A Simulation of the Comparative Costs and Benefits of Skyline Strip Thinning

by

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Strip thinning is recognized as a way of commercial thinning young-growth stands. Strip thinning has been used worldwide. The purpose of this study was to explicitly evaluate the costs and benefits associated with skyline strip thinning in young Douglas-fir (Pseudotsuga menziesii Franco) stands in the Pacific Northwest and to compare the results with the conventional method of cable thinning. A computer simulation model was developed to integrate logging technology, silvicultural treatments, and economic concerns. The computer model was validated using DFSIM. Simulation runs were conducted using data from previous O.S.U. field studies. The integrated results were expressed in present net worth yields over the rotation for specific treatments. The results suggest that in economic terms, strip thinning is always inferior to the conventional method of low thinning. This is due primarily to the reduced growth and yield experienced from strip thinning when compared to the conventional method. It is unlikely, under any foreseeable situation, that enough
logging cost reductions can be realized for the first entry to make the strip thinning alternative competitive. Sensitivity analysis of d/D ratio suggests that strip thinning would be the best alternative only at d/D ratios of 1.15 and greater.
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A SIMULATION OF THE COMPARATIVE COSTS AND BENEFITS
OF SKYLINE STRIP THINNING

INTRODUCTION

The effects of thinning on the yield of natural Douglas-fir
(*Pseudotsuga menziesii* Franco) stands have recently been investi-
gated in the Pacific Northwest (Berg, 1978; McArdle et al., 1961; Reukema, 1979). Generally, net increases in yield have been
observed, although the net increases are highly dependent on initial
stand structure, stand age at the time of thinnings, frequency and
intensity of thinning, and the thinning method chosen.

Commercial thinning operations and recent research at O.S.U.
have focused on matching machine capabilities with silvicultural
treatments in an attempt to maximize net returns (Sessions, 1979; LeDoux and Brodie, 1982) over the life of a stand. Generally, the
initial results suggest that substantial gains in net yield and
profit can be achieved by matching machine size to silvicultural
treatment.

The majority of the research conducted on the effect of coastal
Pacific Northwest Douglas-fir thinning on net volume yield and
profit has been directed toward a method of thinning called the con-
ventional method. The conventional method of thinning generally
involves a systematic tree removal based on spacing desired for the
residual stand. The spacing pattern may be determined through
various approaches such as diameter plus rules, or based on a target
stand density recommended by the silviculturist. The scientific data and methodologies are well developed for evaluating net volume yield and profit for conventionally thinned stands (Curtis et al., 1981; Bruce et al., 1977; Brodie and Kao, 1979; Kao, 1980; LeDoux and Brodie, 1982; LeDoux and Butler, 1981).

An alternative method to the conventional thinning, called strip thinning, can be used. The reported advantages of strip thinning over the conventional method include savings in felling and yarding costs during the initial commercial entry (Aulerich, 1975). The strip thinning method involves the removal of all the trees within alternating small clearcut strips. Cut and leave strips are left in an alternating pattern, sometimes referred to as herringbone thinning (Aulerich, 1975), or chevron patterns (Hamilton, 1980). The savings in felling cost result largely from the faller or cutter being able to fell the stems in each cut strip most efficiently. Less time is spent selecting the trees to be cut and since the trees are being felled in a small clearcut strip, less time is spent correcting hangups. The savings in yarding cost result largely from the hooking crew being able to hook bigger turns faster since the logs are concentrated in small, clearcut strips. The savings in felling and yarding costs during the first entry appear to make strip thinning an attractive thinning alternative.

Although strip thinning seems operationally efficient, it is still not clear how the residual stand will respond, since trees are not individually selected in strip thinning. Some large, vigorous trees are removed while suppressed or damaged trees are left in the
leave strips. This lack of tree selection will affect growth response of the stand.

A study was conducted in 1973 (Aulerich, 1975) to determine the felling and yarding savings when using the strip thinning method. A follow-up study (McCreary and Perry, 1983) measured stand response following the strip thinning. The results, when compared to yield results from conventional thinning, show that the growth and yield response of strip thinning is inferior. These studies do not evaluate the costs or benefits of strip thinning over the life of the stand. It is the intent of this paper to illustrate a methodology for evaluating the costs and benefits of strip thinning, using cable systems, over the life of the stand. These results will then be compared with those from conventional thinning.
Strip thinning is certainly not a new idea. The concept of strip thinning was used as early as 1903 in New England (Tackle, 1959). Strip thinning is applicable to both ground-based and cable systems.

Ground-Based Systems - Precommercial Thinning

Several different variations of strip thinning have been implemented with ground-based equipment. The following are a sample of these variations and their outcomes.

Bulldozer and Blade

Precommercial strip thinning has been attempted using a Caterpillar D-6 crawler-type tractor with a 3.65-meter (12-foot) dirt blade on slopes averaging 40 percent (Tackle, 1959). The stand was 30-year-old even-aged lodgepole pine (Pinus contorta Dougl.) in western Montana. The number of trees per hectare averaged 14,425 (5,838 per acre) and average d.b.h. was 3.81 centimeters (1.5 inches). The stand was thinned by destroying trees in dozer-width swaths. Reserve strips of .60-, 1.82-, and 3.65-meter (2-, 6-, and 12-foot) widths remained. A five-year study on growth response indicated a significant increase in diameter growth only in the heaviest thinning [.60-meter (2-foot) strips] compared to controls. Lotan (1968) reported double the diameter growth in the .60-meter (2-foot) strips, compared to controls, after 11 years. However,
86 percent of the area was unstocked due to this treatment, and volume growth per acre was 20 percent of the unthinned control.

**Dozer and Rotary Cutter**

A rotary cutter, pulled and powered by an International TD-6 Caterpillar, was the mechanical thinning system used on 600 hectares (1,483 acres) of dense jack pine (*Pinus banksiana* Lamb.) reproduction in Minnesota (Aim, 1979); 1.98-meter (6½-foot) swaths and .30-meter (1.0-foot) leave strips were used. Initial density averaged 45,700 trees/hectare (18,495 trees/acre). Thinning removed an average of 37,500 trees/hectare (15,176 trees/acre) and left an average stem density of 8,200 trees/hectare (3,318 trees/acre). However, less than 50 percent of the residual trees were classified as desirable, many stems being injured by the equipment. Growth results after nine years indicated that this non-selective thinning technique was ineffective in providing adequate stocking of desirable trees. Compared to controls, no satisfactory growth resulted.

**Other Variations**

Lynch (1973), in an overview of mechanical thinning in young conifer stands, summarized the results of a number of strip-thinning approaches. A dozer/rolling-crusher combination was used to thin a stand of predominantly 35-year-old lodgepole pine (*Pinus contorta* Doug1.) stocked at 19,768 trees/hectare (8,000 stems/acre). Leave strips varied from 1.21 to 4.57 meters (4 to 15 feet) in width, separated by 4.26-meter- (14-foot-) wide crushed strips. Tree growth
response was still being evaluated, but wildlife browse production (of particular interest in this locale) had increased eight-fold in 18 months. This alone provided some economic benefit. The work was contracted at a cost of $27 to $40 per hectare ($11 to $16 per acre). The equipment could operate on slopes up to 30 percent.

A special bulldozer blade with arms designed to push trees to strip center produced better leave strips in lodgepole (Pinus contorta Doug.) and ponderosa (Pinus ponderosa Laws.) stands than the conventional blade, in studies conducted on the Colville National Forest. Slopes up to 60 percent were treated by operating only in the downhill direction and returning on a "come-back road." At the time of Lynch's paper, the Colville National Forest was using strip thinning on an operational basis.

A study on the Lewis and Clark National Forest used a conventional dozer blade in young, small lodgepole pine (Pinus contorta Doug.) with poor results. Trees were too limber to break off effectively. Regrowth of lower branches and tops from broken and bent trees resulted. This was also a problem in Tackle's study (1959).

Tests conducted on the Medicine Bow National Forest, utilizing the Marden Roller-chopper and the Tomahawk roller mounted on a bulldozer blade, yielded mixed results. Although more effective, the Marden chopper was less precise and caused more damage to the residual stand. The Tomahawk roller proved to be more maneuverable, but had difficulty in treating slash within the strips. Resultant fire hazards, due to the creation of flashy fuels, reduced accessibility;
and visual impact further complicated the situation. Lynch concluded that mechanical strip thinning was a viable alternative in dense, stagnate stands.

**Ground-Based Systems - Commercial Thinnings**

"Line thinning" has become an increasingly popular technique in Great Britain for initial commercial thinnings (Hamilton, 1980). Line thinning includes both row thinning (lines removed following planting rows) and strip thinning (lines do not necessarily follow planting rows). Data from five row thinning experiments in government Forestry Commission woodlands, involving Sitka spruce (*Picea sitchensis* (Bong.) Carr.), Corsican pine (*Pinus nigra* Arn.), or Scots Pine (*Pinus sylvestris* L.), indicated that growth responses to thinning were confined to rows immediately adjacent to those removed. Also, a loss in volume production was associated with line thinning. Finally, the volume losses associated with line thinning increased with the number of adjacent rows removed.

Given the loss in volume production, line thinning still appears an attractive alternative to selective thinning in situations where cheaper harvesting costs and savings in associated timber-marking activities outweigh the reduction in growth potential. Cheaper harvesting costs for line thinning are the result of some small reduction in felling and bucking costs and reduced extraction costs. As cited earlier, Aulerich (1975) concluded that felling and bucking costs were cheaper for the herringbone pattern when he compared four intensities of selective thinning to a herringbone pattern of strip
thinning. Average total felling and bucking time per tree decreased with increased thinning intensity since loggers spent more time cutting trees and less time selecting trees to cut. Also, hang-ups decreased with increased thinning intensities. According to Hamilton (1980), extraction costs of single-row thinning (pole-length extraction by ground skidder) are generally less than selective thinning.

Hamilton's report recognizes two ground-based systems that could be used in conjunction with line thinning: a) pole-length harvesting by ground skidder, and b) shortwood harvesting by forwarder. Use of the forwarder is questionable since there is little difference in extractor costs between line thinning and selective thinning. Indeed, extraction costs are higher compared to selective thinning when the forwarder is used in row thinning operations. Row, strip or herringbone patterns could be used with the skidder systems. The recommended spacing for the herringbone is 20 to 40 meters (65 to 131 feet) between main lines (main racks), with side racks at intervals of 7 to 10 meters (25 to 33 feet) in the main rack and at angles of 35° to 45° to the main rack. The minimum suggested side rack width is 1.98 meters (6.5 feet). Ground-based systems can be used to thin stands with strip or herringbone thinning methods on gentle ground. Stands located on steep, mountainous terrain require the use of cable systems to elevate thinnings.
Steep terrain, fragile soils, and other restrictions may preclude the use of ground-based equipment on some sites. Aulerich's study (1974) also compared production rates, costs, and revenues between tractor and skyline systems in different intensities of selective thinning at Oregon State University. Generally, both systems were profitable, but skyline costs were 1.5 to 1.66 times those of tractor logging. Yarding slope (20-40%) had a much greater effect on tractor operation (15% decline) than skyline production (3%), whereas thinning intensity had the greatest effect on skyline yarding (12% decline as stem removal dropped from 55 to 35%). The study was conducted in a 35-year-old Douglas-fir (Pseudotsuga menziesii Franco) stand (Site III) with trees averaging 25.4 centimeters (10 inches) d.b.h. and stand volumes 61.23 m³ per hectare (10,500 board feet (Scribner) per acre).

Strip removal was also conducted on this site utilizing four herringbone patterns. A comparison of skyline yarding costs between these and the conventionally-thinned stands showed a 17 percent reduction in average turn time for the strip thinning (Aulerich, 1975). A follow-up study by McCreary and Perry (1983) compared individual tree response and net stand yield between the strip-thinned plots, randomly-thinned plots (two intensities: 35 and 55 percent), and a control plot. The thinning occurred in 1972, and data on growth response was obtained in 1978. Generally, their results agreed with those described earlier in Hamilton's (1980)
Strip-thinning growth response appeared to be less effective than conventional thinning of similar intensity. This was partly due to the lack of growth response in trees more than 3.0 meters (10 feet) from strip edges. Data also indicated that a higher percentage of initial basal area could be removed in conventional thinning, with net yield remaining similar between conventional and strip-thinned stands for the five years following. Conclusions were that, although growth response was less for strip thinning on this particular site, reduced logging costs, as well as other potential benefits (reduced logging damage to residual trees, greater flexibility in regeneration planting, and the possibility of interplanting Douglas-fir (Pseudotsuga menziesii Franco) with nitrogen-fixing species), could still make the practice a desirable alternative.

