65% of the variance whereas the factors *BUNCH, CHOK* and *UP* only account for about 5%.

Conclusions

The study results in the following findings:

- A fitted linear model shows that bunching by harvester improves system productivity by about 25 per cent.
- Approximately the same increase of productivity results by bringing two chokermen into action.
- Grading of the bunching strategies by three levels of factor *BUNCH* did not result in definitive findings.

Previous studies about the bunching effect on cable yarding systems did not give definite results (Kellog, 1976; Keller, 1979). Other authors investigated skidder extraction (Biller and Baumgras, 1986; Stokes and Lanford, 1985) while LeDoux and Butler (1982) carried out a simulation analysis, concluding that bunching small diameter logs into skyline corridors can be a feasible alternative for thinning operations. Biller and Baumgras (1986) defined three bunching strategies: (1) bunch volume is smaller than mean load volume, (2) average bunch volume is approximately equal to the mean load volume, and (3) average bunch volume is greater than the mean load volume. They found that strategies (1) and (2) resulted in similar productivity; one and a half times higher than applying non-prebunched baseline conditions. Strategy (3) effected a 50 per cent increase of the mean load volume and approximately doubled skidder production. The investigation leads one to suppose that the „+" as well as the „++" level of the *BUNCH* factor stand for bunch volumes is equal for smaller than the mean load volume.

The present study is the first investigating the interface effect between a single grip harvester and a cable yarding system in thinning operations. The results are promising for the development of steep slope harvesters based on different locomotion principles (wheeled, tracked, legged). The findings of the study need to be refined in the future. Bunching strategies should be stated more precisely following the findings of Biller and Baumgras (1986). Bunch volumes considerably above the mean load volume seem to be most promising to improve cable yarder productivity.

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Affiliation of Authors

Heinimann Hans R.
Section of Forest Engineering at ETH
ETH-Zentrum HG G 23
CH-8092 Zurich, Switzerland
T: +41 1 632 32 35 F: +41 1 632 11 46
E-mail: heinimann@waho.ethz.ch

Rien J.M. Visser
University of Agricultural Sciences Vienna
Institute for Forest Engineering
Peter Jordan Strasse 70/2
A-1190 Vienna, Austria
T: +43 1 47654 4309 F: +43 1 47654 4342
E-mail: visser@edv1.boku.ac.at

Stampfer Karl
Section of Forest Engineering at ETH
ETH-Zentrum HG G 23
CH-8092 Zurich, Switzerland
T: +41 1 632 69 18 F: +41 1 632 11 46
E-mail: stampfer@waho.ethz.ch

Assessment of Site and Stand Disturbance from CTL Harvesting

Clyde G. Vidrine
Cornelis deHoop
Bobby L. Lanford

Abstract

Assessment of stand and ground disturbance resulting from cut-to-length (CTL) winter season harvest demonstrations performed on a 12-year-old pine plantation first thinning, 23-year-old second thinning, and a mixed pine/hardwood natural stand clearcut harvest is reported. The harvests were performed on Martin Timber Company lands in central Louisiana, during February and March, 1997. Machine productivity and harvest costs will be reported separately. Ground disturbance results show that 10.9% of the total harvest area was disturbed to some level, soil compaction in disturbed areas was increased by 21.4% in the most severe cases, rut depth averaged 13.0 inches in the most severely disturbed areas along the corridor trail, logging slash occupied up to 70% of the corridor trail distance, and mean soil density in lightly rutted (one machine pass) traffic areas was 1.44g/cc or 17.4% greater than in undisturbed areas. Mean soil bulk density in traveled areas covered with was 0% to 14% higher than the undisturbed areas. In first thinning harvest trials, 2.1% of the residual trees had bole injuries, and in second thinning trials injury to the stand was less than 1%.

Keywords

logging, cut-to-length, soil compaction, rutting.

Introduction

Forest managers in the South Central region are becoming increasingly interested in Scandinavian-designed timber harvesting/forwarding systems developed during the early 1970's for thinning and clearcutting Southern pine plantations, principally for environmental reasons. Guimier (1997) reported that about 30% of the timber now harvested in Canada is by use of CTL logging systems which is up from 10% in 1990. Loggers are interested in the equipment because of reduced labor costs, reduced workers' compensation insurance costs, and more operable days per year. The CTL system is generally composed of two machines: a harvester and a forwarder. The harvester consists of a felling/processing head and usually a measuring system which allows the operator to cut stems to lengths and diameters in accordance with mill specifications for logs. The forwarder consists of a carrier with a load-carrying rack and loader which allows it to self-load and self-unload onto logging trucks. Advantages claimed for these systems are economic and environmental and include less damage to the residual stand than harvesting by conventional systems, the ability to merchandise products in the woods, recovery of higher valued products, minimum site damage, may eliminate the need for a loader, large forwarder payload, and operator safety and comfort (Tufts and Brinker 1993 and O'Connor 1991). Disadvantages of CTL systems include high initial cost of individual machines, complexity requiring highly skilled mechanics and operators, single-stem processing by the harvester which makes the system very sensitive to tree size, log size/weight limitation, forwarders not as versatile as skidders, and log length limitation of the forwarder (Tufts and Brinker 1993, O'Connor 1991, and Conway 1982). Because the harvester felling head is boom-mounted, the machine does not have to drive to every tree harvested, as is the case with commonly used wheeled feller-bunchers, which reduces the number and severity of tree injuries and ground area compaction. In a site and stand impact study of a first thinning harvest of an 18-year-old pine plantation stand comparing a CTL operation to a feller-buncher-skidder operation, Lanford and Stokes (1995) reported the CTL system disturbed significantly less area than the skidder system. They also reported that the skidder system injured 25 trees per acre compared to 10 trees per acre for the CTL system in that study. After severing the tree from the stump, the boom is retracted to allow the top to fall within the growing space the tree occupied rather than being forced down or carried through the residual stand. Processing the tree in front of the machine and then driving over the slash is reported to reduce soil compaction from the harvester and the forwarder. Seixas et al. (1995) reported that for a single forwarder pass on wet soil, slash coverage at 20kg/m^2 was effective at controlling soil compaction. However, on dry, loamy sand soils, Seixas reported the presence of slash did not decrease soil compaction for a single forwarder pass but for multiple forwarder passes the presence of slash did reduce soil compaction. The forwarder follows in the same path as the harvester and makes fewer trips than a skidder for the same production. Although the CTL system is not being used extensively in Louisiana, many forest managers are interested in its potential for their lands.

Objectives of Study

The objectives of this study were to assess ground disturbance of a CTL harvesting system to the harvested area for first thinning, second thinning and clearcut operations, and damage to residual stands in the first and second thinnings.

Methods

In the first thinning trials of a 12-year genetically improved loblolly pine plantation, which was planted on 8 by 8-feet spacing, every seventh row was removed for an expected corridor center spacing of 56 feet. Desired stand density was 165 trees per acre. The corridor row was clearcut and the three rows to right and left of travel were operator-select thinned. Logging slash consisting of limbs and tops discarded by the harvester was placed in the path in front of the harvester travel way to act as a cushion for the wheeled machines to travel on and to provide ground cover to minimize the disturbances. Stems processed by the harvester-processor were placed on either side of the corridor in "sorted" piles according to the product as pine pulpwood, hardwood pulpwood, or pine logs. Pulpwood was taken to a minimum top diameter of 3-inches and pine logs for plywood manufacture were cut to lengths of either 9 or 17.5 feet with the small end diameter greater than 5-inches. Traffic on each trail consisted of three machine passes--one pass of the harvester as it traveled in operation from roadside into the harvest area (or returning as it operated from the far end of the area to roadside), one pass of the forwarder as it traveled empty from roadside to the far end of the harvest area, and one pass as it loaded itself while traveling to the roadside--all in an effort to minimize loaded travel distance.

In the second thinning study of the 23-year pine plantation with a targeted final stand density of 100 trees/acre, the harvester operator did not align machine travel with planted rows or the corridor cut out from the first thinning but cut new corridors generally perpendicular to the original corridors. Corridor spacings were in accordance within the 32.8-foot "reach" distance of the harvester's boom. The clearcut harvest was in a natural stand and operating width of the harvester was also in accordance with the "reach" of the harvester head.

Site disturbance for the CTL harvest system was assessed by determining the portion of the total harvest area disturbed and the severity of disturbance for the three harvest trials. Percentage of area disturbed was determined from measurements of corridor center-to-center distances and machine trail width along the cut corridor. Severity of disturbance was determined by measuring distance occupied by slash along the corridor trails, depth and width of rutting, and level of soil compaction resulting from the operations of the wheeled machines. Rutting depth and width means were determined from ten measurements each, taken at areas of severe disturbance along the corridor trail--away from slash accumulations or where roots limited rutting depth. Measurements were confined to the most severely disturbed areas and not taken at random along the corridor trail. Soil compaction was determined by comparing values of soil bulk density in undisturbed areas to that of disturbed areas from surface soil core samples taken 0 to 4-inches deep. Soil bulk density values were determined from ten samples each from each of the three harvest trials--first thinning, second thinning, and clearcut operations for undisturbed area values, under slash, and in the deepest of the rutted areas which resulted in a total of ninety samples analyzed. All soil samples for bulk density and moisture content reporting were oven dried to a constant weight at 105° C. Representative values of soil moisture content were determined for background information. Damage to the final stand was determined by visual inspection for tree injuries in one harvest area each for the first thinning and second thinning trials.

Study Sites

The CTL harvests were performed on Martin Timber Company lands in the North Central Louisiana Parishes of Bienville and Natchitoches during February and March, 1997. The first thinning operation was in Bienville parish, Section 28 of Township 15 North, Range 8 West. At that site, the soil is described by the Soil Survey of Bienville Parish as being of the Malbis fine sandy loam (MgB) series and Sawyer very fine sandy loam (SnC) series. The MgB and SnC soils have 1 to 5 percent slopes and are described as well drained soils. Moist Bulk density of the MgB soil is 1.30 to 1.60 g/cc and for the SnC soil 1.45 to 1.60 g/cc. Soil texture classification performed on a sample taken from the first thinning study site indicated the soil to be composed of 6% clay, 36% silt, and 58% sand which is classified as a sandy loam soil. The second thinning was located in Section 17 and the clearcut harvest site was in Section 23--both in Township 11 North, Range 8 West of Natchitoches Parish. According to the Soil Survey of Natchitoches Parish the soils are described as belonging to the Gore-Acadia-Wrightsville series which are level to gently sloping, moderately well drained, some poorly drained, and poorly drained soils that have a loamy surface layer and a clayey subsoil. Those soils are formed in old stream deposits. Moist bulk density is from 1.30-1.50 for the Gore series, 1.35-1.70 for the Acadia series, and 1.35-1.65 for the Wrightsville series.

In the second thinning site a bulldozer cleared out the old rows of the first thinning to facilitate timber cruising. Unfortunately, this caused some problems with the logging equipment's flotation, so the CTL operators cut new rows where the ground was particularly soft. The logging occurred during the time of year when the ground conditions are typically the least favorable for equipment flotation because ground conditions are at their wettest from winter rains and because evapotranspiration is at its seasonal lowest. The logging conditions during these trials were even wetter than normal. Originally, it was planned to perform a conventional harvest operation adjacent to the CTL operation using feller-buncher/

skidders, but ground conditions were too wet on both thinning sites.