The above conclusions were based on 5-year growth-response measurements. Any extrapolations beyond 5 years may not be correct. However, it is likely that the growth-response pattern observed in strip-thinned plots over a 5-year period will not change dramatically over the life of the stand. The growth-response data used in this analysis is based on measurements over a 9-year period (McCready and Perry, 1983; LeDoux, 1982).

Some form of herringbone pattern is the only pattern of line thinning proven to be economical for cable-crane extraction on initial commercial thinnings in Great Britain, according to Hamilton (1980). Other line-thinning patterns have been inefficient in terms of volume available for each set-up. Typical average d.b.h. in an initial line-thinning operation is 12.7 centimeters (5 inches). Both
pole-length harvesting and shortwood harvesting are used.

When extracting pole-length logs with a cable crane (uphill), the recommended distance between main racks is a minimum width of 40 meters (131 feet). Side racks can be up to 30 meters (98 feet) long at an angle of 35° to 40°. Closer spacing for main racks (maximum distance: 35 meters (115 feet)) is recommended for downhill extraction, with side racks up to 24 meters (79 feet) long at similar angles. Main racks used in shortwood harvesting should be 24 meters (79 feet) apart. However, the angles of the side racks are less important with shortwood extraction. When logging downhill, the Forestry Commission report suggests inverting the herringbone pattern. Side racks will then lead slightly upwards across the slope, hopefully reducing the problem of load "snagging."

While the British Forestry Commission has specific recommendations on lateral angles of side racks, the Oregon State University study found that the angle (a range of 30-90 degrees) was not a significant predictor of turn time (90% confidence level) (Aulerich, 1975).

The New Zealand Forest Service has also conducted some cable strip-thinning operations. However, the herringbone pattern was not used. Stems were felled in strips down the slope. Selective thinning was used within the residual strips. On an uphill setting, felled strips were approximately 4.6 meters (15 feet) in width, and residual strips were 11 meters (36 feet) in width (Twaddle, 1977). A downhill setting used 4-meter (13-foot) thinned strips and 11-meter (35-foot) residual strips (Twaddle, 1978). Age of the stands
(Pinus radiata) was 14 years. The downhill setting had a stocking of 900 trees/hectare (364 trees/acre)--post-thinning stocks were 435 trees/hectare (176 trees/acre)--with a mean d.b.h. of 20 centimeters (8.0 inches). The uphill setting was stocked with 988 trees/hectare (400 trees/acre)--with post-thinning stocks at 280 trees/hectare (113 trees/acre)--and the mean d.b.h. was 24 centimeters (9.5 inches).

A Timbermaster Skyline (mobile, three-drum yarding unit) mounted on a 05 Bedford chassis (22 years old) and rigged as a slack skyline was used on both downhill and uphill settings.

Results indicated that average turn volumes were below the capacity of the machine used in the studies. Although the Timbermaster is well suited to strip-production thinning, a smaller machine might be considered in stands similar to those in the downhill settings to lower capital investment.

Another New Zealand Forest Service study was conducted to determine if any productivity gains could be achieved in a stand treated so that the thinning element of the stand was largely concentrated in strips physically apart from the final cross element (Terlesk and Twaddle, 1979). The study involved downhill yarding with a Wilhaul 1347 cable hauler. The hauler is a mobile unit mounted on a Mercedes Benz truck base. It has an integral spar and four drums. The study was conducted in an 11-year-old Pinus radiata (mean d.b.h. 24 centimeters (9.6 inches)) stand with a stocking of 635 trees/hectare (257 trees/acre).

Stand treatment began with planting in 1968, using a 2.4- x 1.8-
meter (8- x 6-foot) spacing. At year four (1972), every third row was precommercial-thinned (a reduction of 2,298 to 1,530 trees/hectare, i.e., 930 to 619 trees/acre); 748 trees/hectare (300 trees/acre) were then low-pruned and the remaining stems removed, leaving 748 trees/hectare (303 trees/acre) remaining at the end of year four. In year seven (1975), alternate pairs of rows were selected as future final crop and thinnings (370 trees/hectare or 150 trees/acre final crop); then 300 trees/hectare (121 trees/acre) were medium-pruned in the final-crop rows. Finally, the unpruned stems were removed in the final-crop rows comprising 300 trees/hectare (121 trees/acre) and in the thinning rows (380 trees/hectare, i.e., 154 trees/acre) in 1975. In year eight (1976), 198 trees/hectare (80 trees/acre) were high-pruned in the final crop rows. At year 11 (1979), the production thinning occurred—in the final-crop rows all trees not high-pruned, i.e., 100 trees/hectare (40 trees/acre), were removed; in the thinning rows all stems (370 trees/hectare, i.e., 150 trees/acre) were removed. Final stocking was 198 trees/hectare (80 trees/acre).

Production results from this final thinning were compared to Twaddle's downhill setting study (Twaddle, 1978), which used a similar-sized hauler, removed 465 trees/hectare (188 trees/acre), but utilized narrow strips of 4 to 6 meters (13 to 20 feet). The comparison indicated gains in productivity of 30 to 40% over the commonly-used narrow extraction strips. This was achieved by increasing the number of pieces per turn from an average of two (Twaddle, 1978) to three in the current study. The concentration of stems
underneath the skyline in the current study enabled the choker setters to increase average turn volume. The paper concluded that large gains in operation efficiency could result from planning the growing and harvesting of tree crops as a single system.

Clearly, much experimentation with strip thinning has been conducted and reported for both ground-based and cable systems. The results, although valuable, do not provide insight into the costs and benefits of strip thinning over the life of a stand. It is the lack of a complete-systems, long-term, integrated look at the benefits and costs of strip thinning that motivated this research effort.
STUDY OBJECTIVES

The purpose of this study is to develop a methodology that would allow the determination of costs and benefits for cable strip-thinning. Specific objectives include:


The intent of this study is to specifically compare the costs and benefits of strip thinning to those derived from conventional thinning. The comparison would be made over the life of a specific stand and would effectively integrate logging, silvicultural, and economic concerns into a complete systems approach. The objective of this study is not to provide management guidelines for either
strip thinning or conventional thinning but, rather, to provide a
detailed comparison of the two thinning techniques.
ROWTHIN MODEL DESCRIPTION

ROWTHIN, a computer program written in Fortran V, combines Monte Carlo and system simulation techniques and uses the subroutines of the GASP V simulation language (Pritsker, 1974) to collect and report data. The simulation is a combination of next-event, discrete, and stochastic subroutines. Specifically, the model evaluates how alternative-diameter classes, stand densities, yarding efficiencies, external and lateral yarding distances, spatial tree-distributions, cut-and-leave strip widths, skyline road-widths, multiple entries, and discount rates affect the costs and benefits of strip thinning.

The simulation comprises five main routines. The first distributes trees over the cutting unit; the second fells and bucks trees into logs; the third yards logs; the fourth simulates tree growth between entries; and the fifth computes the economic conditions for each entry.

The Tree Distribution Routine

ROWTHIN assumes that the cutting unit is a rectangle of given dimensions. A rectangular cutting unit was chosen because of the data available and also for modeling ease. The spatial distribution of trees in the cutting unit is determined by dividing the unit into a rectangular grid. Each rectangle in the grid is approximately square, and exactly one tree is assigned to each square. The number of squares (i.e., number of trees) in the grid is input to the model.
and is determined from field-measured stand density for a specific stand.

Initially, each tree is located at the center of the square to which it is assigned. The tree location is then perturbed in both coordinates by random amounts, which are distributed normally, with a zero mean and standard deviation computed by multiplying the length of one square by a fraction called the spatial distribution coefficient (SPC). The value of SPC is entered as a model parameter. The tree diameter at breast height is then assigned by taking a pseudo-random observation from a truncated normal distribution. The parameters (mean, standard error, minimum, maximum) of the tree distribution are specified on the GASP control cards. The distribution parameters for the simulation runs summarized in this manuscript came from field plot-data (McCreary and Perry, 1983; LeDoux, 1982) and are summarized in Appendix XII.

By varying the value of SPC, the user can control the extent of randomness when placing trees within the cutting unit. When SPC is nearly 0, each tree lies close to the center of its square; trees, under this condition, very nearly line up in rows or columns. This may approximate the conditions present on a plantation. As SPC increases, so does randomness in tree placement, resulting in more clusters and gaps and more closely approximating natural growth conditions. The user can then evaluate productivity and cost for a range of tree distributions rather than for a fixed tree-distribution pattern. SPC may be estimated by visually comparing plots of trees generated by this methodology with plots of actual tree locations.
observed in the field plots, or by measuring the coefficient of variation in the butt-to-butt distances for a representative tree sample. Using the former method, we have found a reasonable range for SPC under natural growth conditions to be 0.4 to 1.0 (LeDoux and Butler, 1981). The simulation results obtained so far are relatively insensitive to moderate changes in this coefficient.

The Felling and Bucking Routine

Once the trees have been placed on the unit and assigned to respective user-input-defined cut-or-leave strips, ROWTHIN initiates the felling and bucking operation, starting with the cut strip closest to the landing (Fig. 1). Trees are selected for felling and bucking based on their distance to the skyline corridor. Trees are then felled and bucked into logs of specified lengths. The bucking rules are input to the model. The volume of all logs coming from a tree is computed, summarized, and stored. The algorithm continues to fell and buck trees until all strips scheduled for cutting in that entry have been processed. The bucking rules used in this simulation are shown in Appendix XI. The formula for computing individual log volumes (Dilworth, 1970) is:

\[
\text{Volume/log in ft}^3 = 0.00545 D^2 L
\]

where, \( D \) = mid-diameter of the log in inches

\( L \) = log length in feet.

Felling, bucking, and limbing time is computed using a regression equation (Adams, 1967) of the following form:
Locate individual tree to be cut; identify DBH, height; flag as cut

Buck tree into log(s) 40-36-32-24-12 lengths

Compute log volumes of all logs from this tree

Compute and accumulate felling and bucking time

All trees been cut Yes

Return felling and bucking time and other summary data

Set attributes and schedule a yarding event

No

STOP

Figure 1. Flowchart of ROWTHIN's Felling and Bucking Routine.
Felling time/tree (minutes) = 0.559 + 0.00419(DBH)^2
Bucking and Limbing time/tree (minutes) = 0.781 + 0.00681(DBH) + 1.123(NCUTS)

where,
DBH = tree diameter, inches
NCUTS = Number of bucking cuts/tree
(integer)

The felling, bucking, and limbing time is accumulated and stored for all trees in each entry.

The Yarding Routine

Once all the trees for an entry have been felled and bucked, ROWTHIN initiates the yarding routine (Fig. 2). To build a turn, ROWTHIN determines the closest unlogged cut strip to the landing. ROWTHIN then scans for the closest log to the skyline corridor. This log becomes the first log in the turn, with additional logs hooked in order of increasing distance from the first-hooked log. As each log is hooked, checks ensure that it is in fact close enough to the other logs to be hooked, that a choker is available with which to hook it, and that it can be hooked without exceeding the yarder's payload capacity. If a log is too big or too far to be added to the current turn of logs, it will be skipped and yarded in a later turn. One-payload capacity is used for the entire corridor.

The simulation then uses a regression equation (Aulerich, 1975) to compute turn time for the turn of logs hooked. The regression equation used was developed for strip thinning by Aulerich in 1975. The regression equation used is as follows:
YARDING ROUTINE
(Single Stage Yarding Only)

INITIALIZE VARIABLES.

Determine the closest Row to landing, say Row C, which still contains at least one Log to be yarded.

Search Rows C, ..., C+k* to find the Log closest to the landing. Flag this Log as Yarded and put it in Current Turn of Logs.