Timber cruise summaries for the first and second thinning trials are provided in Table 1. Cruise data on the clearcut harvest site, which was a mature upland pine-hardwood stand, was not taken.

The CTL Machines

The CTL machines used in this study consisted of a Ponsse HS 15 Ergo harvester and Ponsse S 15 Ergo forwarder (Lumpkin, 1996).[1] Both 114-kw (153-hp) diesel engine powered machines were 6-wheeled all-wheel drive and were equipped with 700/55-34 tires on the single axle and 700/50-26.5 tires on the tandem axles. The tandem axles on both machines were equipped with 34-inch wide "over-the-tire" type metal tracks and tire chains were fitted to the 700/55-34 single axle tires for the tests. According to Ponsse technical data, total weight of the harvester is 13,050 kg (28,770 lb), and for the forwarder total weight is 10,970 kg (24,184 lb) + 12,000 kg (26,455 lb) load capacity. Specified ground clearance for the front axle was 560 mm (22-inches) and 640 mm (25-inches) for the rear axles--for both machines. Wheel tread measured 2.1 m (83-inches) and wheelbase measured about 4.8 m (190-inches) with the tandems spaced 1.4 m (57-inches). The knuckleboom/slideboom- mounted harvester head had an outreach distance of 10-meters (32.8 feet) from the pivot center.

Discussion of Results

Site disturbance assessment values for the first thinning, second thinning, and clearcut CTL harvest trials conducted in North Central Louisiana during a wet harvest season for sandy loam soils are given in Table 2. For the first thinning trial of the plantation planted on 8 by 8-ft spacing with 7th row removal, corridor trail spacing was 56.0 feet--in exact agreement with the expected value. Mean corridor center spacing for the second thinning harvest was 52.0 feet but the harvester travel was not in alignment with first thinning corridor removal. Trail spacing for the clearcut harvest was not measured because the harvest area was irregular in that mixed pine-hardwood natural stand. Overall width of the corridor opening was about 15 feet, which was controlled by spacing of the planted stand. Mean spacing between rutted centers along the trail was from 84.6 inches for the clearcut harvest to 86.4 inches for the first thinning. Those values are in agreement with the 83-inch wheel tread measurement and indicates that the forwarder traveled in the tracks made by the harvester. Mean rut depth and width were 13.0 and 36.6-inches for each rut in the most severely rutted areas along the corridor trail for the first thinning study. Mean rut depth in the second thin and clearcut harvests were somewhat lower. Considering the rutted width of 36.6-inches and trail center spacing of 56-feet for the 1st thinning, 10.9% of the area was disturbed by travel of the harvester and forwarder but at varying levels of severity. The 10.9% disturbance value does not include disturbance at the end of the harvest area as the harvester travels from the end of a completed corridor to the beginning of the next corridor. Considering the depth of the harvest area in this trial was typically 581 feet and the spacing between corridors was 56 feet which the harvester traversed at the far end of the harvest area every second pass, the area disturbed by wheel traffic was 11.4%. Ground area disturbance for the 2nd thin harvest was somewhat higher at 12.4% since the rutted width was higher and the trail center spacing was less than for the first thinning operation. Again, the 12.4% value did not include ground disturbance at the end of the harvest area as the harvester moved from a completed corridor to the next corridor. Ground area disturbed for the clearcut was not determined because trail centers could not meaningfully be measured but should not be appreciably different than for the thinning trials. Hunt, 1995, in a CTL harvest soil disturbance study reported average trail spacing to be 17.7 m (58 feet) with trail width 3.1 m (10 feet) and resulting area disturbance of 17.9% but with space between ruts not accounted for.

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[1] The use of brand or trade names is for the relative convenience and is not an endorsement by the authors or their respective organizations.

Soil compaction occurred along the wheel traffic areas for the three harvest trials as was evident from the resulting permanently formed wheel ruts. Soil bulk density was as high as 1.53 g/cc in the deepest ruts of the sandy loam soils of moisture contents from 22.4 to 24.1% (dry weight basis) for the first and second thinning harvest trials where mean rutting depth was as high as 13.0-inches. The presence of logging slash deposited along the trail reduced compaction levels resulting from multipass wheel traffic from 1.53 g/cc in the unprotected rutted areas to 1.35 g/cc. Undisturbed soil bulk density determined from samples taken near the vicinity of the trails varied from 1.23 for the clearcut harvest, 1.24 for the second thinning, to 1.35 g/cc for the first thinning harvest. In the first thinning, the bulk densities of the samples from the undisturbed soil were essentially identical to the samples from under the slash. Samples taken from the exposed ruts (1.53 g/cc) had bulk densities that were significantly higher than samples from the undisturbed and slash sites (both 1.35 g/cc).

In both the second thinning and the clearcut corridor trails however, bulk densities of samples from the rutted areas, under slash, and undisturbed areas were all significantly different indicating that compaction occurred in both the rutted areas and the under slash trafficked areas. In the rutted areas soil density was 1.53 g/cc compared to 1.34 g/cc in the under slash trafficked areas. Undisturbed soil bulk density was 1.24 g/cc.

An additional five samples were taken from light ruts where a machine had made only one pass resulting in ruts 2 to 6 inches deep. While the mean of these samples resulted in what is considered a reasonable value of 1.44 g/cc (compared to 1.23 g/cc for the undisturbed site and 1.49 g/cc for the rutted site), the small sample size prevents a statistically sound conclusion.

All bulk density values reported are on a dry weight basis and were determined from cores taken 0 to 4-inches deep. According to Proctor Density tests for sandy loam soils, the optimum moisture content for maximum compaction is about 12% (Oglesby and Hicks, 1982) which indicates that compaction would have been even more severe than resulted from these trials had soil moisture been about 12%.

Although it wasn't an objective of this study to determine soil moisture which would limit operations, it was found that logging operations could not be performed on the sandy loam soil having a moisture content of 41.6%. Operations could not be performed because of wheel rutting to the ground clearance limit of 22 inches. The harvester and forwarder were both equipped with 700 mm wide tires with 34-inch wide "over-the-tire" tracks on the tandem axles. Operations were performed with some level of rutting where the soil moisture was about 25% as discussed earlier.

Slash accumulations were highly variable in depth and spacing. Spacing between slash deposits along the corridor travel paths, which resulted in soil unprotected from wheel compaction, varied from a mean of 10.4 feet for the clearcut harvest to 22.0 feet for the second thinning harvest. Distance occupied by slash varied from an average of 8.7 feet for the first thinning to 18.9 feet for the clearcut trials. In the second thinning, slash occupied 34.6% of the corridor trail distance while in the clearcut slash occupied 69.6% of the trail. Considering the presence of slash significantly reduced soil bulk density in the traveled areas for the three harvest trials and that from 34.6% to 69.9% of the distance is covered with slash, it is important to note that considerably less than 12.4% of the total area is impacted as noted earlier. Mean slash depth varied from 6.2 inches for the second thinning to 8.5 inches for the clearcut harvest after having been compacted by three machine passes.

Damage to the residual stand was found to be 2.1% in the first thinning trial which was determined by inspecting all trees in one of the harvest blocks which was of area 0.75 acres. Three trees out of 137 trees were found to be injured--one injury being 2 by 3 inches at 1.5 ft above ground, 3 by 4 inches 4-ft above ground, and one a continuous strip from 2.5 to 6-ft above ground. This was equivalent to 4 trees per acre being injured. Lanford and Stokes (1995), reported 10 trees per acre to be injured in a similar study. In the second thinning harvest trial damage to the 100 tree/acre final stand was found to be 0.6% in which only one tree was found to be injured out of 163 trees inspected in one of the harvest areas. That injury was 2 by 3 inches at 6-ft above ground and that tree was next to the corridor. The machine operators were highly skilled, which resulted in a minimum of injuries to the final stand.

Table 1. Timber cruise summaries of the first-thinning and second-thinning tracts. Confidence intervals are 95%.

	First thinning trial		Second thinning trial	
	Pre-harvest	Post-harvest	Pre-harvest	Post-harvest
Tract number	4-6-814		4-6-814	
Age, years	12		23	
Average DBH, in	6.1±0.1	6.8±0.2	9.9±0.4	10.7±0.4
Quad. mean DBH, in	6.2±0.2	7.0±0.2	10.1±0.6	10.8±0.6
Basal area, ft^2/ac	91.6±7.09	42.6±2.62	90.7±9.98	65.4±6.94
*Merch. ht, ft	26±0.3	28±0.2	48±1.0	49±1.0
Harvested area, ac	15.6		19.5	
# trees/ac	431±40	160±12	163±16	103±11
Vol. (cords/ac)	21.67±1.84	10.36±0.84	32.39±3.75	23.51±2.40
(CCF/ac)	16.02±1.25	7.57±0.49	25.91±3.00	18.81±1.92

*Average merchantable height to a 2 inch top diameter

Table 2. Site Disturbances from first thinning, second thinning, and clearcut CTL harvests.

	--mean values with 95% confidence interval[2]--		
factor evaluated	first thin	second thin	clearcut
Trail Traverse Results			
rut depth, inches	13.0±1.6	9.3±1.3	10.4±1.3
rut width, inches	37.1±2.7	38.7±2.4	41.6±3.9
rut center spacing, inches	86.4±2.0	84.7±1.7	84.6±2.9
corridor trail center spacing, feet	56.0±2.3	52.0±6.5	--
percentage of total area disturbed	10.9	12.4	--
soil mc in undisturbed site, %[3]	25.8±2.8	27.0±4.4	29.4±2.2
soil mc under slash, %	28.9±3.5	29.0±5.0	26.7±1.9
soil mc in trail rut, %	24.1±2.4	22.4±2.8	24.8±3.6
soil mc in shallow ruts (2-6 inches), %	--	--	23.1±2.5
soil bulk density, undisturbed site, g/cc	1.35±0.05	1.24±0.08	1.23±0.09
soil bulk density, under slash, g/cc	1.35±0.06	1.34±0.08	1.39±0.05
soil bulk density, in rutted site, g/cc	1.53±0.03	1.53±0.09	1.49±0.09
bulk density in ruts 2 to 6-inches, g/cc	--	--	1.44±0.11
spacing between slash deposits, feet	18.8±3.7	22.0±11.0	10.4±2.37
distance along slash deposits, feet	8.7±1.7	10.0±4.27	18.9±5.3
space along trail occupied by slash, %	46.5	34.6	69.9
slash depth, inches	6.7±1.2	6.2±1.3	8.5±2.0
soil mc too wet to operate, %	41.6±8.4	--	--
Stand damage, % residual trees injured	2.3	0.6	--

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[2] Confidence interval reported only when applicable.

[3] Soil moisture content reported on dry weight basis.

Conclusion

Assessments of ground and stand disturbances from CTL winter harvest demonstrations performed on a first pine plantation thinning, second thinning, and a mixed pine-hardwood clearcut harvest in North Central Louisiana show low adverse impact from operation of the system for extremely wet soil conditions. Ground disturbance results show about 11% of the total harvest area was disturbed to some level. Soil compaction in disturbed areas was increased by 21.4% in the most severe cases. Rut depth averaged 13-inches in the most severe cases and was limited to the corridor trail and only in that portion of the trail not covered with slash. Logging slash from tops and limbs removed from felled trees covered up to 69.9% of the corridor trail distance in the clearcut trials and was shown to limit compaction significantly in that portion of the trail. In first thinning harvest trials with 160 trees per acre left, 2.1% of the residual trees had some bole injury and in the second thin trials injury to the stand was 0.6%. The ability of the harvester to operate with 7th row removal in an 8 by 8-ft spacing stand should allow leaving more quality crop trees in first thinning operations compared to conventional feller-buncher/grapple-skidder operations doing 3rd or 5th row removal in first thinning harvests. The value of that capability needs to be further explored.

Acknowledgments

The authors would like to thank Martin Timber Company employees William F. Weiger (Forest Manager) and Sam Soule (District Forestry Manager) for their cooperation with this study, Ponsse employees Hannu Suutari and Kalevi Turkia, and cooperating logging the machine system. The timber cruise was performed by Martin Timber Co. employees.

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Authors Affiliation

Clyde G. Vidrine
Louisiana Tech University
Ruston, LA

Cornelis deHoop
Louisiana State University
Baton Rouge, LA

Bobby L. Lanford
Auburn University
Auburn University, AL

Harvesting Yield Related to Geometric Form of the Operation Area

Dario Aedo-Ortiz
Rodolfo Neuenschwander
Pablo Aracena

Abstract

The yield of a harvester-forwarder thinning operation was determined and analyzed under different alternatives of geometric forms of the harvesting unit.

The project was developed using Discrete - Event Simulation. The model was generated and run in ProModel PC for Windows environment.

No significance difference in yield was obtained when the average extraction distance remain constant under different shapes of the operation area.

Average extraction distances that were 110 m longer or shorter in relation to the original operation distance was significantly different in yield.

Keywords

simulation, logging analysis, mechanized logging, thinning productivity, harvester, forwarder.

Introduction

The use of cut-to-length systems is increasing around the world, USA and Chile are not the exceptions. In this context, production studies of the harvester - forwarder system in both thinning and clear cut operations are highly important.

This article presents the results of a research referred to harvesting yield under different geometric forms of the operation area based on the project DIUT 310-40 at the Forest Production Department of University of Talca related to the analysis of the input and output data of a forest harvesting simulation model. The used model is related to a discrete-event simulation research developed at the Forest Engineering Department of Oregon State University (Aedo-Ortiz 1994, Aedo-Ortiz et al.1997).

The harvesting system analyzed consist of single-grip harvester and a forwarder operating in a softwood thinning operation in the Pacific Northwest (Kellogg & Bettinger 1994).

The actual system was unbalanced, the bottleneck was produced by the forwarder. The forwarder unloading time consumed more than 9 minutes in average per cycle. Therefore, it was considered to include a new machine in the system. In this case was included a loader because this machine allowed both a reduction in the unloading time and a higher production.

The main goal of the study is to quantify the influence of the geometric form and average extraction distance of the operation area in the yield of the harvesting system considering the operation as a stochastic process, i.e. the confidence limits for the yield are more important than its average.

Methodology

The discrete-event simulation model was developed under ProModel PC environment. The two variables of the system that are directly related to the geometric form of the operation area are the traveling empty distance (ted) and the traveling loaded distance (tld) of the forwarder. In this case tld is function of ted.

Then, only the ted variable is generating the randomness related to the geometric form of the operation. The experiment allowed only variability of the ted between replications of the simulation run. In other words, statistical distributions and linear regressions are modeling the system, but the groups of random numbers that represents the model are constant between replications with the only exception of the group related to the ted.

The operation area of the base model has a minimum extraction distance (med) = 77 m, a maximum extraction distance (Med) = 728 m, and the average extraction distance (AED) = 280 m. The area form can be modeled by a Beta distribution with shape parameters $a_1 = 1.386$ and $a_2 = 3.072$ (K-S p-value = 0,54), see Figure 1.

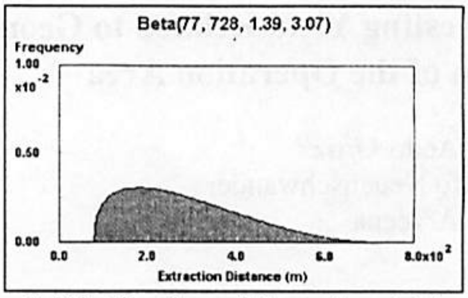

Figure 1. Distribution of the ted variable of the base model.

Three experiments were developed; each of them is explained below.

Case 1

The first questions to answer was: If med, Med and AED remain the same as in the base model, but the form of the operation area change, does the yield change significantly?

In this experiment, four different forms were considered, these are showed in figures 2, 3, 4 and 5.

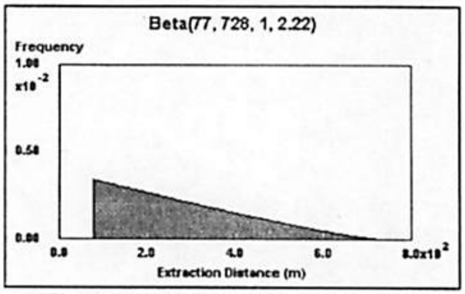

Figure 2. Alternative shape 1.

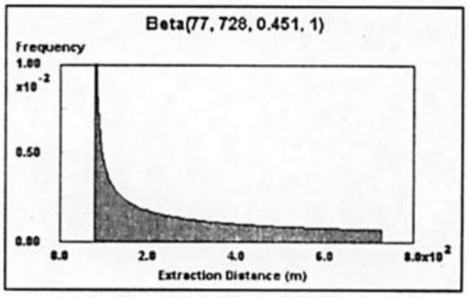

Figure 3. Alternative shape 2.

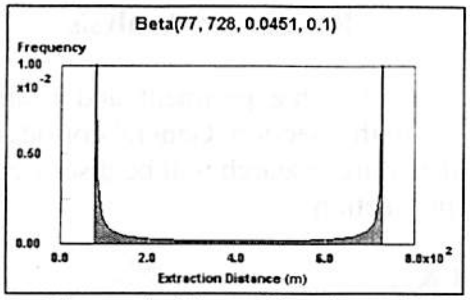

Figure 4. Alternative shape 3.

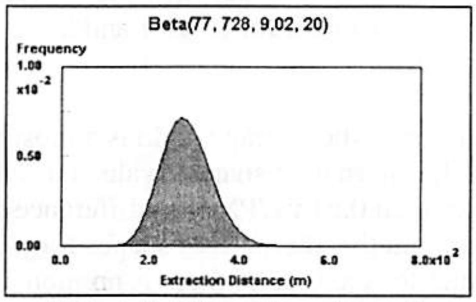

Figure 5. Alternative shape 4.

Case 2

The second question to answer was: If med and AED remain the same as in the base model, and symmetric forms around AED are considered, does the yield change significantly?

In this experiment, six different forms were considered; these are showed in figures 6 to 11.

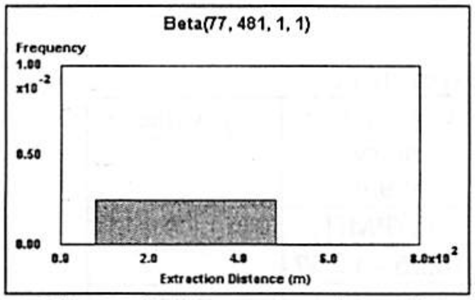

Figure 6. Alternative shape 5.

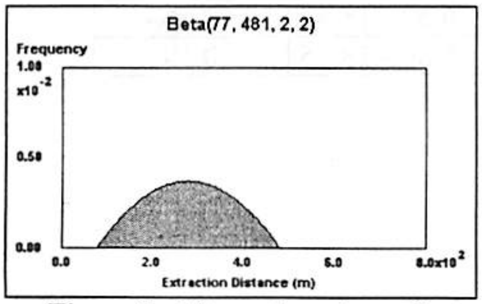

Figure 7. Alternative shape 6.

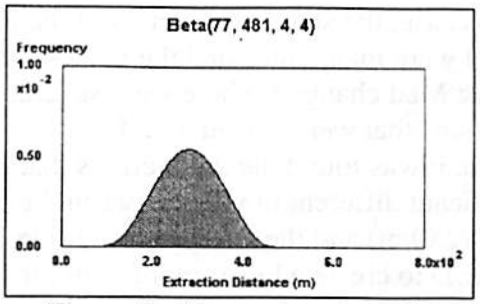

Figure 8. Alternative shape 7.

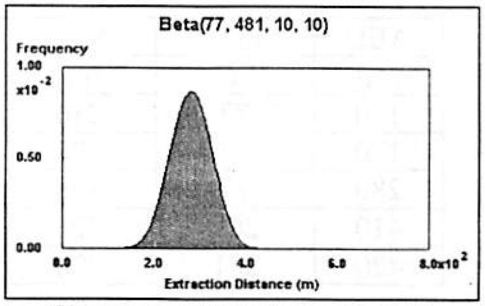

Figure 9. Alternative shape 8.

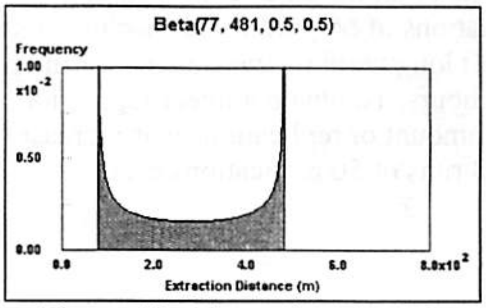

Figure 10. Alternative shape 9.

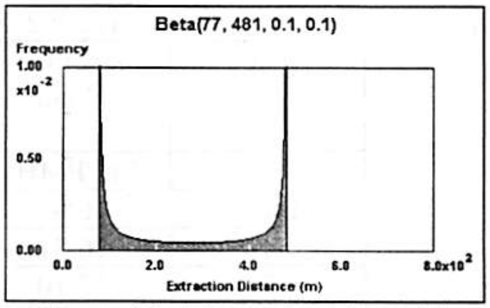

Figure 11. Alternative shape 10.

Case 3

The questions to address in this case were two: 1) If the same shape of the base model is maintained, how much does the AED need to change to cause a significant difference in yield?; and 2) can a linear regression between AED and average yield be found?

In this case, the shape parameters of the base model were maintained and the values for AED, med & Med changed. There were several situations that were considered. Using binary search, it was found the AED critics that gave a significant different in yield between the base AED (280 m) and the alternatives. Table 1 shows the AED to create a linear regression for the yield.

Table 1. Alternative areas considered under case 3.

AED	med	Med
[m]	[m]	[m]
120	77	216
170	77	377
280	77	728
410	267	728
420	281	728

Finally, each of the runs that were used in the analysis of all the cases consisted of 50 replications of 66 productive machine hours (PMH) long within a transient or warm up period of 18 hours. To obtain a linear regression, in case 3 the amount of replications was increased up to 150 (3 runs of 50 replications each).

Results and Analysis

The results of each experiment and its analysis are given in this section. General considerations about the entire research will be discussed in the following section.

Case 1 & 2

The results of these experiments are given in Table 2 and Table 3 for cases 1 and 2 respectively.

In these cases the average yield is almost the same for all the alternative shapes evaluated. There is no more than 0.61 m^3/PMH of difference between the base and the alternatives shapes for the first case, and for the second there is no more than 0.48 m^3/PMH. Moreover, the p-values associated to a comparison of two samples through a t-test are for case 1 bigger than 0.19, when one of the sample is the base shape and for the case 2 bigger than 0.26.