Search Rows C, ..., Ck to determine closest Log to First-Hooked Log, only considering Logs which:
1. Lie on the same side of the Cutting Unit as the First-Hooked Log;
2. Can be Hooked (added to already Hooked Logs) without exceeding the system Payload;
3. Lie within a Distance d* of the First-Hooked Log.

Add to Current Turn of Logs. Flag as Yarded.

Compute Turn Time via regression equation. Update production statistics with data on Current Turn.

Yes

More Logs remain to be yarded?

No

DONE

*Input parameter

Figure 2. Flowchart of ROWTHIN’s Yarding Routine.
Total Turn Time
Minutes
(Delay Free) = 3.814
  + .00528(SYD)
  + .806(XLT)
  - .752(CREW)
  + .027(XLD)
  + .00149(XLA)

where,
  n = 168
  R^2 = 45.1
  se = 3.74
  SYD Limits = 0-600
  XLT Limits = 1-4
  CREW Limits = 3-4
  XLD Limits = 0-200
  XLA Limits = 30-90

and where
  SYD = slope yarding distance in feet
  XLT = logs per turn, integer
  CREW = number of workers on the hooking crew, integer
  XLD = lateral yarding distance in feet
  XLA = lead angle of turn, in degrees

After each turn is yarded, its attributes are collected and stored; the process is repeated until all logs in all current strips have been yarded. Upon completion, summary statistics of the yarding operation are reported.

The Growth Routine

Once all the logs have been yarded for a given entry, ROWTHIN initiates the growth routine (Fig. 3). The growth routine begins by locating the closest leave strip to the landing. The trees within leave strips are 'grown' based on their distance to a cut edge, the diameter (breast height) at the age of treatment, and the amount of time that has elapsed between entries.

Two growth functions were developed from recorded stand data (McCreary and Perry, 1983) and additional measurements taken from
SUBROUTINE GROWTH

START

Locate tree to be grown; identify DBH, height, distance to edge; flag as grown

Tree within ≤ 15' from cut edge?

Yes

Use growth equation for ≤ 15'

No

Use growth equation for > 15'

Compute new tree DBH

Accumulate growth information

Update tree attributes

All trees been grown?

Yes

Schedule a Felling and Bucking Event

No

STOP

Figure 3. Flowchart of ROWTHIN's Growth Routine.
New tree DBH's are computed and tree attributes within leave strips within the same stand (LeDoux, unpublished data). An explanation of how this was done and limitations of when this is applicable, as well as curves of these functions, are detailed in Appendix VII. The equations 'grow' trees depending on their distance from a cut edge. Trees located within leave strips that are a distance of less than or equal to 15 feet from a cut edge are 'grown' with the following equation:

\[
\text{Annual Diameter Growth (DBH) per tree in inches} = 0.292 \times 10^{-2} - 0.175 \times 10^{-1} \times \text{DIST}^* + 0.201 \times 10^{-1} \times \text{DBH}^*
\]

where,
- \( n = 56 \)
- \( R^2 = 57.6 \)
- \( \text{se} = 0.460 \times 10^{-2} \) feet
- \( \text{DIST Limits} = 0.32-11.0 \) feet
- \( \text{DBH Limits} = 5.0-23.0 \) inches

and where
- \( \text{DIST} = \text{Distance to a cut edge, in feet} \)
- \( \text{DBH} = \text{Diameter (breast height) at time of treatment, in inches} \)
  - Statistically significant at .05 level

Trees located at distances greater than 15 feet from a cut edge are 'grown' with the following equation:

\[
\text{Annual Diameter Growth (DBH) per tree in inches} = -0.203 \times 10^{-1} + 0.150 \times 10^{-1} \times \text{DBH}^*
\]

where,
- \( n = 18 \)
- \( R^2 = 46.2 \)
- \( \text{se} = 0.331 \times 10^{-2} \) inches

and where
- \( \text{DBH} = \text{Diameter (breast height) at time of treatment, in inches} \)
  - Statistically significant at .05 level

New tree DBH's are computed and tree attributes within leave strips...
are updated and stored. The derivation of the cumulative growth equations is detailed in Appendix VII.

The Economic Routine

Once all logs have been yarded for a specific entry and cutting pattern, ROWTHIN initiates the economic routine (Fig. 4). The economic routine takes volumes, costs, and revenues for each entry and computes the total net revenue, present net worth, and (following the final harvest) computes the cumulative present net worth and the soil expectation value. The discount rate used in the computations is input to the model. The economic information computed is stored and reported at the end of the simulation.

For this simulation an interest rate of three (3) was used. The effect of inflation on costs and/or revenues over time was not treated. Clearly, the discount rate, inflation of costs or net revenues, changes in pond values of logs, or new technological developments in logging machinery will all affect the comparison of strip thinning to conventional thinning. It would be beyond the scope of this study to evaluate these effects. A set of reasonable conditions was chosen and used in this comparison. A model user could evaluate other sets of conditions by making additional ROWTHIN simulations.
SUBROUTINE ECONOMIC

START

Pass in Volume, Removed/entry and Logging Cost/entry

Compute Pond Value based on avg. DBH and Volume Removed

Identify Time of Cut, Rotation Length and Discount Rate

Compute PNW for entry

Store Volume, Revenue, PNW for entry

Schedule a Growth Event and return

All entries been logged? Yes Print out Volumes, PNW, per entry

Compute $S_e$ and return

STOP

Figure 4. Flowchart of ROWTHIN’s Economic Routine.
ROWTHIN MODEL VALIDATION

The growth components of ROWTHIN were validated by comparing total volume yields per acre predicted by the simulation with rates observed for similar conditions using DFSIM (Curtis et al., 1981). In each test, those stand attributes which were necessary input to the simulation were taken from measured field plot data (Appendix XII). Simulation runs were conducted for two rotation lengths, 45 and 60 years, with a no-thinning option. Similar comparisons were made with the same rotation lengths using a thinning option. The results of the comparisons are summarized in Table 1. Each condition was simulated using two different random streams. The same seeds were used in alternate simulations. The initial conditions are summarized in Appendix XII.

The intent of the above validations or comparisons is to establish and evaluate ROWTHIN's ability to simulate (fed real data) growth and yields similar to those simulated by DFSIM (a state-of-the-art Douglas-fir simulation model). Since ROWTHIN is an individual tree model and DFSIM is a stand model, assumptions about the growth similarity will be made and tested. The assumption is made that both models, fed similar initial conditions (as in Appendix XII), will produce comparable volume yields over the life of a specific stand. The implicit assumption is that the growth equations used in ROWTHIN would produce comparable volume yields to those simulated by DFSIM.
ROWTHIN's growth and yield prediction potential for a non-thinned stand is compared to a similar treatment (in DFSIM) for a 45- and 60-year rotation (Table 1). The assumption is that both models, fed similar initial conditions (with a no-thin treatment), would produce comparable net total/acre volume yields.

The results from this comparison are summarized in Table 1. ROWTHIN predicts a net total/acre volume yield, at age 45, of 670 m³/hectare (9,594 ft³/acre) — a mean of two runs. DFSIM, for the identical conditions and rotation length predicts a total per acre yield of 646 m³/hectare (9,244 ft³/acre). ROWTHIN overestimates the total per-acre yield by 3.79%. Using similar conditions as above, but allowing the stand to grow to a rotation age of 60 years instead of 45 years, ROWTHIN predicts 1,045 m³/hectare (14,946 ft³/acre) (mean of two runs) compared to DFSIM's 878 m³/hectare (12,568 ft³/acre) — an 18.92% overestimate. The larger error for the 60-year rotation suggests that we are growing more volume with ROWTHIN when compared to DFSIM. The majority of this error is attributable to the data used for the growth equations within ROWTHIN. Any future comparisons are based on net volume yields.

The growth equations used in ROWTHIN are developed from field plot measurements of a young stand. Thus, the growth equations do not consider mortality or a "senility" factor that would allow a drop-off in growth as the stand became older. ROWTHIN stand volume yield projections for longer rotations (60+ years) would be based on growth rates of a young stand, resulting in gross errors. It
Table 1. Comparing total volume yields per acre for ROWTHIN and DFSIM simulations.

<table>
<thead>
<tr>
<th>Validation Test No.</th>
<th>ROWTHIN</th>
<th>DFSIM</th>
<th>Error (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1a. 45-Year Rotation (No-Thinning Option)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Total volume, m³/hectare (ft³/acre)</td>
<td>674 (9,649)</td>
<td>646 (9,244)</td>
<td>+4.38</td>
</tr>
<tr>
<td>2. Total volume, m³/hectare (ft³/acre)</td>
<td>667 (9,539)</td>
<td>646 (9,244)</td>
<td>+3.20</td>
</tr>
<tr>
<td><strong>1b. 60-Year Rotation (No-Thinning Option)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Total volume, m³/hectare (ft³/acre)</td>
<td>1070 (15,314)</td>
<td>878 (12,568)</td>
<td>+21.85</td>
</tr>
<tr>
<td>2. Total volume, m³/hectare (ft³/acre)</td>
<td>1019 (14,578)</td>
<td>878 (12,568)</td>
<td>+16.01</td>
</tr>
<tr>
<td><strong>2. 45-Year Rotation (Thinning Option)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Total volume, m³/hectare (ft³/acre)</td>
<td>716 (10,240)</td>
<td>714 (10,223)</td>
<td>+0.17</td>
</tr>
<tr>
<td>2. Total volume, m³/hectare (ft³/acre)</td>
<td>724 (10,360)</td>
<td>714 (10,223)</td>
<td>+1.34</td>
</tr>
<tr>
<td><strong>3. 60-Year Rotation (Thinning Option)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Total volume, m³/hectare (ft³/acre)</td>
<td>1096 (15,687)</td>
<td>1029 (14,715)</td>
<td>+6.61</td>
</tr>
<tr>
<td>2. Total volume, m³/hectare (ft³/acre)</td>
<td>1141 (16,318)</td>
<td>1029 (14,715)</td>
<td>+10.89</td>
</tr>
</tbody>
</table>
would be beyond the scope of this research effort to develop a "sen-
tity" factor for ROWTHIN. It is for this reason, and based on Vali-
dation Tests 2 and 3, that the cost and benefit analysis is con-
ained to 60-year (or shorter) rotations.

Validation Test No. 2

This test compares the total yields simulated by ROWTHIN to those produced by DFSIM for a 45-year rotation, with an entry into the stand at age 30 (Table 1). The removal strategy simulated by ROWTHIN involves removing and leaving alternating 5.5-meter (18-foot) strips (Fig. 5). The simulation removes 5.5-meter (18-foot) strips at age 30, leaving 5.5-meter (18-foot) strips for final harvest at age 45. Trees removed average 29 centimeters (11.4 inches) in DBH, with an average volume removed of 292 m³/hectare (4,178 ft³/acre) to a 10-centimeter (4-inch) top.

The remaining strips are grown for 15 years, with final harvest at age 45 resulting in an average DBH of 35 centimeters (13.8 inches) and with a volume yield of 428 m³/hectare (6,122 ft³/acre). The total volume removed from a 45-year rotation is predicted by ROWTHIN to be 720 m³/hectare (10,300 ft³/acre), a mean of two runs. The same stand and initial conditions are then input into DFSIM with essentially the same treatment. DFSIM predicts a total yield of 714 m³/hectare (10,223 ft³/acre). Correcting the ROWTHIN results for mortality of 2.3 m³/hectare (33 ft³/acre) results in a total volume of 717 m³/hectare (10,267 ft³/acre), a .43% higher estimate compared to DFSIM.
Validation Test 2 and 3

Strip widths of 5.5m (18 ft) were selected because annual diameter growth response was shown to fall off significantly beyond 3-4.6m (10-15 ft) from a cut edge (McCreary and Perry, 1983). Leave-strip widths of 5.5m (18 ft) would allow residual trees to be within 2.7m (9 ft) or less of a cut edge, thus maintaining good annual diameter growth. The assumption for this test is that ROWTHIN will grow similar volume yields per hectare (per acre) compared to DFSIM since all residual trees will be within 2.7m (9 ft) of a cut edge. Indeed, the results were similar.

Figure 5. ROWTHIN Validation Removal Strategy.
Validation Test No. 3

ROWTHIN's ability to predict per/hectare (per/acre) volumes for a 60-year rotation (with an entry at age 30) is compared to DFSIM in Table 1. The stand conditions and treatment are identical to Validation Test No. 2, except we are allowing the residual stand to grow to age 60 instead of age 45. The first-entry (age 30) results are identical to those for Validation Test No. 2. The total volume per hectare (per acre) for a 60-year rotation reported by ROWTHIN is 1,182 m³ (16,907 ft³) (a mean of two runs). The total volume for similar conditions is predicted by DFSIM to be 1,029 m³/hectare (14,715 ft³/acre). Correcting the ROWTHIN prediction for mortality of 63 m³ (905 ft³) results in a total volume of 1,119 m³/hectare (16,002 ft³/acre), an 8.75% higher estimate in volume compared to that reported by DFSIM.

ROWTHIN growth equations are based on direct measurements of field plots that are between 30 and 45 years old. The growth and yield predictions generated by ROWTHIN will deviate from DFSIM predictions in an increasing manner as one goes to longer rotations. The 8.75% error suggests that we are starting to extrapolate growth and yield beyond our young-stand data. The 8.75% error also suggests that ROWTHIN can safely be used to predict growth and yields up to a 60-year rotation. Beyond a 60-year rotation, ROWTHIN growth and yield predictions are expected to result in large errors when compared to DFSIM and, therefore, the cost/benefit analysis will be confined to 60-year rotations or less. Rotation
ages of 45 and 60 years were chosen because of the data available.

Validation Test No. 4

The yarding component of ROWTHIN was validated by comparing production rates predicted by the simulation for three random-number seeds with rates observed in field experiments (Table 2). In the tests, those stand attributes used for input to the simulation approximated the conditions under which the production test (Aulerich, 1974) was conducted; turn sizes were comparable.

The differences between predicted and observed production figures do not exceed five (5) percent in this study. Although the validation test comparisons showed small errors, considerably larger errors could result when using ROWTHIN to predict outside the range of stand and operating conditions spanned by the respective field study. Three chokers were used for the validation test as well as in the comparative simulations. Use of more than three chokers when strip thinning will clearly change the comparisons.
Table 2. Comparing yarding production for field tests and ROWTHIN simulations.

<table>
<thead>
<tr>
<th>Validation Test No.</th>
<th>Field Test</th>
<th>ROWTHIN</th>
<th>Error (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Logs per turn</td>
<td>Volume per turn, m³ (ft³)</td>
<td>Production rate, m³/hr (ft³/hr)</td>
</tr>
<tr>
<td>1.</td>
<td>2.4</td>
<td>.83 (29.52)</td>
<td>8.5 (300.71)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.83 (29.52)</td>
<td>8.5 (300.71)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.83 (29.52)</td>
<td>8.5 (300.71)</td>
</tr>
<tr>
<td>2.</td>
<td>2.4</td>
<td>.83 (29.52)</td>
<td>8.5 (300.71)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.83 (29.52)</td>
<td>8.5 (300.71)</td>
</tr>
<tr>
<td>3.</td>
<td>2.4</td>
<td>.83 (29.52)</td>
<td>8.5 (300.71)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.83 (29.52)</td>
<td>8.5 (300.71)</td>
</tr>
</tbody>
</table>
Simulations were run for three strip-thinning strategies operating in mountainous terrain characteristic of the Pacific Northwest. The results are summarized in Table 3. Simulation number one considers a single entry at age 30, which removed 5.5-meter (18-foot) strips leaving alternating 5.5-meter (18-foot) strips for final harvest at age 45 (Fig. 6). Simulation number two considered a single entry at age 30 which removed 5.5-meter (18-foot) strips, leaving alternating 5.5-meter (18-foot) strips for final harvest at age 60. Simulation number three considered an entry at age 30 that removed 5.5-meter (18-foot) strips, leaving alternating 11-meter (36-foot) strips. A second entry, scheduled at age 45, would remove a 5.5-meter (18-foot) strip from the center of the 11-meter (36-foot) strip. The remaining 2.7-meter (9-foot) strips would be final-harvested at age 60.

The growth and yield results of the three runs are shown in Table 3. Three comparable conventional-thinning strategies were run using DFSIM. The growth and yield results are summarized in Table 4.

Comparison of ROWTHIN and DFSIM Results

The cost and benefit comparison (expressed in cumulative present net worth and using net volume yields) of ROWTHIN and DFSIM simulations is shown in Table 5.

For each case simulated, the cumulative present net worth is greater for the DFSIM simulations. These results would favor conventional thinning over strip thinning. The outcomes are largely
Table 3. Summary of growth and yield for three ROWTHIN simulations (DBH is of material cut).

<table>
<thead>
<tr>
<th>Simulation No.</th>
<th>Entry Age</th>
<th>Average DBH cm. (in.)</th>
<th>Volume Cut m³/hectare (ft³/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Commercial Thinning (Remove 5.5m (18’) strips, leave 5.5m (18’) strips)</td>
<td>30</td>
<td>29 (11.47)</td>
<td>292 (4,178)</td>
</tr>
<tr>
<td>Final Harvest</td>
<td>45</td>
<td>35 (13.80)</td>
<td>428 (6,122)</td>
</tr>
<tr>
<td>Total Volume Removed</td>
<td></td>
<td></td>
<td>720 (10,300)</td>
</tr>
<tr>
<td>2. Commercial Thinning (Remove 5.5m (18’) strips, leave 5.5m (18’) strips)</td>
<td>30</td>
<td>29 (11.47)</td>
<td>292 (4,177)</td>
</tr>
<tr>
<td>Final Harvest</td>
<td>60</td>
<td>44 (17.30)</td>
<td>890 (12,730)</td>
</tr>
<tr>
<td>Total Volume Removed</td>
<td></td>
<td></td>
<td>1182 (16,907)</td>
</tr>
<tr>
<td>3. Commercial Thinning (Remove 5.5m (18’) strips, leave 1m (36’) strip; remove 5.5m (18’) strip from center at age 45; remove 2.7m (9’) strip at age 60)</td>
<td>30</td>
<td>29 (11.57)</td>
<td>215 (3,082)</td>
</tr>
<tr>
<td>Commercial Thinning</td>
<td>45</td>
<td>32 (12.52)</td>
<td>222 (3,177)</td>
</tr>
<tr>
<td>Final Harvest</td>
<td>60</td>
<td>45 (17.91)</td>
<td>645 (9,236)</td>
</tr>
<tr>
<td>Total Volume Removed</td>
<td></td>
<td></td>
<td>1083 (15,495)</td>
</tr>
</tbody>
</table>
Removal Pattern for
Simulations Number 1 and 2

- 5.5-meter (18-foot-width) strips
- Cut
- Leave
- Cut
- Leave
- Cut
- Leave

Removal Pattern for
Simulation Number 3

- 5.5 meters (18 Feet) Wide
- Cut
- Leave
- Cut
- Leave
- Cut
- Leave

- 11 meters (36 Feet) Wide
- Cut
- Leave

Figure 6. ROWTHIN Application Strategies.
Table 4. Summary of growth and yield for three DFSIM simulations (DBH is of material cut).

<table>
<thead>
<tr>
<th>Simulation No.</th>
<th>Entry Age</th>
<th>Average DBH cm. (in.)</th>
<th>Volume Cut m³/hectare (ft³/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Commercial Thinning (d/D ratio = .71, 365 trees/hectare (148 stems/acre) removed)</td>
<td>30</td>
<td>23 (9.18)</td>
<td>116 (1,663)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Final Harvest</strong></td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>46 (18.23)</td>
<td>598 (8,560)</td>
</tr>
<tr>
<td></td>
<td><strong>Total Volume Removed</strong></td>
<td></td>
<td>714 (10,223)</td>
</tr>
<tr>
<td>2. Commercial Thinning (d/D ratio = .71, 365 trees/hectare (148 stems/acre) removed)</td>
<td>30</td>
<td>23 (9.18)</td>
<td>116 (1,663)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Final Harvest</strong></td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>56 (22.02)</td>
<td>912 (13,052)</td>
</tr>
<tr>
<td></td>
<td><strong>Total Volume Removed</strong></td>
<td></td>
<td>1028 (14,715)</td>
</tr>
<tr>
<td>3. Commercial Thinning (d/D ratio = .71, 365 trees/hectare (148 stems/acre) removed at age 30; 148 trees/hectare (60 stems/acre) removed at age 60)</td>
<td>30</td>
<td>23 (9.18)</td>
<td>116 (1,663)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Commercial Thinning (d/D ratio = .87)</strong></td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>42 (16.71)</td>
<td>207 (2,964)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Final Harvest</strong></td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>61 (23.98)</td>
<td>716 (10,253)</td>
</tr>
<tr>
<td></td>
<td><strong>Total Volume Removed</strong></td>
<td></td>
<td>1040 (14,880)</td>
</tr>
</tbody>
</table>
Table 5. Cumulative present net worth comparison for ROWTHIN and DFSIM simulations.

<table>
<thead>
<tr>
<th>Simulation No.</th>
<th>Total Logging Cost $/Ha ($/acre)</th>
<th>Total Pond Value $/Ha ($/acre)</th>
<th>Cumulative Present Net Worth per Ha (per acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ROWTHIN</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Commercial thinning at age 30, final cut at age 45</td>
<td>10,568 (4,277)</td>
<td>25,172 (10,187)</td>
<td>4,545 (1,840)</td>
</tr>
<tr>
<td>2. Commercial thinning at age 30, final cut at age 60</td>
<td>13,163 (5,327)</td>
<td>50,119 (20,283)</td>
<td>7,057 (2,856)</td>
</tr>
<tr>
<td>3. Commercial thinning at age 30 and age 45, final cut at age 60</td>
<td>12,681 (5,132)</td>
<td>45,881 (18,568)</td>
<td>6,501 (2,631)</td>
</tr>
<tr>
<td><strong>DFSIM</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Commercial thinning at age 30, final cut at age 45</td>
<td>9,968 (4,034)</td>
<td>32,676 (13,224)</td>
<td>6,050 (2,452)</td>
</tr>
<tr>
<td>2. Commercial thinning at age 30, final cut at age 60</td>
<td>10,385 (4,203)</td>
<td>57,898 (23,431)</td>
<td>8,151 (3,299)</td>
</tr>
<tr>
<td>3. Commercial thinning at age 30 and age 45, final cut at age 60</td>
<td>10,178 (4,119)</td>
<td>59,437 (24,054)</td>
<td>9,068 (3,670)</td>
</tr>
</tbody>
</table>
dependent on the growth and yield of the residual stand. When strip thinning, one would mechanically remove all trees regardless of their vigor or size in the cut strips; likewise, one would leave trees in strips regardless of their size or vigor. In contrast, when conventional thinning is used, one would remove inferior trees in the early entry, leaving the most vigorous, biggest trees for final harvest. When comparing the growth and yield for strip thinning versus conventional thinning, the strip-thinned stand will grow smaller trees than the conventional method for the same rotation. The differences in tree size and volume are almost entirely attributable to the size and vigor of the residual stand. A residual stand consisting of large, vigorous trees will outproduce a similar stand that consists of a mix of vigorous large trees and inferior small trees.

The selection of a special silvicultural treatment to be used in the initial entry is a challenging decision the forest manager must make. Once the treatment is applied to a stand, it largely dictates what that stand will yield over a period of years in product and net yield. The simulations summarized reflect the philosophy of low thinning. Low thinning, as applied here, involves removing the dead, suppressed, poor-risk, poor-form, and diseased trees in the first entry, leaving the better-dominant and co-dominant trees for the future crop. This was accomplished in DFSIM with a d/D ratio of .71. This d/D ratio simulates conditions where the initial entry removes all poor-risk, low-diameter stems, leaving the larger trees to grow. Not all managers may wish
to treat their stands in this manner.