Then, the hypothesis that the yield of the base shape is equal to the yield of the alternative shapes can not be rejected, when AED is maintained constant despite of 1) the shape of the operation area, 2) the minimum extraction distance and 3) the maximum extraction distance.

Table 2. Results of case 1 experiment.

Shape	Average Yield	Standard Deviation	Confidence Interval at 95%	p-value
	[m^3/PMH]	[m^3/PMH]	[m^3/PMH]	[-]
Base	16.92	2.27	16.26 - 17.57	-
1	16.31	2.84	15.49 - 17.13	0.24
2	17.10	2.59	16.36 - 17.85	0.70
3	17.42	3.11	16.52 - 18.32	0.36
4	17.51	2.22	16.86 - 18.15	0.19

Table 3. Results of case 2 experiment.

Shape	Average Yield	Standard Deviation	Confidence Interval at 95%	p-value
	[m^3/PMH]	[m^3/PMH]	[m^3/PMH]	[-]
Base	16.92	2.27	16.26 - 17.57	-
5	17.40	2.02	16.81 - 17.98	0.26
6	16.98	2.28	16.32 - 17.64	0.89
7	16.77	2.45	16.05 - 17.48	0.75
8	16.76	2.71	15.98 - 17.55	0.76
9	16.93	1.89	16.38 - 17.48	0.98
10	16.98	2.42	16.28 - 17.69	0.88

Case 3

In this case, the significant difference in yield ($p\text{-value} < 0.05$) was found between the base AED and AEDs of 180 m and 390 m. It is important to highlight that a difference between AED bigger than 110 m is required to have confidence intervals that are not overlapping at a 95% of confidence.

The linear regression between yield in m^3/PMH and AED in m found is given below.

$$\text{MEAN(Yield/AED)} = 20.798 - 0.013 \times \text{AED}$$

$$\text{p-value} \qquad 0.000 \quad 0.000$$

$$R^2_{ADJ} = 0.3312$$
$$120 \leq \text{AED} \leq 420$$
$$n = 750$$

The residual and probability plot of the regression had acceptable shapes. It is important to mention that the maximum expected yield of the system is 20.9 m^3/PMH, but the regression allows only mean yield between 15.3 and 19.2 m^3/PMH for 420 and 120 m respectively.

Conclusions

Remarking that the analysis was developed allowing just variability due to geometric variables of the operation area, the cut-to-length system gave no significant difference in yield when alternative shapes were analyzed under the same AED. It was necessary to modify the AED of the base operation area in more than 110 m to obtain significant difference in yields.

Acknowledgements

Funding for this paper came from the Research Department (Project 310-40) and the College of Forest Sciences of University of Talca, Chile. Special thanks to Michael Bourke for the critical review of the manuscript.

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Authors

Dario Aedo-Ortiz and Rodolfo Neuenschwander are at the Forest Production Department of University of Talca, Talca, Chile. Pablo Aracena is private consultant, Talca, Chile.

Tools for road location and cable setting design: Identifying ridges by running GIS hydrologic functions on inverted topography

Finn Krogstad

Abstract

Ridge networks can be viewed as the topographic negative image of stream networks, suggesting that ridge networks might be mapped by running GIS hydrologic functions on inverted topography. Two approaches for connecting local ridge networks are considered: leveling vs. bridging the peaks. The resulting ridges identify topographic limits on cable yarding. The ridge network can be tailored to the size of the cable system under consideration by changing the ridge extent so as to ignore minor and more easily spanned ridges. This approach is of limited utility in topography in which ridges are not well defined (i.e. glaciated or terraced) and are not significant in road and harvest layout. This approach may be a useful addition to our set of planning tools.

Keywords

ridges, GIS, harvest planning, transportation planning.

Introduction

Rapid identification of ridge networks may aid harvest design in identifying the topographic limitations on cable systems and might aid road design in avoiding streams and steep side-slopes. Alternate approaches for identifying ridges using digital elevation models (DEMs) include local topographic slope and curvature. Slope provides an estimate of road construction costs, and in steep terrain slope is minimized at ridges and streams (where there is no clear upslope direction). Local topographic curvature can be used to identify the divergent knobs that can make good cable landings. While slope and curvature identify local site limitations, they don't 'see' beyond the adjacent cells, so they don't identify the larger topographic features that control harvesting and transportation.

Streams on Inverted Topography

Ridge networks (Figure 1) can be thought of as a mirror image of the drainage network, suggesting that we might identify ridges as inverted streams by running GIS hydrologic functions on inverted

topography (multiplying the elevation in each cell of a DEM by -1). A standard approach to delineating a stream network (ESRI 1991) is to identify local flow direction, and hence the number of upslope cells (contributing area) that eventually flow into a given cell. The stream network can then be defined as all cells that have more than some minimum contributing area.
If a grid cell is below all its immediate neighbors, then all flow will stop there. It is possible that these 'sinks' are real, but since water and sediment tend to fill local sinks, these 'sinks' are commonly the result of measurement error. A common approach to creating a working stream network is to fill these local sinks up to the level of their lowest neighbor, so flow can continue on (ESRI 1991). This approach can be applied to delineating ridge networks as follows:

1. Invert topography (multiply by -1)
2. Fill sinks (i.e. cut inverted peaks)
3. Identify flow direction for each cell
4. Identify streams (ridge network) as all cells exceeding some minimum contributing area.

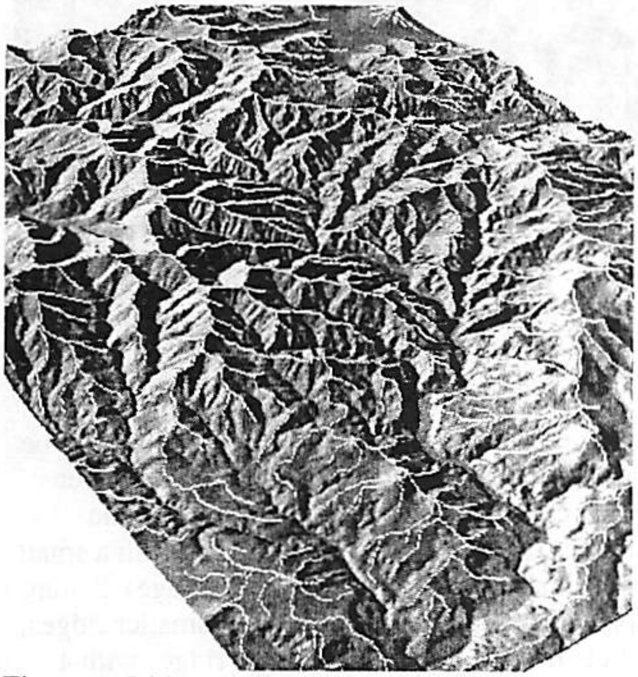

Figure 1. Ridge networks (white lines) suggest constraints on harvest and road designs in steep topography.

The resulting ridge network (Figure 3) is a poor representation of the ridge network in all the areas where ridges had to be cut down to 'flow' past a saddle. The accuracy of the ridges at each saddle however suggests an alternate approach to identifying ridge networks.

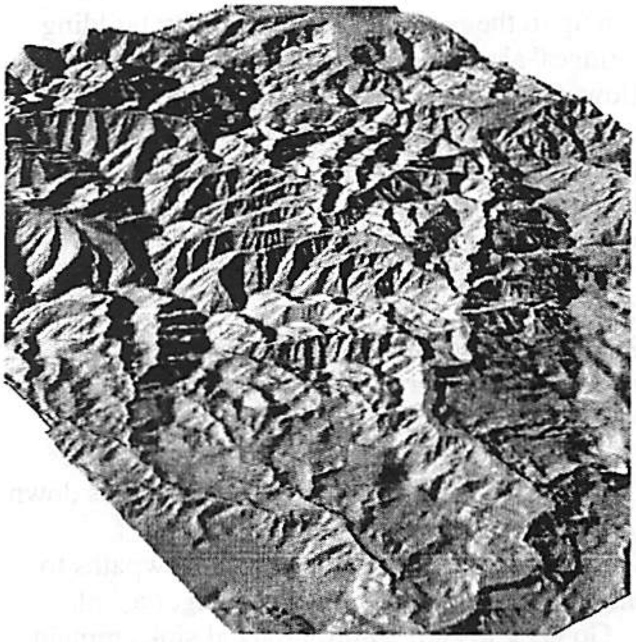

Figure 2. Inverting the topography in Figure 1 yields a similar looking topography with its own set of ridges and stream networks.

Figure 3. Cutting off peaks so the network can 'flow' to the next peak results in a ridge network that does not follow the original ridgeline.

Bridging Saddles

Instead of cutting off the peaks, we can identify the saddles between peaks and the streamlines that run up to the peaks on either side. By building 'bridges' along these ridgelines, we can make a flow pattern that allows the ridge network to continue across saddles without loosing the alignment of the original ridgeline. This more lengthy process includes the following steps, and will be used in the rest of the paper.

1. Invert topography
2. Identify local sinks (inverted peaks)
3. Delineate watersheds of these sinks
4. Identify cells bordering each watershed
5. The lowest of these border cells are saddles
6. Identify the flowpath from these saddles down to the adjacent two sinks
7. Reset the elevation along these flowpaths to that of the local sink so it is no longer a sink
8. Go back to step 2 until no local sinks remain
9. Identify all cells with a contributing area greater than the prescribed minimum

Extent of Ridge Networks

Just as with stream networks, one might ask where a ridge begins. A stream network can be defined in GIS by determining local flow directions, counting the number of cells that flow into a specific cell, then defining the stream network as all the cells that exceed a certain minimum contributing area.

The extent of the ridge network will similarly vary with the size of the minimum downslope area needed to start a ridge network (Figure 4). This downslope contributing area should be set to identify the ridges that will tend to limit the yarding system used. A small downslope area will identify all minor ridges that will be of significance to shorter reach cable systems. Settling a larger downslope area will produce a ridge network that ignores the smaller ridges that can be spanned by longer cables.