The sensitivity effect of the d/D ratio (in effect, the sensitivity of alternate thinning policies on the comparison of strip thinning and conventional thinning) was evaluated. Table 6 shows the comparison of three different d/D ratios (thinning treatments) with RONTHIN simulation number one. A low thinning (d/D = .71) results in the largest cumulative present net yield of $6,058 per hectare ($2,452 per acre). A d/D ratio of .90 (still a thinning from below, which favors taking a fewer larger-diameter stems along with the low-diameter stems) yields a cumulative net return of $5,416/hectare ($2,192/acre)—still better than strip thinning. Strip thinning becomes the better alternative when a d/D ratio of 1.15 is used. It is not clear whether managers would thin from above (d/D = 1.15) and leave a poorer-quality stand to grow. If they did choose to remove the bigger-diameter stems in the first entry, then strip thinning would be most applicable under the conditions of this study.

In light of the results summarized above, one may wonder: why bother with strip thinning at all? The answer to this question is that preliminary results (Aulerich, 1975) show a reduction in logging costs (felling and yarding) of about 20 percent in the first entry. A 20-percent reduction in logging costs has appeal for the logger and to the landowner. Although a 20-percent reduction in logging costs in the first entry is appealing, an integrated complete systems-analysis approach explicitly looking at all the costs and benefits over the life of a stand shows that conventional
Table 6. Comparison of d/D ratios (thinning treatments) net returns with ROWTHIN simulation number one (DBH is of material cut).

<table>
<thead>
<tr>
<th>Simulation Number</th>
<th>Entry Age (yrs)</th>
<th>Average DBH cm. (in.)</th>
<th>Volume Cut m /Ha (ft /ac)</th>
<th>Cumulative Present Net Worth $/Hectare ($/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DFSIM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1a. Commercial thinning, d/D = .71</td>
<td>30</td>
<td>23 (9.18)</td>
<td>116 (1,663)</td>
<td>6,058 (2,452)</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>46 (18.23)</td>
<td>598 (8,560)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Final Cut</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1b. Commercial thinning, d/D = 90</td>
<td>30</td>
<td>25 (10.08)</td>
<td>138 (1,972)</td>
<td>5,416 (2,192)</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>44 (17.48)</td>
<td>553 (7,906)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Final Cut</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1c. Commercial thinning, d/D = 1.15</td>
<td>30</td>
<td>32 (12.88)</td>
<td>234 (3,349)</td>
<td>3,862 (1,563)</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>37 (14.69)</td>
<td>349 (4,994)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Final Cut</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ROWTHIN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Commercial thinning (remove 5.5m (18') strips, leave 5.5m (18') strips)</td>
<td>30</td>
<td>29 (11.47)</td>
<td>292 (4,178)</td>
<td>4,546 (1,840)</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>35 (13.80)</td>
<td>428 (6,122)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Final Cut</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
thinning net benefits far outweigh any logging cost reduction when strip thinning (Table 5). Another way to illustrate the difference in net benefits between strip and conventional thinning is through another example.

Using the data for simulation number one (Table 7), which looks at one entry into the stand at age 30 (final cut at age 45), we observe a difference of 33.2 percent in cumulative present net worth: $4,546/hectare ($1,840/acre) for strip thinning versus $6,058/hectare ($2,452/acre) for conventional thinning. The detailed data for this comparison is shown in Table 7. Using this data (on an acre basis) and solving for what the total logging cost would have to be for strip thinning at the first entry so that the cumulative present net worth for strip thinning would be equal to the cumulative present net worth for conventional thinning results in a value of $465.81. This suggests that total logging costs for strip thinning the first entry would have to be reduced by an additional 76.12 percent (from $1951/acre to $465.81/acre) in order that cumulative net returns be equivalent for strip and conventional thinning. The computations are detailed below for acres only:

- cumulative present net worth for conventional thinning = $2,452/acre
- present net worth for final-cut strip thinning = $1,066/acre
- the additional present net worth need at entry one for strip thinning = $2,452 - $1,066 = $1,386
- actual net revenue need at entry-one strip thinning = ($1,386)(1.03)° = 3,364.19
Table 7. Detailed data for comparison of ROWTHIN and DFSIM simulation number one (DBH is of material cut).

<table>
<thead>
<tr>
<th>Simulation Number</th>
<th>Entry Age</th>
<th>Avg. DBH (cm.)</th>
<th>Volume Removed (m³/ha)</th>
<th>Total Logging Costs ($/ha)</th>
<th>Total Pond Value ($/ha)</th>
<th>Present Net Worth ($/ha)</th>
<th>Cumulative Present Net Worth ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ROWTHIN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Commercial thinning at age 30, final cut at age 45</td>
<td>30</td>
<td>(11.73)</td>
<td>10,514</td>
<td>4,820</td>
<td>9,464</td>
<td>1,912</td>
<td>1,912</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>(13.02)</td>
<td>14,776</td>
<td>5,747</td>
<td>15,708</td>
<td>2,634</td>
<td>4,546</td>
</tr>
<tr>
<td><strong>DFSIM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Commercial thinning at age 30, final cut at age 45</td>
<td>30</td>
<td>(9.18)</td>
<td>4,109</td>
<td>2,510</td>
<td>2,873</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>(18.23)</td>
<td>21,151</td>
<td>7,457</td>
<td>30,635</td>
<td>5,908</td>
<td>5,058</td>
</tr>
</tbody>
</table>
- total logging cost for entry-one strip thinning would have to be: $3,830 - $3,364.19 = $465.81

At this point we should focus on the detailed logging costs for entry-one strip thinning. These are:

- Felling, bucking and limbing cost/acre = $256.90
- Yarding cost/acre = $1,149.60
- Loading and hauling cost/acre = $544.50
- Total logging cost/acre = $1,951

We must remember that the felling, limbing, bucking, and yarding costs above already have a savings of about 20 percent built in. Thus, when we say we need to reduce logging costs from $1,951/acre to $465.81/acre (or 76.12 percent), we are essentially saying that we need to have strip thinning costs that are 19% of conventional thinning costs to be competitive. It is unlikely that this magnitude of logging-cost savings can be achieved. Note that the example used here uses a d/D of .71. The break-even results would change for other d/D ratios.

Options/Alternative Applications

The above results apply only to the given set of conditions simulated. Although we do not have data on alternate management possibilities of the cut-and-leave strips once implemented, one cannot dismiss other possible management options. For example, the cut strips might be planted with nitrogen-fixing plants in hopes that the nitrogen produced would enhance the growth of the residual stand. It is not clear that the leave strips would get enough light
to make this option feasible. Another management option may be to graze the leave strips. Again the question of enough light must be addressed. Another option might be using the cut strips to get a regeneration advantage. The issue of enough light and/or shade-tolerant species selection must be dealt with. Also, logging damage to the new stand during the final removals must be determined. Yet another option may be to selectively thin poor-quality, low-diameter trees from within the leave strips. This would then enhance growth of the residual trees but would also leave fewer stems for the final crop. The logging options of removing trees from within leave strips must also be evaluated. It is beyond the scope of this study to deal with these other management options, even if we had the data. However, given the data, an analyst could easily evaluate other options by using the ROWTHIN model as it is—or, with minor modifications to the computer program, ROWTHIN can be used to develop reliable benefit and cost estimates of alternate strip-thinning options.
SUMMARY AND CONCLUSIONS

The question of whether to use strip or conventional thinning is indeed a complex one. The manager evaluating whether to use one method over the other must consider many factors—one of which is the economics, that is, the net returns possible from each thinning method. ROWTHIN's current design allows the manager to estimate the costs and benefits associated with strip thinning.

Integrated results of ROWTHIN and DFSIM simulations suggest that the net returns in all cases simulated are higher when using the convention low-thinning method. This is primarily due to the increased growth and yield obtained by the conventional method. Conventionally-thinned stands produce bigger and more valuable stems than strip-thinned stands.

Results from breakeven analysis suggest that total logging costs for strip thinning in the first entry must be reduced by an additional 76 percent in order for the net returns of both thinning methods to be equivalent. It is unlikely that this magnitude of cost savings can be realized.

This manuscript summarizes a research effort that, in an integrated economic sense, suggests that net returns from strip thinning are inferior to those derived from conventional low thinning. Admittedly, the results of this study are specific to a given-site class of Pacific Northwest coastal Douglas-fir, an initial stand structure, stand age at time of thinning, frequency and intensity...
of thinning, and the thinning method chosen. At this point, it is not clear that any embellishment on strip thinning or any combination of site class, stand structure, timing and intensity would offset the differences in cumulative net revenue compared with conventional low thinning.

Although this type of analysis does not provide all the answers a manager needs to decide on whether to strip or conventional thin, it does give the manager economic insight into the best ways to manage the young stands of the future.
LITERATURE CITED


APPENDIX I

Computer Code Listing for ROGTHIN

PROGRAM MAIN(INPUT,OUTPUT,TAPE7,TAPE5=INPUT,TAPE6=OUTPUT)
DIMENSION HSET(2000)
COMMON /GCDM/ ATRIB(25),JEVNT,MFA,MFE(IO0),MLET,
1 MCRDR,MPAP,NXAPT,NXFL,NN(100),NNRT,MPRT,PPARM(50,4),
1 MMU,TBEG,TEND,TFIN,TRIB(125),HSET
COMMON /UCOM/:
TBAT(2,0:40,40,3),HSET(2),HTR(2,0:40),EDGE(2,0:40),
1 EDGE(2,0:40),LEN(2,500),ISTU(2,40),KENTR(2,0:40),
1 NENTR,KENTR,
2 YTIME,TIME,HLOGS,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
3 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
4 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
5 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
6 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
7 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
8 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
9 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
10 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
11 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
12 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
13 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
14 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
15 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
16 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
17 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
18 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
19 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
20 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
21 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
22 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
23 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
24 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
25 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
26 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
27 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
28 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
29 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
30 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
31 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
32 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
33 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
34 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
35 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
36 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
37 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
38 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
39 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
40 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
41 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
42 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
43 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
44 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
45 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
46 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
47 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
48 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
49 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
50 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
51 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
52 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
53 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
54 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
55 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
56 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
57 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
58 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
59 YTIME,TIME,HLONG,IPER,TAPE,TDEN,THETA,BT10E,pN(0),
60 LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
61 INDST(2,500),ISTU(2,40),KENTR(2,0:40),KENTR, KENTR,
DO 5 LR=1,2
DO 6 ISTR=0,40
  NTR(LR,ISTR)=0
  CONTINUE
  5 CONTINUE
  DO 7 KKENTR=0,5
    TVOL(KKENTR)=0.0
    CONTINUE
  7 CONTINUE

INITIALIZE VARIABLES

C INPUT INITIAL CONDITIONS
C
READ(5,101) BCOST,CH,CSLOPE,DISCT,FCOST
READ(5,101) HLCOST,SP,SPC,SSLOPE,TAPER
READ(5,101) XI,UD,YD,WD,UW
READ(5,102) NENTR,HSTR(LR),ISTR(1),ISTR(2)
READ(5,102) ((ISTR(LR),ISTR(LR)),LR=1,2)
READ(5,102) (ISTULR(ISTR(LR)),ISTR(LR)),LR=1,2)
READ(5,102) (ISTULKSTR(LR),ISTR(LR)),LR=1,2)
READ(5,102) ((LOGTAB(LSTEN,ILTPE,ILTYPE=),LSTEN=1,2))
READ(5,102) (LSIZE(LTYPE),IYPE=1,5)
READ(5,102) NENTR,HCRE,TREES
C DO PRELIMINARY CALCULATIONS AND CHECKS
TTHETA=TAN(THETA)
CTHETA=COS(THETA)
STHETA=SIN(THETA)
WRITE(6,101) TTHETA,CTHETA,STHETA,UCOR
DO 300 LR=1,2
C DO CHECKS ON INPUT VARIABLES
IF ((CH.LT.0.0) .OR. (DISCITED.E.0.0) .OR. (DISCITED.E1.0))
1.0. (UD.LT.0.0) .OR. (SPC.LT.0.0) .OR. (SPC.E.0.0)
1.0. (YD.LT.0.0) .OR. (YD.E.0.0) .OR. (YD.E.0.0)
1.0. (XI.LT.0.0) .OR. (XI.E.0.0) .OR. (XI.E.0.0)
1.0. (NENTR.GT.5) .OR. (ISTR(LR).GT.1000)
1.0. (ISTR(LR).GT.40) .OR. (ISTR(LR).GT.40)
1.0. (NENTR.GT.1000) THEN WRITE(6) "INPUT PARAMETERS OUT OF RANGE."
STOP
ENDIF
C CHECK THAT STRIP WIDTHS ARE MULTIPLES OF THREE
DO 100 ISTR=1,NSTR(LR)
IF ((ISTR(LR).NE.ISTR(LR)/3).DI.3) THEN
WRITE(*,*) 'STRIP WIDTHS NOT MULTIPLES OF THREE' STOP END IF
100 CONTINUE C COMPUTE INDST(.,.)
ISTR=ISTR+1 IF (ISTR.GT.NSTR(LR)) THEN WRITE(*,*) 'NOT ENOUGH STRIPS.' STOP ELSE 
ISTR=ISTR+1 IF (ISTR.GT.NSTR(LR)) THEN WRITE(*,*) 'TOO MANY STRIPS.' STOP END IF
150 CONTINUE IF (ISTR.LT.HSTRCLR)) THEN WRITE(*,*) 'TOO MANY STRIPS.' STOP END IF
200 CONTINUE KENTR(1,0)=0 KENTR(2,0)=0 C CREATE A SPACE-EVENT TO START SIMULATION
C ATRIB(1)=0.0 ATRIB(2)=1.0 CALL FILEM(1) RETURN END SUBROUTINE EVNTS (IX)
GO TO (101,102,103,104), IX
101 CALL SPACE RETURN
102 CALL HARVEST RETURN
103 CALL ECON RETURN
104 CALL GROWTH RETURN END
SUBROUTINE SPACE

COMMON /GCOM1/ TDM(2,0:40,40,5),SD(2),TRB(5),JEYNT,NFA,MFE(100),NCRDR,NNAPO,NNAPTPNATR,HNFIL,NOCt00),,TRYNPRNTPPARIIO4)

COMMON /UCOM1/ TDAT(2,0:40,40,3),HSTR(2),NTR(2,0:40),LR,

1UY,UXD,UXD,L,SP,YCA,TE,STL,CSLOPE,MCRED,

2DVL,DFULG,XLA,CFTH,CH,SCP,NI,MTREES,BTD,STLVP,

3K,UT,THETA,BTINE,PMY(5),LBSIZE(5),ESTA,

4LOGTAs(5),LZLB(100,5),EDGE(2,0:40),EDGEZ(2,0:40),

5INDST(2,500),IST(2,40),NENT1(2,0:40),NENTR.KRENT,

7NENT1,TIME,MOGSL,STEM,AYER,DIAH,ENGL,COSANG,

8RAY,MLG,MLG,RTS,CSLGB,ANLBO,PROP(5),W.COST,TCOST(5),

9RT(5),NRE'(5),DISC,MTRENS,STHET,CTHET,STHET,WEH,SGM(5)

COMPUTE THE FOLLOWING:

S=APPROXIMATE LENGTH OF A CELL SIDE
K=NUMBER OF COLUMNS WITHIN GRID
L=NUMBER OF ROWS WITHIN GRID
A=HEIGHT OF CELL
B=LENGTH OF A CELL
C=X-COORDINATE OF LOG (1,1)
D=Y-COORDINATE OF LOG (1,1)
DST=DISTANCE TO LI OR L2
DSTNDISTANCE TO LI' OR L2'

S=SQR(UYD*UXD/NTREES)
K=(INT(UYD/S)/2)+2
L=(INT(FLOAT(NTREES)/K)+2)

A=UXD/K
B=UYD/L
D=100 I=1,K

DO 110 J=1,L

X=X+RMNRM(1,1)
R=RMRM(2,2)
C=C+(SPC*R3)
D=D+SPC*R4
IF (C.LT.UXD/2.) C=UXD/2.
IF (C.GT.UXD/2.) C=UXD/2.
IF (D.LT.0.) D=0.
IF (D.GT.UYD) D=UYD.
IF (D.EQ.0.) THEN

59
LR=1:
ELSE
LR=2
ENDIF
DL=ABS(C+(3.-2.*LR)*(D.*TTHETA+IJXEI,))CTHETA
DLF': B S (C
IF (ABS(C).LE.UCOR/2.) THEN
ISTRzO
IF ((ISTR.LT.0).OR. (ISTR.GT.NSTR(LR))) THEN
WRITE(6,*) 'STRIP INDEX OUT OF RANGE.'
STOP
ENDIF
ELSE
ISTR=MOST(LR,INT(DL/2.));+1
ENDIF
ITR=NTR(LR,ISTR)+1
IF (ITR.GT.J) THEN
WRITE(6,102)LR,ISTR,ITR
STOP
ENDIF
IF (ISTR.EQ.0) THEN
TDAT(LR,ISTR,ITR,1)=C
TDAT(LR,ISTR,ITR,2)=L
ELSE
TDAT(LR,ISTR,ITR,1):DL
TDAT(LR,ISTR,ITR,2):LP
ENDIF
TDAT(LR,ISTR,ITR,3):RH0R(33)
CONTINUE
100 CONTINUE
RTREE:Kp
WRITE(6, 105)NTREE3,TREE
IF CORRIDOR STRIP
DO 100 LR=1,2
DO 1400 ISTR:1,NSTR(LR)
1100 IFL=0
DO 1300 ITR:1,HTR(LR,ISTR)-1
IF (TDAT(LR,ISTR,ITR,2).GT.TDAT(LR,ISTR,ITR+1,2)) THEN
IFL=1;
DC (1:0) ICH=1,3
TEMP=TDAT(LR,ISTR,ITR,ICH)
TDAT(LR,ISTR,ITR+1,ICH)=TEMP
TDAT(LR,ISTR,ITR+1,ICH)=TDAT(LR,ISTR,ITR,ICH)
CONTINUE
ENDIF
ENDF
1200 CONTINUE
FORMAT(I2,150) LR=1,2
DO 1400 ISTR=1,NSTR(LR)
1100 IFL=0
DO 1300 ITR=1,HTR(LR,ISTR)-1
IF (TDAT(LR,ISTR,ITR,2).GT.TDAT(LR,ISTR,ITR+1,2)) THEN
IFL=1;
DC (1:0) ICH=1,3
TEMP=TDAT(LR,ISTR,ITR,ICH)
TDAT(LR,ISTR,ITR+1,ICH)=TEMP
TDAT(LR,ISTR,ITR+1,ICH)=TDAT(LR,ISTR,ITR,ICH)
CONTINUE
ENDIF
ENDF
1200 CONTINUE
102 FORMAT(I2,510)
STOP
CONTINUE IF (IF.L.E.0.1) GOTO 1100
CONTINUE
C SCHEDULE HARVEST EVENT

ATRIB(1)=TMOV
ATRIB(2)=2.0
CALL FILEM(1)
RETURN
END

C SUBROUTINE HARVEST SERVES AS A CONTROL MODULE FOR ENTRYS INTO CUTTING UNIT

SUBROUTINE HARVEST

COMMON /GCOH1/ ATRIB25),JENF,hFA,FE(100),MLE(I00),HRHO(50,4),NMCRTH
tHAPM,NNATR,NHFT,HNUTM,HPF,NPARM(50,4),IADJ
COMMON /UCOPI1/ TDAT(2,0:40,40,3),HSTR(2),ATRIB(2,0:40),LR,
UYD,UXD,YBE,UXL,AC,YE,SLOPE,SLKPR,HCREW
COMMON /UCOPI1/ TDAT(2,0:40,40,3),HSTR(2),ATRIB(2,0:40),LR,
UYD,UXD,YBE,UXL,AC,YE,SLOPE

IF (KENTR.LT.NENTR) THEN
KENTR=KENTR+1
TVOL(KENTR)=0.0
HSTENS=0.0
YTINE=FTINE=BTINE=0.0
FBCOST=XHLCOST=YCQST=0.0
IF (KENTR .EQ. 0) THEN
NLOGS=0
LR=1
ISTR=0
CALL FBUC
LR=2
CALL FBUC
CALL YARD.
ELSE
DO 40 LR=1,2
STRID=UXD/STHETA/2.
DO 50 ISTR=1,ISTR(LR)
XWIDTH=ISTU(LR,ISTR)/STHETA/2.
40 CONTINUE
50 CONTINUE
END

C****SUBROUTINE HARVEST SERVES AS A CONTROL NODULE FOR ENTRYS INTO CUTTING UNIT
**SUBROUTINE YARDS**

The LOGTA subroutine is designed to process data related to logging and yarding operations. It calculates various parameters such as diameter (DBH), angle (COSANG), and length (STLEN) of logs. The subroutine performs arithmetic operations and conditional checks to determine the validity and length of logs within a strip. The output is tailored for specific applications in forestry and logging operations, ensuring efficient resource management and planning.
C
C SUBROUTINE YARD
C COMMON /GCom1/ ATRIB(35), JEWL, HFA, NFE(100), HLE(100), HSTOP, HSECTION, NOBAR, MAFIL, HAEIL, MFIL, HAE(100), MAFIY, NASS, PAQAI, CO(10),
2 TMOD, TYPG, TCLR, TFIN, TTRIB(25), ITSET
C COMMON /UCOaI1/ TIIAT(2,0:40,40.3), NSTR(2), HTR(2,0:40), LR,
1 UYD, UXD, UU, XIIDL
C C SLOPE CSLOP'E CREA
3 BFVLT, BFVLC, XLA, CFTTN, CNSPCL, ABNTREESSY, XRLP, XMYE, FTIME, NLO6S, LST, TAPER, DIAM, ANGLE, 
4 COSANG, XLEN, HLT, PCP, ISLOG, TVLOG, TVO(100), ISLOG, TCST(0:5),
5 MTOOLS, TVR, TVRE(4:5), TVCOST, TVCOST, TVTIME(0:5), DISC,
6 TERENCE, T0M, ADBBA, PDBB4V, TTHETA, CTTHETA, CTYTA, WDIR, XDH(10:5)
C
C C SORT LOGS BY LIF DISTANCE
C C
100 IF (IFL .EQ. 0) GO TO 106
10 DO ILOG = 1, LLOGS
2 IF (ILOG(1) .LT. LLOG(ILOG+1)) THEN
3 DO J = 1, 6
4 IF (LOG(ILOG+J) .LT. LOG(ILOG+J+1)) THEN
5 ZLOG(ILOG+J) = ZLOG(ILOG+J+1)
6 CONTINUE
7 IF (LLOG .GT. LLOGS) THEN
8 ISLOG = ISLOG + 1
9 GO TO 60
10 CONTINUE
11 IF (ISLOG .EQ. 0) GO TO 106
12 ISLOG = 1
13 C DETERMINE FIRST UNYARED LG IN LOG ARRAY
14 IF ((LOG(1) .LE. LLOGS)) THEN
15 ISLOG = ISLOG + 1
16 GO TO 40
17 CONTINUE
18 IF (ISLOG .GT. LLOGS) GO TO 60
19 C DO FIRST LOG COMPUTATIONS
20 DL = LOG(1) - 1
21 DL(1) = LOG(1) - 1
22 XLEH = LOG(1)
23 LOG(1) = ISLOG(1) + 1
24 IF ((HFA .LE. HLE(0.0))) THEN
25 IF (LOG(1) .LE. WUW) THEN
26 IF (CAAA .EQ. 1) THEN
27 SL = 1 - PM(STRP)
28 IF (HFA .EQ. 0) THEN
29 IF (LOG(1) .GT. LLOG(15)) THEN
30 SDR FOR CLOSEST ELIGIBLE LG TO FIRST-HOOKED LG
31 DO SO TLOG = ISLOG, 1
32 END
IF (ILOG1LOG4.NE.0.AND.
    ZLOG(ILOG,6sUUv.LE.RC,f)) THEN
    DISTSQR*2L06(ILOG,1)_DL),*2+(ZLOG(ILOG,2)_DLP)**2
    IF(DISTSQR .LT. XMIN)THEN
        XHINDISTSOR
        INHLOG:JLOG
    EDIF
ENDIF
30 CONTINUE
IF(SORT(XMIN).LE. XNDL)THEN
    NLT:NLT+ I
    R CA
    R CAF -UT
    ZLOG(INHLOG,u=o
    IF(MLT .LT. NCA) GO TO 90
    ENDIF
NLE:HLEiaL.T
C
C*ts*SUBROUTINE ECON COMPUTES PRESENT NET WORTH PER ENTRY
C
SUBROUTINE ECON
COMMON /GCOII1/ ATRIB(25) ,JEVNT,MFA,MFE(I0Q) ,NLE(00) ,MSTOP,
    MCRDR,NAAP0,MMAPT,MMAT,MMFL,MMO(100),MNTRY,MPRINT,PPAM(50,4),
    2TMN,T4U0,T4CLR,T71N,T7IN(25),T7SET
COMMON /UCO1II/
    TDAT(2,0:40,40,3) ,NSTR() ,HTR2.0:40) ,LR,
    1UYD,UXD,UU'J,XMIIL,SP,NCA,YE,SLOPE,CSLOPE,NCREU,
    2BFVLT,BFVLG,XLA,CFTIU,CH,SPC,L,A.B,HTREES,SYII,STRLF.,
    K,UT,THETA,3TIàiE,pNU(0:5),LSIZE(5) ,ISTR,
    4LQGTAB(0:5),ZLOG(100,63,EDGE(2,0:40).EDGE2(2,0:40),
    61NS(2,250),ISIU(2,40),KENTR2,0:40),KEMT,KEKTR,
    7YTIME,FTIME,HLOG,LISTEM,TAPER,DIA:.20,ANHIE,COSSH,
    BTSANH,MLE,HLT,RCAP,ISLOG,MYLOG,TVOL(0:5),HCCST,TGOST(0:5),
    9TREV(0:5),TREV(0:5),TCOST,TCOST,FST,COST,KTIME(0:5),SSET,
    INSTEK,TD3N,APOEHN,PMONVAL,TTHETA,CHTHETA,STHETA,CHCOR,CDBH(0:5)
C
C
XI'BP$tKKN IR)AVGDH
PONDVALZ(-20.1061.'8.393*AVGDBH),,000.
FBCOST*((.1026-.0036*XDBH(KKENTR))*TVOL(KKENTR))II.30
XHLCOSTa( . 196930-.0088sXDBH(g1ENIR) )*TVOL(1ETR)
YCOST:(.72260_IO246?83*XDBHC1KENTR))*TVOL(1ETR)
ICOST C KKENTR ) =FBCOST+HL COST+YCOST
TREV(I1ENTR=TREV(I1ENTR)+TVOL(KKENTR):IPOIVAL
TNREV(KKENTR):IREV (KKENTR)-TCOST (}(KENTR)