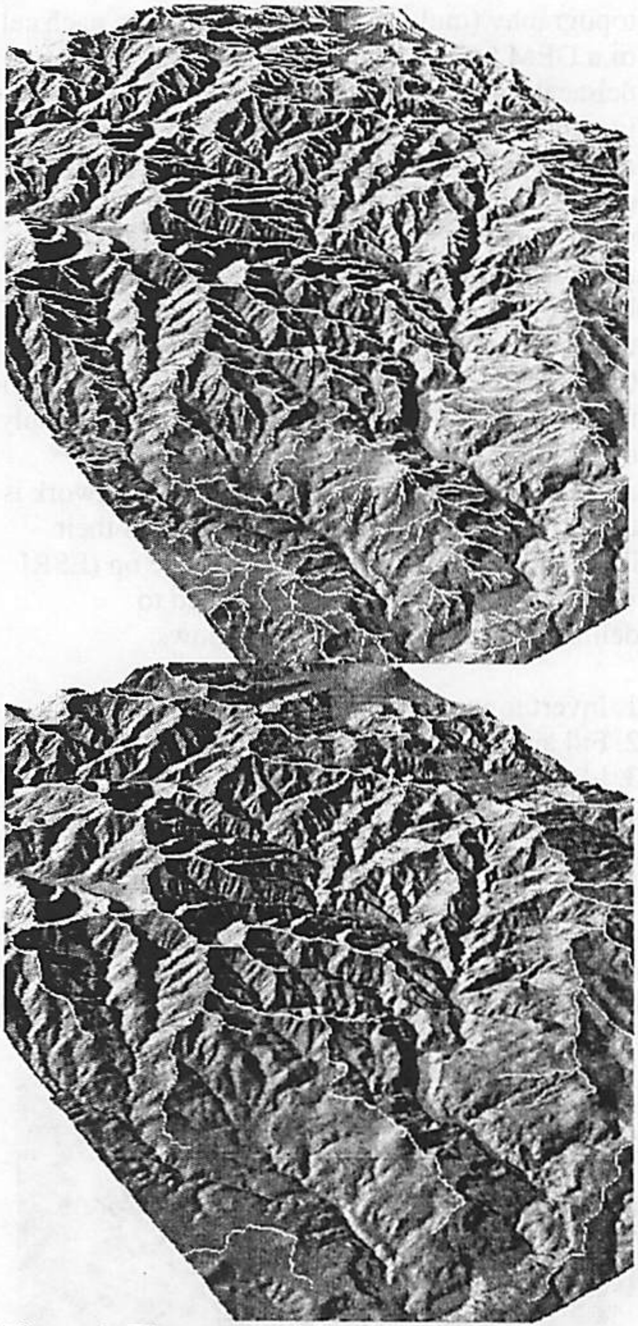

Figure 4. The extent of the ridge network can be tailored to the yarding system used. A shorter reach cable system will be restricted by the smaller ridges that can be identified with a small contributing area (15 acre, upper image). A long span cable system can span these smaller ridges, and is limited only by the larger ridges with a large contributing area (100 acre, lower image).

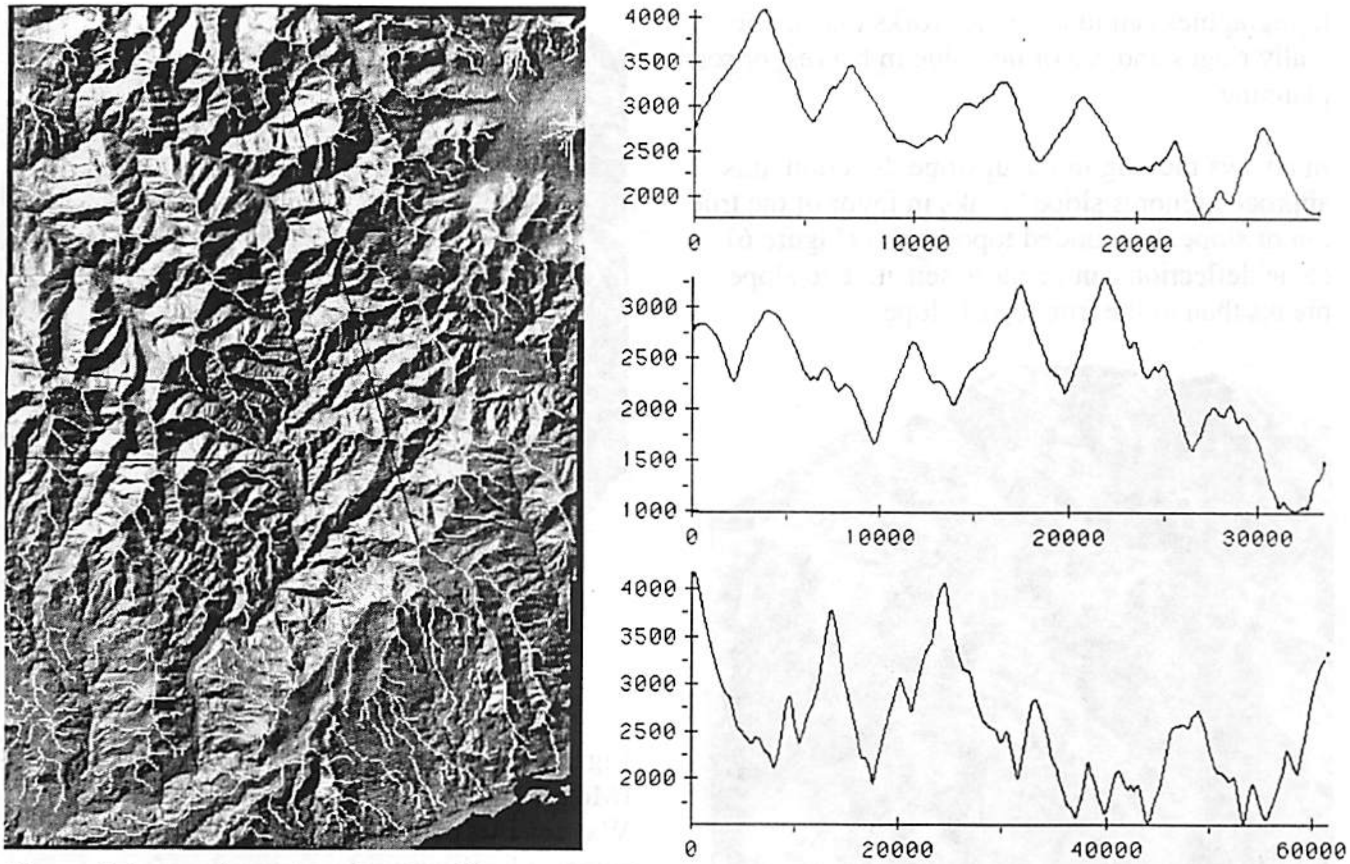

Figure 5. Inspection of random profiles across a landscape suggests that this approach is roughly successful at finding the ridges that will constrain cable settings and the non-ridges that will not. The bottom profile corresponds to the generally North-South line on the shaded map.

Preliminary Evaluation

These ridges appear to be well correlated with road locations, landings, and setting boundaries in the planning area for which it was developed (Upper Washougal R., Washington). The coarse ridge network in Figure 4 is well correlated with existing and planned road locations (where ownership permitted) and the span of the skyline harvest units. While grades along the smaller ridges were far too steep for useful road alignment, the lower extent of these ridges roughly approximated the landing locations for planned conventional reach skyline settings (Schiess 1998), so an alignment passing through the lower ends of these ridges actually did approximate the planned road network.

Another quick approach to evaluating these ridge delineations is to lay profiles across a landscape (Figure 5) and visually check that the ridges identified on the map would really provide topographic limits to long span cable yarding. The ridges identified on the map generally correspond to the high points along the profiles, and notable exceptions (such as the 27000-30000 section in the middle profile) correspond to areas where the profile is running parallel the ridge. A more detailed evaluation of deflection and cable reach would involve site specific profile alignments (not random) but the following problems may render irrelevant any more detailed testing.

Problems in Other Topographies

This technique for ridge identification was designed for steep dissected topography, in which harvest and transportation options are severely limited by ridges. The approach is less successful as a guide to road and setting design in areas where ridges are not the dominant topographic feature. Independent of whether ridges exist or not, this algorithm will still invert the topography, 'pour water' on it, and identify the resulting flow paths as ridges. The following examples show how applying this approach many other topographies can identify networks that are not really ridges and are of no value in harvest or road planning.

In always moving in the upslope direction, this approach ignores slope breaks in favor of the true top of slope. In rounded topography (Figure 6) cable deflection can be more sensitive to slope breaks than to the true top of slope.

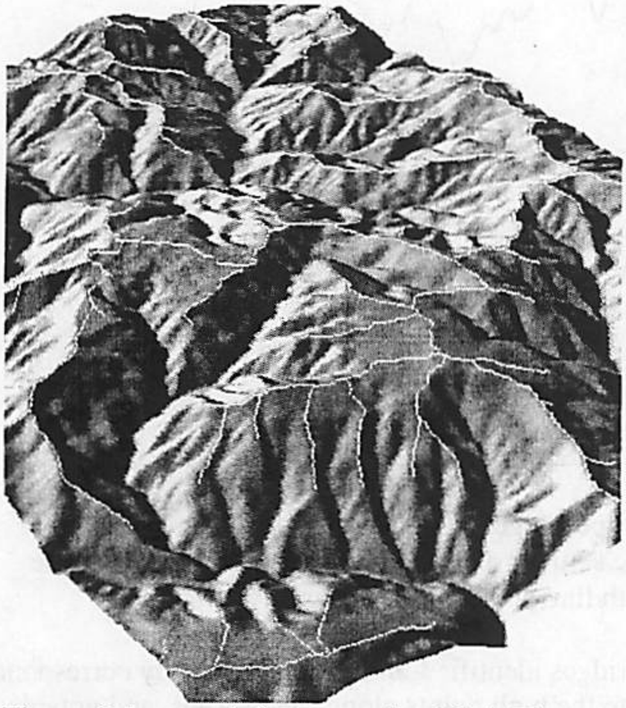

Figure 6. In rounded topography (High Plateau Mountain quadrangle, Northern California) the resulting ridges will be less significant in harvest planning than the slope breaks.

Glacial erosion of broad valleys (Figure 7) erases any preexisting ridge network, leaving smooth valley walls without distinguishable ridges. This method will identify the raised areas along the valley wall, but these are of minimal value in either road or setting layout. The incised glacio-alluvial terraces in the valley bottom also lack a recognizable ridge network. No clear approach has been identified to ignore all of the topographies in which no real ridge exists, but subsequent revisions will at least be focussed on identifying exact saddle locations, and eliminating the embarrassing situations in which the ridge network crosses the stream network (Figure 7).

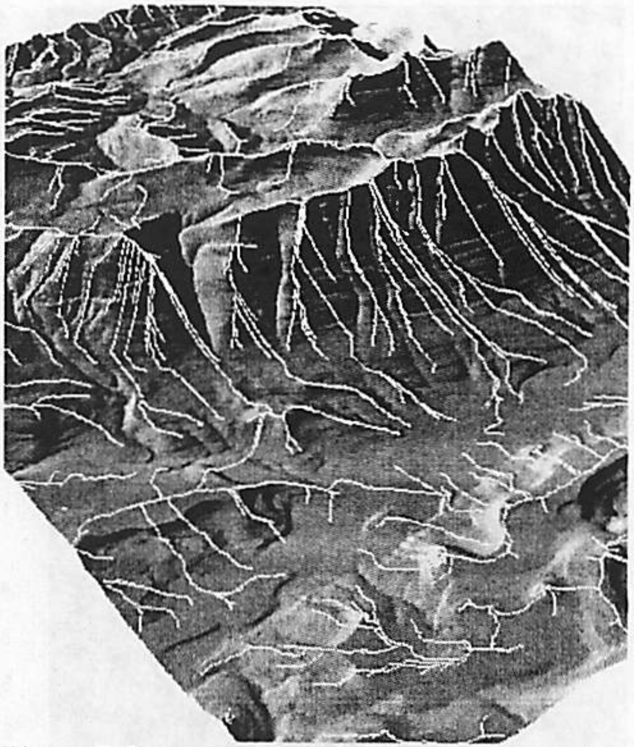

Figure 7. In topographies lacking any real ridges (Mount Higgins quadrangle, Northwest Washington) this approach will still try to find ridges, identifying ridge networks of no topographic significance. Neither the glacially carved slopes in the middle, nor the terraced glacial outwash in the foreground have ridges that would be of significance in harvest or transportation planning.