C C
SCHEDULE GROWTH EVENT
ATRIB(1)=NW
ATRIB(2)=4.0
CALL FILENC1)
RETURN
END

C C
SUBROUTINE GROWTH GROWS TREES BETWEEN ENTRIES
SUBROUTINE GROWTH
COMMON /GCOM1/ ATRIB(25),JEVENT,NFA,NFE(100),MLE(100),NSTRF,
INCSEP,INMAP,NAPT,N ATT,INFL,HNG(100),NKTRY,NFRNT,PPAM(50,4),
ZTHOU,ITBEG,ICNT1,ITIM,ITRDZ(25),IMSET
COMMON /UCOM1/ 1 BAT(2,0:40,40,3),NSTR(2),NTH(2,0:40),LR,
1U7D,UXD,UXL,UXM,SP,TK,SK,CSLOPE,CSTOE,MCREV,
ZPFVLT,ZPFLV,XLA,CTTHN,IN,SPC,L,A,B,TREES,STD,STLP,
IN,UT,THETA,STIME,PMU(0:5),LSIZE(0):ISTR,
4LOGTAB(40,5),LOG(100,8),(EDG1(2,0:40),(EDG2(2,0:40),
6NBB(12,500),ISTU(2,40),KENTR(KKENTR),
7TIME,TIME,MOB,DSTH,L,STEB,EKGU,DIAM,MN,MF,CONAN,
B3HANG,XMLI,MLT,RCAP,ISLOG,INMSWGV,TVOL(1:5),ALHCT,TCOST(1:5),
FREV(2),TFREV(2,5),TFCOST,TCOST,TFTIME(1:5),DISC.
1NSTENS,TDBM,AvgDBM,PONDVAL,THETA,STHETA,STHETA,WCOR,(DBH(0:5))
DO 500 LR=1,2
ICUMU=0.0
EDGI=0.0
ILFLG=0
LSTR=0
DO 400 ISTR=1,NISTR(LR)
IF (KKEIITR.LT.KKENTR(LR,ISTR)) THEN
C LEAVE STRIP
IF (ILFL.GE.80) THEN
C CUT STRIP / LEAVE STRIP BOUNDARY
ILFLG=1
EDGI=ICUMU
ENDIF
ELSE
EDGI=LR,ISTR):EDG
ENDIF
400 CONTINUE
IF (ILFLG.EQ.1) THEN
   C LEAVE STRIP / CUT STRIP BOUNDARY
   ILFLG=0
   DO 350 JSTR=ISTR+1,ISTR-1
   EDGE2(LR,JSTR)=ICUMU
   CONTINUE
   LSTR=ISTR
   ENDIF
   ICUMU=ICUMU+ISTR(LR,ISTR)
   CONTINUE
   DO 450 JSTR=ISTR+1,NSTR(LR)
   EDGE2(LR,JSTR)=ICUMU
   CONTINUE
   N=KENTR+1 - KTIME(KKENTR)
   C1=-0.0292245
   C1=-0.015524
   C2=-0.0201005
   C2=-0.0203446
   B1=(1+C1)**N
   B2=(1+C2)**N
   CALL FILEM(1)
   RETURN
ENDIF
   ICUMU=ICUMU+ISTR(LR,ISTR)
   CONTINUE
   DO 700 ITR=1,NTR(LR,ISTR)
   IF (KENTR.LT.KENTRCLR,ISTR) THEN
      EDG2=EDGE2(LR,ISTR)
      DO 800 ISTR=1,NSTR(LR,ISTR)
      IF ((DIST1.LT.15.) .OR. (DIST2.LT.15.)) THEN
         TDAT(LR,ISTR,ITR,3)=AHM(DIST1,DIST2)+C12
         ELSE
         TDAT(LR,ISTR,ITR,3)=B1+TDAT(LR,ISTR,ISTR,3)
      ENDIF
      CONTINUE
      ELSE
      TDAT(LR,ISTR,ITR,3)=B2+TDAT(LR,ISTR,ISTR,3)
      ENDIF
   CONTINUE
   CONTINUE
300 CONTINUE
900 CONTINUE
C SCHEDULE A HARVEST EVENT
C ATRIB(1)=TNO
ATRIB(2)=2.0
CALL FILEM(1)
RETURN
C****SUBROUTINE OTPUT OUTPUTS SIMULATION RESULTS
C
SUBROUTINE OTPUT
COMMON /GCOM/ ATBIR(25), JEVNT, NHM, HFE(100), ALE(100), NSTOP,
VCRDR, NMAP0, NMAP, NMAT, NMIN, NMID(100), NMRT, PFRAT, PPARH(50,4),
2TMU, TTBEG, TTIME, TTRIP(20), TSET
COMMON /GCOM/ EEROH(100), IRH(100), KXRRH(100), MMMG(100),
100TMR(100), SSDBF(25,5), STHP(25,5), VHNM(100)
COMMON /GCOM/ TFAIL(100,40,40,3), MSTR(2), MTR(12,0,40), LR,
URD, URD, XAMLD, SF, MCA, VE, SLOPE, COLPHE, MCREW,
2BFULT, PFULT, ILN, FTTHM, CN, STC, L, AP, MTREES, SYB, STRP,
3X, UT, THETA, BT1ME, FAV(I,15), LEXEC(2), ISTR,
4LDIST(100,5), LOG(100,5), EDIST(12,0,40), EDDC(12,0,40),
6INDST(2,500), ISTU(2,40), KHER(2,1,40), HENTR, KHERTR,
7TIME, FITR, MLOG, LIST, TAFER, DISH, GDM, ANGLE, COSWAV,
8SIMAV, XEM, XLT, ICP, ILFD, INLOG, YELOG, YX1(10,5), MLCDT, TCOST(0,5),
9TREX(10,5), TREV(0,5), TCOST, FCOST, ATNTE(0,5), DISC,
1HSTERS, TDBH, NVGDRN, PONDVAL, TTHETA, CTHTETA, CTHTETA, WCOR, XDBH(0,5)
WRITE(6,700)
700 FORMAT(//,2X,6D10.17,/,2X,***,59X,***,1.7,2X,**%,59X,***,1.7,2X,**%
2X,"***",5X),/5X,20,40,10,NEHTR
WRITE(6,104) KTIME(I), XDBH(I), TVOL(I), TCOST(I), TREV(I)
104 FORMAT(5X,10,5F10.2)
20 CONTINUE
3MHOURLY PRODUCTION RATE FOR YABRING,F10.4)
RETURN
END
APPENDIX II

Example Input Data for ROWIHIN

```
01 GEN.LEDOUX,TESTRUN,2.6,1983.1,7=
02 STA,5=
03 LIM.4,4,300.2,2000=
04 COL.1,4TIME.2,MLT.5,SYH.4,XLB.5,MT=
05 PRI.1,HWF.2=
06 PAR.1.0.0-10.0.10.0.1.0=
07 PAR.2.0.0-10.0.10.0.1.0=
08 PAR.3.1.1.2.4.7.20.4.3.5=
09 PAR.4.17.0.5.6.6.6.1.0=
10 INL.0.YES.ES.0. YES=
11 SEE.11337.43989.48275.23398=
12 FIN=
13 1.10 22.00 30.00 .03 1.00
14 1.133000.00 1.40 19.00 .14
15 0.79 120.00 598.00 12.00 46.00
16 1.30 1.60 1.12
17 2 2 2
18 18 18 18 18
19 18 18 18 18
20 18 18 18 18
21 18 18 18 18
22 18 18 18 18
23 18 18
24 2 1 2 1 2 1 2 1 2
25 2 1 2 1 2 1 2 1 2
26 2 1 2 1 2 1 2 1 2
27 2 1 2 1 2 1 2 1 2
28 2 1 2 1 2 1 2 1 2
29 2 1
30 26 30 60 60
31 0 0 0 0 0 0 0 0 0
32 0 0 0 0 0 0 0 0 0
33 0 0 0 0 0 0 0 0 0
34 0 0 0 0 0 0 0 0 0
35 0 1 0 0 0 1 0 0 0
36 0 0 0 0 0 0 0 0 0
37 0 0 0 0 0 0 0 0 0
38 0 0 0 0 0 0 0 0 0
39 0 0 0 0 0 0 0 0 0
40 0 0 0 0 0 0 0 0 0
```
Example Input Data for ROWTHIN (continued):

Cards 1-12 are required for GASP IV input. Users interested in interpreting the required GASP IV values are referred to The GASP IV Simulation Language (Pritsker, 1974).