Applications

This approach to ridge network identification will never replace slope and curvature mapping as a guide in planning harvest layouts and road networks. It may however be a useful addition to other design tools, and may provide a quick tool in its own right. The gradient of the ridgeline can be shown in the color of the line, providing a visual guide for identifying ridge sections where roads can follow the ridgeline vs. where the road will have to drop down to a sideslope road. The ridge network might also replace contour lines as the topographic information laid on maps that already cluttered by many other information layers.

Acknowledgement

I would like to thank of Phil Hurvitz for the substantial assistance he has provided in this project.

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Affiliation

College of Forest Resources,
University of Washington,
Seattle WA, 98195,
206.685.2091,
fkrogsta@u.washington.edu.
http://members.aol.com/FKrogstad

Comparison of Commercial Thinning Production and Costs Between Silvicultural Treatments, Multiple Sites, and Logging Systems in Central Western Oregon

Mohammad M. Hossain
Eldon D. Olsen

Abstract

This study is focussed on the comparative analysis of commercial thinning production and costs between alternative thinning treatments, multiple sites, and logging systems. The three silvicultural treatments are: (1) light thinning, leaving 110-120 tpa, (2) heavy thinning, leaving 50-55 tpa, and (3) light thinning, with small openings (0.5 acre opening in 20% of the area) followed by under planting with a mixture of Douglas-fir, western hemlock, and western redcedar. The sites include units from five thinning sales (Walkthin, Tapthin, Millthin 1, Millthin 2, and Flatthin), which are located in three USFS ranger districts: Oakridge, McKenzie, and Blue River located in the central Western Oregon of USA. The three different logging systems used in thinning were small skyline yarding system, tractor skidding system, and a mechanized (cut-to-length) system depending on topography and requirement. The detailed time study data collection method was used. This is one of the first instances where such a large-scale comparison has been made under controlled conditions.

Keywords

thinning production/costs, skyline yarding, tractor skidding, cut-to-length, delay -free cycle time, costs comparison.

Introduction

Staffs from the Willamette National Forest and Oregon State University have started a joint study on managing young conifer stands for multiple resources in the Central Western Cascades of Oregon. Young (35 to 55 year old) Douglas fir stands are the target of intensive management in the next several decades (Kellogg 1993). Concurrent research is being done on the response of vegetation and wildlife to thinning regimes. This report's focus is on harvesting production rates and costs.

The overall study design consists of four replications of four silvicultural treatments (Kellogg, et al., 1997):

- "Control" (no thinning), with approximately 618 trees per hectare (250 tpa).

- "Light thinning", leaving 272-296 residual trees per hectare (110-120 tpa).

- "Light thinning, with small openings" (0.20 hectare (0.5 acre) openings in 20% of the stand). After logging, the openings were planted with a mixture of Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*).

- "Heavy thinning", leaving 124-136 residual trees per hectare (50-55 tpa), followed by underplanting with a mixture of Douglas-fir, western hemlock, and western redcedar.

The sites include units from five thinning sales (Walkthin, Tapthin, Millthin 1, Millthin 2, and Flatthin), which are located in three USFS ranger districts: Oakridge, McKenzie, and Blue River. Since no harvesting was done in the control units, they were not part of this report.

Stand density, thinning prescription, and tree removal for different treatments, sites, and logging systems are shown in Tables 1, 2, and 3 (Kellogg, et al. 1997).

Each location has been divided into three treatments (light, heavy, and light with openings). Again each treatment is replicated into two sites depending on slope limitation for tractor versus skyline and mechanized versus skyline. Additional summary information of these thinning sales of the Willamette Young Stand Project is shown in Appendix A.

Because of the interdisciplinary nature of the Willamette Young Stand Project, a uniform name was given to each of the treatments. These names focused on the post harvest condition of the stand no matter what the site location, the equipment system used, or preharvest stocking level. The light thin had a post harvest density of 115 trees per acre. The heavy thin had 53 trees per acre. The light with openings had 0.5-acre openings in 20% of the unit for a density of 92 trees per acre for the entire unit.

The heavy thin treatments tended to be assigned to units with the lowest initial stocking levels. The designation as a heavy thin treatment does not therefore mean that it always had more trees removed than a light thin. In three of the five sites, the heavy thin actually had the fewer trees removed than the light thin. The assignment of the treatments was beyond the control of this report.

The use of these treatments in the comparisons of harvesting costs implies that the post harvest condition is more important than the trees per acre removed. This would be true if interference of the residual trees with the harvesting activities was significant. This was not formally evaluated.

Little is known about commercial thinning under these conditions. Appropriate time and motion studies are needed during the logging operation to evaluate harvesting economics. The analysis for this purpose is confined to a single entry harvesting model with roads in place. Researchers from the Department of Forest Engineering, Oregon State University did the time and motion study data collection.

The effectiveness of three different logging systems will be compared: small skyline yarding system, tractor skidding system, and a mechanized (cut-to-length) system (Kellogg 1993). The types and specifications of logging equipment and the method used are shown in Appendix B. This Appendix was prepared from Kellogg, et al. (1997 and 1998).

Table 1. Thinning density and harvesting intensity of skyline yarding sites in trees per acre

Site	Walkthin			Tapthin			Millthin 1		
Treatment	Pre-Harvest	Post-Harvest	Thinning removed	Pre-Harvest	Post-Harvest	Thinning removed	Pre-Harvest	Post-Harvest	Thinning removed
Light	233	115	118	260	115	145	---	---	---
Heavy	169	53	116	180	53	127	195	53	142
Light w/ openings	212	92	120	230	92	138	---	---	---

Table 2. Thinning density and harvesting intensity of tractor skidding sites in trees per acre

Site	Tapthin			Millthin1			Millthin 2		
Treatment	Pre-Harvest	Post-Harvest	Thinning removed	Pre-Harvest	Post-Harvest	Thinning removed	Pre-Harvest	Post-Harvest	Thinning removed
Light	260	115	145	200	115	85	---	---	---
Heavy	180	53	127	195	53	142	---	---	---
Light w/ openings	---	---	---	---	---	---	196	92	104

Table 3. Thinning density and harvesting intensity of mechanized site in trees per acre

Site	Flatthin		
Treatments	Pre-Harvest	Post-Harvest	Thinning removed
Light	262	115	147
Heavy	334	53	281
Light with openings	214	92	122

This paper will focus only on delay free multiple regression models building on skyline yarding, tractor skidding, mechanized harvesting and forwarding operations. The regression models will be constructed based on delay free detailed time study data. The predicted values from the regression models will be used for cost calculation. The mean costs for each treatment will be determined using actual production, current ownership costs and operating costs of the machine, and labor costs of personnel.

Commercial thinning logging production rates and costs for three levels of residual (light, heavy, and light with openings) will be reported.

No detailed analysis or regression model building will be done for the felling and bucking operations. The felling cost data available from the study of Kellogg et al. (1997) on tractor sites will be used here for calculating total harvesting costs. Total costs of felling and bucking, and tractor skidding will be determined to make it comparable with the total mechanized harvesting and forwarding costs.

Objectives of the study

1. to compare harvesting costs between the treatments at each site
2. to compare harvesting costs between sites for the same treatment type
3. to compare harvesting costs between logging systems for the same treatment type.

Methods and Procedures

Total extraction costs comparison

The average extraction costs in \$/m^3, \$/ccf and 95% confidence intervals for each treatment were determined.

Treatment comparison

The results of the regression models are sufficient to compare treatments in each site. As the indicator variables approach (Olsen, et al. 1998) for regression model building is used, the coefficient of the significant indicator variable for treatment will indicate the amount of difference of the treatment from the base treatment. In this analysis light treatment is set up as base. In this stage the comparison is on a cycle time basis. Later comparisons of treatments were done after calculating total extraction costs. The 95% confidence interval of mean costs was also calculated for comparison. The predicted value of the mean cycle time was calculated by using average variable values in the regression equation.

Thinning sites comparison

The treatment cost calculated in each site is the basis for comparing across sites. The sites are compared between the same treatment type from different sites. For example, light treatment of skyline yarding system of Walkthin site is compared with that of Tapthin site. Mean extraction cost along with its 95% confidence interval was calculated for comparison. The comparison of sites was also done over a range of extraction distances.

Logging systems comparison

Here the extraction costs are compared for the same treatment type among three systems. For example, heavy thin extraction costs between Tapthin skyline yarding, Tapthin tractor skidding and Flatthin forwarder operations were done. For this purpose extraction distance is varied within a range applicable to all systems. Costs were calculated for each system for each of the distance. Confidence intervals at the 95% level were also calculated at different distance for comparison of the mean costs.

Felling costs comparison in ground based

The felling costs of tractor site and harvesting costs of mechanized site are compared between the same treatment type of both sites. Diameter at breast height (DBH) varied from 15 cm to 35 cm. Mean costs at both sites for each diameter type along with 95% confidence intervals was calculated for comparison. The example of this cost comparison is between the light thin tractor site manual felling and the light thin harvester operation.

Total costs comparison in ground based

The total harvesting costs of felling and tractor skidding and similarly total costs of harvester and forwarder operations were calculated. The costs along with their 95% confidence intervals are compared between the tractor site and mechanized site for each treatment type.

Comparison limitations and variability

The initial stocking levels were not uniform among treatments or between sites. So although the final stocking levels after harvesting are identical for the same treatment (even between sites and logging systems), the removal rate, measured in trees per hectare, varied a great deal. This introduced uncontrolled and unwanted variation into the comparisons. For instance the heavy thinning did not always result in the highest number of trees removed as would be expected.

Logging crews and equipment were only held constant at each site. Therefore between sites comparisons had many sources of variation. Two other serious variations occurred due to a mixture of seasons and tree diameter differences among sites. Crew and season were not possible to include as variables because the data were not collected that way.

Results

Table 4 and Table 5 summarizes all of the costs showing mean costs and 95% confidence interval. Table 6 is the summary table of statistical difference at 95% confidence level comparing costs between treatments, sites, and logging systems. The variation of skyline yarding cost with extraction distance is shown as an example in Figure 1. The comparison of heavy thin extraction costs between three logging systems is shown in Figure 2. The Tapthin felling costs and Flatthin harvesting costs are compared between treatments as shown in Figure 3. The felling and harvesting costs variation with tree size are shown in Figure 4.

Discussion and Conclusions

Comparison of treatments

Using the average values of regression variables and a common delay percentage, a comparison can be made of each treatment within a site. These are shown in Table 6a for seven situations. This comparison has the best standardization of conditions for this study because it was on the same site with the same equipment and crew. The yarding sites used skyline machines while the skidding sites used crawler tractors. The Tapthin yarding and the Millthin yarding showed no difference in any of the treatments. The Walkthin yarding, Tapthin skidding, and Millthin skidding found a difference between the light thinning and the other treatment(s). In Flatthin forwarding the light with openings was different than the other two treatments.

The general conclusion is that there is not a marked difference in extraction costs between treatments. The comparison is with the light thin treatment as the base. The heavy thin was more expensive in the tractor-logged cases. The light with openings was more expensive in the forwarding case. In the other cases, the treatments were higher on one site and lower on another, giving inconclusive trends.

Comparison of sites

The sites were compared with each other for a given treatment. There are many sources of variation between sites, primarily differences in the equipment and crew, the logging method, the delays, corridor and landing changes, and the treatment of the fiber material. Distance variables were standardized. Although the final stocking was held constant, the volume removed per acre could not be controlled and is different between sites. Only comparisons on the skyline yarding sites were possible.

No significant difference was found between the Walkthin yarding and the Tapthin yarding on light treatments nor on light with openings treatments.

All three sites were different on the heavy thin treatment. The comparison is shown in Table 6b. This demonstrates the range of costs that could be expected for a given treatment.

Table 4. Mean extraction costs of all sites with 95% confidence intervals in Metric unit

Site	Treatments		
	Light ($/m^3)	Heavy ($/m^3)	Light with Openings ($/m^3)
Walkthin yarding	19.98 ±1.63	17.24 ±1.38	18.47 ±1.50
Tapthin yarding	19.05 ±1.46	20.00 ±1.56	20.02 ±1.58
Millthin 1 yarding	N/A	25.96 ±2.51	N/A
Tapthin skidding	9.08 ±0.98	12.00 ±1.29	N/A
Millthin 1 skidding	6.59 ±0.67	9.95 ±1.99	N/A
Millthin 2 skidding	N/A	N/A	7.17 ±0.83
Flatthin forwarding	6.70 ±0.97	6.70 ±0.97	9.12 ±1.32

Table 5. Mean extraction costs of all sites with 95% confidence intervals in English unit

Site	Treatments		
	Light ($/ccf)	Heavy ($/ccf)	Light with Openings ($/ccf)
Walkthin yarding	56.63 ±4.62	48.85 ±3.92	52.35 ±4.24
Tapthin yarding	53.98 ±4.14	56.66 ±4.42	56.73 ±4.48
Millthin 1 yarding	N/A	73.57 ±7.11	N/A
Tapthin skidding	25.74 ±2.78	34.02 ±3.66	N/A
Millthin 1 skidding	18.69 ±1.90	28.19 ±5.64	N/A
Millthin 2 skidding	N/A	N/A	20.33 ±2.35
Flatthin forwarding	18.99 ±2.75	18.99 ±2.75	25.85 ±3.75

Table 6. Summary table of statistical difference at 95% confidence level. (Same letters in a row show no difference at 95% confidence level).

a. Costs comparison of treatments within site

	Light	Heavy	Light w/ Openings
Walkthin yarding	A	B	B
Tapthin yarding	A	A	A
Millthin 1 yarding	A	A	N/A
Tapthin skidding	A	B	N/A
Millthin 1 skidding	A	B	N/A
Millthin 2 skidding	N/A	N/A	N/A
Flatthin Forwarding	A	A	B

b. Costs comparison of yarding sites for same treatment type

	Walkthin Yarding	Tapthin Yarding	Millthin Yarding
Light	A	A	N/A
Heavy	A	B	C
Light w/ openings	A	A	N/A

On the tractor skidding sites the light and heavy were both significantly different between the two sites as shown in Table 6c. The Tapthin site had consistently higher costs.

c. Costs comparison of skidding sites for same treatment type

	Tapthin Skidding	Millthin 1 Skidding	Millthin 2 Skidding
Light	A	B	N/A
Heavy	A	B	N/A

Comparison of logging systems

The skyline yarding costs are approximately double the tractor skidding costs. The skyline costs are more sensitive to yarding distance, again increasing at a higher rate than skidding as the distance increases.

A comparison between the tractor and the forwarder can only be inferred. The mechanized system forwarding was only done on the Flatthin site. In addition the felling costs must also be included since the forwarding only works in combination with a harvester which bunches the wood along the skid trails prior to forwarding.

The harvester cost is much higher than the manual felling which accompanies the skidder operation. So although the forwarder has a cheaper cost than the tractor skidding for all treatments and over most of the extraction distances range, adding in the harvester cost negates the cost advantage. The two systems do not have statistically significant differences that are consistent.

The harvester cost changes nonlinearly with DBH. At about 25 cm DBH the harvesting cost is minimum (Figure 4).

Relative differences among treatments, sites, and systems

The most dramatic and consistent differences in the study were between the skyline yarding costs and the tractor skidding cost. Under all conditions the skyline was far more expensive. As yarding distance increased, the gap between costs widens even more.
The mechanized system has costs similar to tractor skidding at the study average distances. When distance increases the harvester/forwarder system becomes cheaper than the felling/skidding system.

Differences between sites were clear for skidding. The costs for skyline yarding sites tended to not be significantly different from each other when compared for the same treatment. This demonstrates that a range of costs can be expected based on site specific operating conditions.

The experimental design of the study standardized conditions for comparing among treatments. In about 1/2 of the parings a cost difference was established between treatments. Surprisingly, the light thin with openings tended to be more expensive than the base case of light thin.

In two of six of the parings the heavy thin was more expensive than the base case of light thin. In general the costs of heavy thin and light with openings were similar.

It appears that the cost of the thinning treatments need not be a major consideration when deciding on wildlife habitat manipulation. The most dramatic impact will be caused by the steepness of the slope dictating whether skyline yarding is required.

Importance of confidence intervals and sensitivity analysis

The confidence intervals allowed us to test if differences in costs were significant. These intervals were calculated from the unexplained variation in cycle times, cycle volumes, and delay percentages. This is often omitted in reports on production and costs. In general the confidence intervals showed that the differences in costs were not statistically significant.

Conclusions from this study are only valid within the range of conditions studied. Sensitivity analysis showed that extraction distance and piece size has a dramatic effect on the costs. When making comparisons these variables must be standardized. A sensitivity graph should be shown which reflects the changes in costs at different distance and DBH.

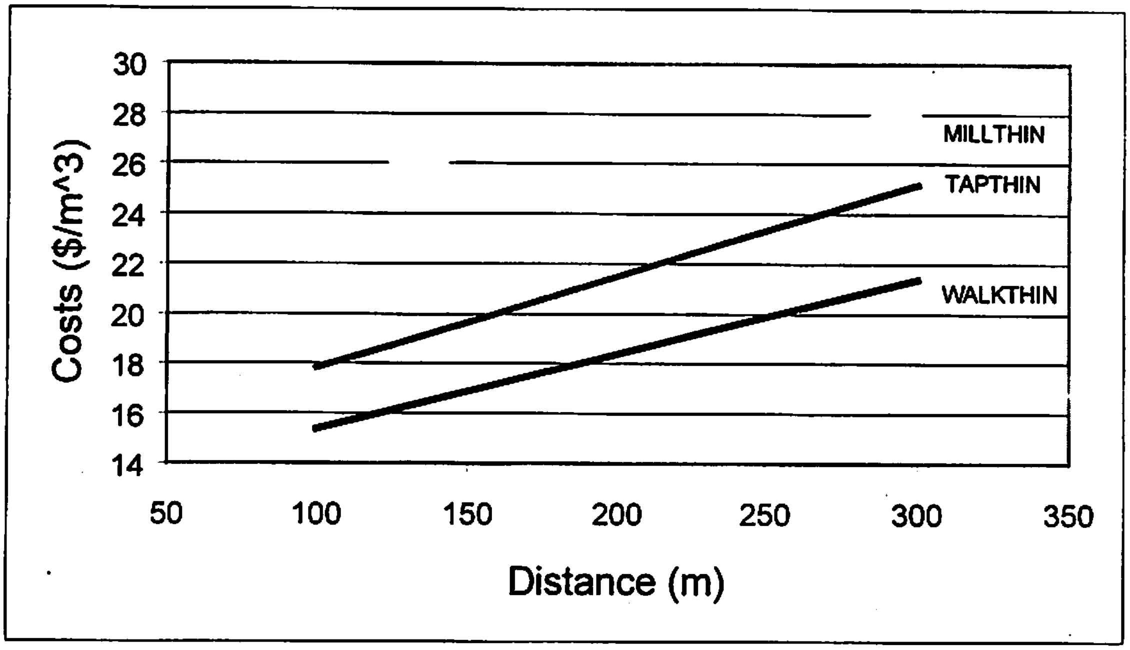

Figure 1. Comparison of heavy thin skyline yarding costs between sites at different distances.

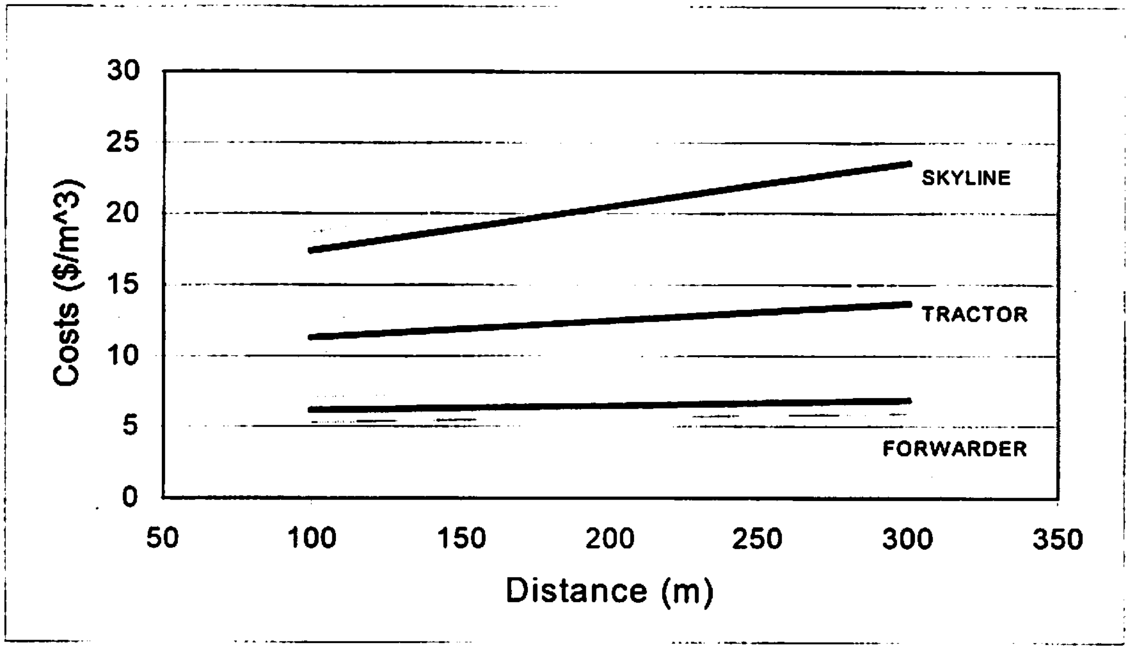

Figure 2. Comparison of heavy thin extraction costs between Tapthin skyline, Tapthin tractor and Flatthin forwarder operations at different distances with 95% confidence intervals.

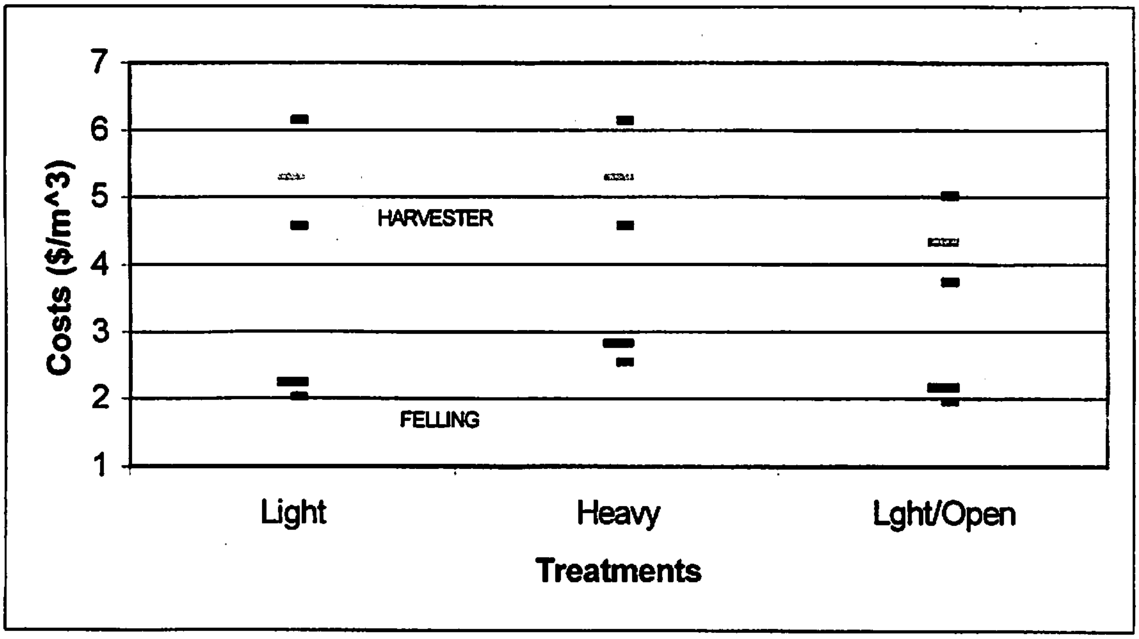

Figure 3. Comparison of Flatthin harvester operation costs with Tapthin tractor site felling costs with 95% confidence intervals.

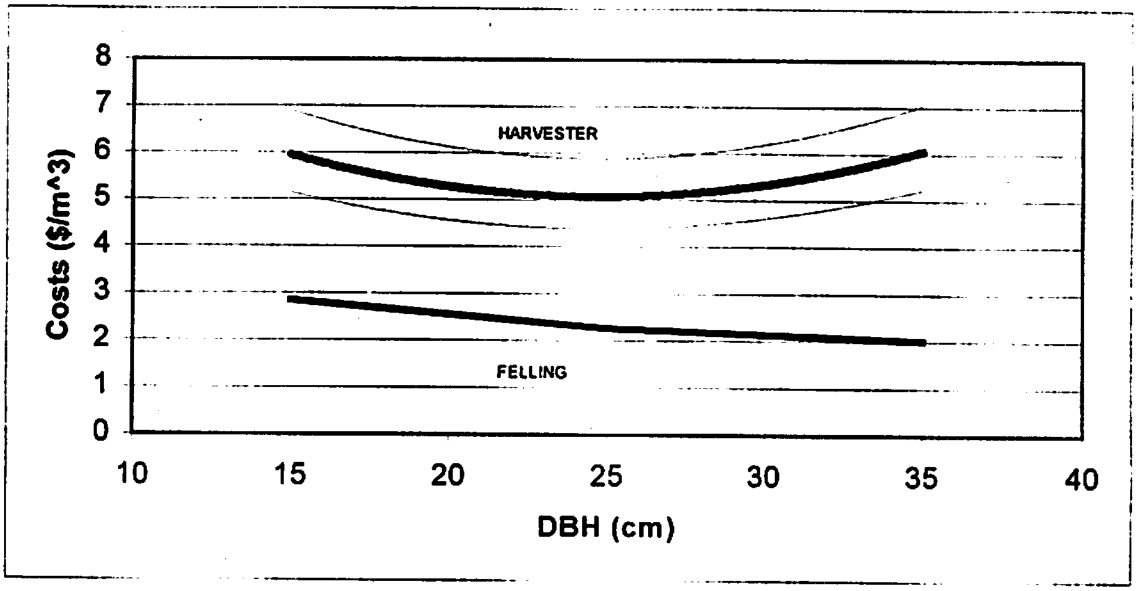

Figure 4. Comparison of costs between light thin harvester and light thin tractor site felling with 95% confidence intervals.

Acknowledgment

The authors are thankful to Dr. Loren D. Kellogg for his project data and Mr. Mark E. Miller, Jr. for providing help in data preparation and analysis.

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Authors

Dr. Mohammad M. Hossain is a Research Associate and Dr. Eldon D. Olsen is Associate Professor of Forest Engineering, Oregon State University, Corvallis, OR.

Appendix A

Table A.1. Study sites and stand description[1] before and after commercial thinning in Metric unit.

Sale Name (Ranger District)	Treatment	Unit #	Logging System	Unit area (ha)	Before harvest mean dbh (cm)	Before harvest trees /ha	Harvest cu.m. /ha	AED[5] (m)	Slope (%)	Harvest season
Walk Thin (Oakridge)	Light	85	Skyline	22.3	24.4	576	158	174	5-80	Summer
	Lt. w/Open.	86	Skyline	14.2	26.4	524	251	174	5-80	Sum/fall
	Heavy	88	Skyline	19.0	27.7	417	209	174	5-80	Winter
	Lt. w/Open.	89	Skyline	16.2	26.4	524	149	174	5-80	Sum/fall
Tap Thin (Blue River)	Heavy[2]	1	Tractor	11.7	27.7	445	145	211	0-40	Fall
	Heavy	1	Skyline	7.7	27.7	445	147	186		Sum/fall
	Light	3	Tractor	13.4	24.9	642	213	211	0-40	Sum/fall
	Light	3	Skyline	24.3	24.9	642	213	186		Sprg/sum
	Lt. w/Open.[2]	4	Tractor	1.6	27.2	568	165	211	0-40	Fall
	Lt. w/Open.	4	Skyline	12.9	27.2	568	184	186		Summer
Mill Thin 1 (McKenzie)	Light	1	Tractor	32.4	30.0	494	222	163	0-15	Summer
	Light[3]	1	Skyline	4.8	30.0	494	222	114	0-50	Summer
	Heavy	2	Tractor	6.9	30.0	482	250	163	0-15	Summer
	Heavy[3]	2	Skyline	27.9	30.0	482	250	114	0-50	Fall/wintr
Mill Thin 2 (McKenzie)	Lt. w/Open.	4	Tractor	19.8	30.0	484	279	163	0-15	Fall
Flat Thin (Oakridge)	Heavy	81	Mech.[4]	20.2	26.9	824	351	280	0-20	Sum/fall
	Lt. w/Open.	82	Mech.	38.9	30.0	529	296	280	0-20	Fall/wintr
	Light	84	Mech.	31.9	29.2	647	279	280	0-20	Fall

[1] The stand characteristics were determined from a cruise of trees greater than 13 cm. dbh. Commercial thinning occurred between December 1993 and March 1997 (Han 1997).

[2] Combined together to form one data set

[3] Combined together to form one data set

[4] Mechanized

[5] Average Extraction Distance

Table A.2. Study sites and stand description[1] before and after commercial thinning in English unit

Sale Name (Ranger District)	Treatment	Unit #	Logging System	Unit area (ac)	Before harvest mean dbh (in)	Before harvest trees /ac	Harvest ccf /ac	AED[5] (ft)	Slope (%)	Harvest season
Walk Thin (Oakridge)	Light	85	Skyline	55	9.6	233	22.5	570	5-80	Summer
	Lt. w/Open.	86	Skyline	35	10.4	212	35.8	570	5-80	Sum/fall
	Heavy	88	Skyline	47	10.9	169	29.8	570	5-80	Winter
	Lt. w/Open.	89	Skyline	40	10.4	212	20.7	570	5-80	Sum/fall
Tap Thin (Blue River)	Heavy[2]	1	Tractor	29	10.9	180	20.7	693	0-40	Fall
	Heavy	1	Skyline	19	10.9	180	21.0	610		Sum/fall
	Light	3	Tractor	33	9.8	260	30.4	693	0-40	Sum/fall
	Light	3	Skyline	60	9.8	260	30.4	610		Sprg/sum
	Lt. w/Open.[2]	4	Tractor	4	10.7	230	23.5	693	0-40	Fall.
	Lt. w/Open.	4	Skyline	32	10.7	230	26.3	610		Summer
Mill Thin 1 (McKenzie)	Light	1	Tractor	80	11.8	200	31.7	534	0-15	Summer
	Light[3]	1	Skyline	12	11.8	200	31.7	375	0-50	Summer
	Heavy	2	Tractor	17	11.8	195	35.7	534	0-15	Summer
	Heavy[3]	2	Skyline	69	11.8	195	35.7	375	0-50	Fall/wintr
Mill Thin 2 (McKenzie)	Lt. w/Open.	4	Tractor	49	11.8	196	39.8	534	0-15	Fall
Flat Thin (Oakridge)	Heavy	81	Mech.[4]	50	10.6	334	50.2	920	0-20	Sum/fall
	Lt. w/Open.	82	Mech.	96	11.8	214	42.3	920	0-20	Fall/wintr
	Light	84	Mech.	79	11.5	262	39.8	920	0-20	Fall

[1] The stand characteristics were determined from a cruise of trees greater than 5 in. dbh. Commercial thinning occurred between December 1993 and March 1997 (Han 1997).

[2] Combined together to form one data set

[3] Combined together to form one data set

[4] Mechanized

[5] Average Extraction Distance

Appendix B

Table B.1. Skyline yarding operation equipment and crew

	Yarder	Loader	Skidder	Carriage	Crew
Walkthin	• Koller K501 trailer mounted 3-drum yarder • 33 ft. tower • Skyline drum, 1640 ft. of 0.75 in diameter wire rope • Mainline drum 1965 ft. of 0.5 in diameter wire rope	Thunderbird 634 crawler-mount loader	1982 Cat D-7G	Eaglet mechanical slackpulling carriage	5-person crew • Yarder engineer • Chaser • Loader operator • Rigging slinger • Hook tender
Tapthin	• Koller K501 trailer mounted 3-drum yarder • 33 ft. tower • Skyline drum, 1640 ft. of 0.75 in diameter wire rope • Mainline drum 1965 ft. of 0.5 in diameter wire rope	Koehring 266L crawler-mount loader	John Deere grapple skidder	Eaglet mechanical slackpulling carriage	7-person crew • Yarder engineer • Chaser • Loader operator • Rigging slinger • Hook tender • 2 choker setter
Millthin	• Madill 071 mobile 4-drum yarder • 70 ft. tower • Skyline drum, 2000 ft. of 0.87 in diameter wire rope • Mainline drum, 2200 ft. of 0.5 in. diameter wire rope • Haulback drum, 4400 ft. of 0.5 in. diameter wire rope.	Case 125B Crawler mount-loader		Danebo mechanical slackpulling carriage	5-person crew • Yarder engineer • Chaser • Loader operator • Rigging slinger • Hook tender

Table B.2. Tractor skidding operation equipment and crew

	Tractor	Loader	Crew
Tapthin	• John Deere 550 crawler with winch line	• Koehring 6630 tract-mount loader	• Chaser • Loader operator • Tractor operator
Millthin 1	• Case 550 crawler with winch line	• Case 125B tract-mount loader	• Chaser • Loader operator • Tractor operator
Millthin 2	• Case 550 crawler with winch line	• Case 125B tract-mount loader	• Chaser • Loader operator • Tractor operator

Table B.3. Harvester-forwarder operation equipment and crew

	Harvester	Forwarder	Crew
Flatthin	• 2618 Timberjack (tracked carrier) with south fork squirt boom • Waterous 762b hydraulic harvesting head	• 1210 Timberjack 8-wheel drive • Bogie tracks used	• Harvester operator • Forwarder operator