Card 13

This card contains the following data:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-7</td>
<td>F7.2</td>
<td>Maximum Distance for Hooking Turns</td>
</tr>
<tr>
<td>8-14</td>
<td>F7.2</td>
<td>Chordslope, percent</td>
</tr>
<tr>
<td>15-21</td>
<td>F7.2</td>
<td>Yarding Efficiency</td>
</tr>
<tr>
<td>22-28</td>
<td>F7.2</td>
<td>Discount rate, decimal</td>
</tr>
<tr>
<td>29-35</td>
<td>F7.2</td>
<td>Felling Cost/ft²</td>
</tr>
</tbody>
</table>

Card 14

Card 14 contains the following data:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-7</td>
<td>F7.2</td>
<td>Hauling and Loading Cost/ft³</td>
</tr>
<tr>
<td>8-14</td>
<td>F7.2</td>
<td>Yarding System Payload, lbs</td>
</tr>
<tr>
<td>15-21</td>
<td>F7.2</td>
<td>Spatial Distribution Coefficient</td>
</tr>
<tr>
<td>22-28</td>
<td>F7.2</td>
<td>Percent Sideslope</td>
</tr>
<tr>
<td>29-35</td>
<td>F7.2</td>
<td>Taper Rate, inches/linear foot</td>
</tr>
</tbody>
</table>

Card 15

Card 15 contains the following data:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-7</td>
<td>F7.2</td>
<td>Corridor Angle, Radians</td>
</tr>
<tr>
<td>8-14</td>
<td>F7.2</td>
<td>Skyline Block Width, ft</td>
</tr>
<tr>
<td>15-21</td>
<td>F7.2</td>
<td>Skyline Block Length, ft</td>
</tr>
<tr>
<td>22-28</td>
<td>F7.2</td>
<td>Skyline Corridor Width, ft</td>
</tr>
<tr>
<td>29-35</td>
<td>F7.2</td>
<td>Weight/Unit Volume, lbs/ft³</td>
</tr>
</tbody>
</table>

Card 16

Card 16 contains the following data:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-7</td>
<td>F7.2</td>
<td>Maximum Distance for Hooking Turns</td>
</tr>
<tr>
<td>8-14</td>
<td>F7.2</td>
<td>Yarding Efficiency</td>
</tr>
<tr>
<td>15-21</td>
<td>F7.2</td>
<td>Yarding Cost/ft²</td>
</tr>
</tbody>
</table>
Card 17

Card 17 contains the following data:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-7</td>
<td>17</td>
<td>Number of entries into unit</td>
</tr>
<tr>
<td>8-14</td>
<td>17</td>
<td>Number of strips on left side of skyline block</td>
</tr>
<tr>
<td>15-21</td>
<td>17</td>
<td>Number of strips on right side of skyline block</td>
</tr>
</tbody>
</table>

Cards 18 - 23

Cards 18-23 contain the following data:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-70</td>
<td>1017</td>
<td>Cut-and-leave strip widths</td>
</tr>
</tbody>
</table>

Cards 24 - 29

Cards 24-29 contain the following data:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-70</td>
<td>1017</td>
<td>Entry schedule, 1 = first entry, 2 = second entry</td>
</tr>
</tbody>
</table>

Card 30

Card 30 contains the following data:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-7</td>
<td>17</td>
<td>Entry age for skyline corridor</td>
</tr>
<tr>
<td>8-14</td>
<td>17</td>
<td>Entry age for first entry</td>
</tr>
<tr>
<td>15-21</td>
<td>17</td>
<td>Entry age for final cut</td>
</tr>
</tbody>
</table>

Cards 31 - 60

Cards 31-60 contain the bucking rules as described in Appendix X.

Card 61

Card 61 contains the following data:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-70</td>
<td>1017</td>
<td>Log lengths desired, ft.</td>
</tr>
</tbody>
</table>
Card 62 contains the following data:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-7</td>
<td>I7</td>
<td>Number of chokers flown</td>
</tr>
<tr>
<td>8-14</td>
<td>I7</td>
<td>Number on rigging crew</td>
</tr>
<tr>
<td>15-21</td>
<td>I7</td>
<td>Number of trees per skyline block</td>
</tr>
</tbody>
</table>
APPENDIX III.
Example Output from ROMTHIN

<table>
<thead>
<tr>
<th>LINE</th>
<th>LEM, LEND, TESTRUN, 2, 8, 1983, 1, /*</th>
<th>**GASP INPUT ERROR TYPE I80 **</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>STA, 5, 002</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>LIM, 4, 4, 300, 2, 0030</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>COL, 1, TLINE, 2, MTL, 2, STR, 4, XLR, 5, UI</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>PRL, X, RLF, 2, 004</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>PAR, 1, 0, 0, 0, 0, 0, 0, 0, 0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>PAR, 2, 0, 0, 0, 0, 0, 0, 0, 0</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>PAR, 3, 0, 0, 0, 0, 0, 0, 0, 0</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>PAR, 4, 0, 0, 0, 0, 0, 0, 0, 0</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>INI, 0, YES, YES, YES, YES, YES</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>SEE, 11327, 43985, 40275, 35785</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>FIN, 11327, 43985</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>1.10 20.00 30.00 03 1.00</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>1.123000.00 1.40 19.00 1.40</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>0.79 120.00 398.00 12.00 46.00</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>45.00 1.40 1.12</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>2 26 26</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>10 18 10 10 10 10 10 10 10 10 10</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>15 18 10 10 10 10 10 10 10 10 10</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>10 18 10 10 10 10 10 10 10 10 10</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>10 18 10 10 10 10 10 10 10 10 10</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>10 18 10 10 10 10 10 10 10 10 10</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>2 26 26</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>2 1 2 1 2 1 2 1 2 1 2 1 2 1 2</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>2 1 2 1 2 1 2 1 2 1 2 1 2 1 2</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>2 1 2 1 2 1 2 1 2 1 2 1 2 1 2</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>2 1 2 1 2 1 2 1 2 1 2 1 2 1 2</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>2 1 2 1 2 1 2 1 2 1 2 1 2 1 2</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>2 1 2 1 2 1 2 1 2 1 2 1 2 1 2</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>2 1 2 1 2 1 2 1 2 1 2 1 2 1 2</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>2 1 2 1 2 1 2 1 2 1 2 1 2 1 2</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>30 30 30 30</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>30 30 30 30</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>0 0 0 0 0 0 0 0 0 0 0 0 0 0 0</td>
<td></td>
</tr>
</tbody>
</table>
null
GASP IV VERSION 01JAN76

072  0  MAN NCLI=  5  MNSTA=  0  MNHIS=  0  MNPRN=  4  MNPRT=  0  MNSTR=  4  MNTRY=  300
073  2  MNATE=  2  MNFIL=  1  MNSET= 2000  MNQEO=  0  MNQED=  0  MNFLAG=  0
074  1  IIPDF=  Y  IIPDS=  Y  IISUM=  Y  IIIPIR=  Y

075  1  COLCT NO.  1  LLABC+TIME
076  1  COLCT NO.  2  LLABC=MLT
077  1  COLCT NO.  3  LLABC=STO
078  1  COLCT NO.  4  LLABC=3LD
079  1  COLCT NO.  5  LLABC=UT

080  PRIORITY FILE 1=HVF (2)

081  1  PARAMETER SET  1 = 0.  -1.000E+02  .1000E+02  .1000E+01
082  1  PARAMETER SET  2 = 0.  -1.000E+02  .1000E+02  .1000E+01
083  1  PARAMETER SET  3 = .1120E+02  .4900E+01  .2050E+02  .3500E+01
084  1  PARAMETER SET  4 = .1700E+02  .1600E+02  .1800E+02  .1000E+01

085  1  MPSTOP=  0  DJLCA=  Y  JJJREG=  Y  TTBEG=  0.  TTFIN=  .1000E+21
086  1  JJFIL=  Y
087  1  ITHER=  11327
088  1  43989  49275  53985
089  1  "GASP FILE STORAGE AREA JUMP AT TIME 0.  **
090  1  MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA = 1

091  1  PRINTOUT OF FILE NUMBER  1
092  0  THOM =  0.
093  0  OUTIN =  0.
094  100  FILE CONTENTS
**INTERMEDIATE RESULTS**

**NO. TREES SPECIFIED = 510 NO. TREES CREATED = 510**

```
*** ENTRY AVE VOLUME LOGGING FUND ENTRY ***
*** AGE DRH CUT COST VALUE PMU ***
*** GASP SUMMARY REPORT ***
```

**HOURLY PRODUCTION RATE FOR YARDING 580.6017**

**PARAMETER SET 1 = 0.**
-0.1000E+02 0.1000E+02 0.1000E+01

**PARAMETER SET 2 = 0.**
-0.1000E+02 0.1000E+02 0.1000E+01

**PARAMETER SET 3 = 1.**
0.1120E+02 0.4900E+01 0.2600E+02 0.3500E+01

**PARAMETER SET 4 = 1.**
0.1700E+02 0.1600E+02 0.1800E+02 0.1000E+01
<table>
<thead>
<tr>
<th>Statistic</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.0001</td>
<td>0.0002</td>
<td>0.0003</td>
<td>0.0004</td>
<td>0.0005</td>
<td>0.0006</td>
<td>0.0007</td>
<td>0.0008</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.0001</td>
<td>0.0002</td>
<td>0.0003</td>
<td>0.0004</td>
<td>0.0005</td>
<td>0.0006</td>
<td>0.0007</td>
<td>0.0008</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.0001</td>
<td>0.0002</td>
<td>0.0003</td>
<td>0.0004</td>
<td>0.0005</td>
<td>0.0006</td>
<td>0.0007</td>
<td>0.0008</td>
</tr>
</tbody>
</table>

**Note:** The table above summarizes the mean and standard error statistics for the data provided.
Some of the outputs produced by GASP IV are not particularly useful. However, they cannot be suppressed without modifying the GASP subroutines. A line-by-line examination of the foregoing example output shows that lines 1 through 65 are an echo check of the input data. Lines 66 through 106 are output by GASP IV. Line 107 reflects the desired number of trees versus the actual number created by the ROWTHIN algorithm. Lines 110 through 117 summarize the results from a simulation run; results are on a skyline block basis. Line 118 shows the hourly productivity in cubic feet. Lines 119 through 132 are GASP IV output. Lines 134 through 141 show detailed descriptive statistics for a simulation run. Lines 142 through 152 are GASP IV output.
PROGRAM PNU COMPUTES TOTAL LOGGING COST, TOTAL REVENUE, AND DETERMINES THE PRESENT NET WORTH FOR EACH USER DEFINED ENTRY. THE USER INPUTS THE FOLLOWING STAND ATTRIBUTES ON A PER ENTRY BASIS FOR THE NUMBER OF ENTRIES OF INTEREST.

USER DEFINED INPUTS:

USER DEFINED INPUTS:

1. AVERAGE STAND DIAMETER IN INCHES, DBH(I).
2. AVERAGE VOLUME REMOVED PER ACRE, IN CUBIC FEET, TVOL(I).
3. THE TIME OF EACH ENTRY, AGE IN YEARS FROM 0, ENTRY(I).
4. THE DISCOUNT RATE CHOSEN, DISC.
5. THE NUMBER OF ENTRIES CONSIDERED FOR EACH ANALYSIS, N.

VARIABLE DEFINITIONS:

ENTRY(I) = AGES OF ENTRIES FROM 0.
DBH(I) = AVERAGE STAND DIAMETER FOR EACH ENTRY; INCHES.
TVOL(I) = VOLUME IN CUBIC FEET PER ACRE FOR EACH ENTRY.
TREV(I) = TOTAL REVENUE FOR EACH ENTRY, DOLLARS.
TLCOST(I) = TOTAL LOGGING COST PER ENTRY, DOLLARS.
TNREV(I) = TOTAL NET REVENUE PER ENTRY, DOLLARS.
CPNU(I) = CUMULATIVE PRESENT NET WORTH FOR EACH ENTRY.
PHWI(I) = PRESENT NET WORTH FOR EACH ENTRY, DOLLARS.
N = NUMBER OF ENTRIES CHOSEN TO EVALUATE, INTEGER.
DISC = DISCOUNT RATE CHOSEN FOR THE ANALYSIS.

DIMENSION ARRAYS, IF MORE THAN FIVE ENTRIES ARE SCHEDULED THE ARRAY DIMENSIONS MUST BE CHANGED ACCORDINGLY.

FUNCTIONS:

READ IN USER DEFINED INPUT CONDITIONS.

APPENDIX IV

Computer Code Listing for PNU

00001 PROGRAM MAIN(INPUT,OUTPUT,TAPE2,TAPES=INPUT,TAPES=OUTPUT):
CONTINUE

CONTINUE

READ(5,100)(ENTRY(I),I=1,N)
READ(5,101)DBH(I),I=1,N
READ(5,103)(TVOL(I),I=1,N)
READ(5,104)DISC,N

WRITE(6,100)(ENTRY(I),I=1,N)
WRITE(6,101)DBH(I),I=1,N
WRITE(6,102)(TVOL(I),I=1,N)
WRITE(6,103)DISC,N

FUNCTION TREV(I) COMPUTES THE POND VALUE PER ENTRY BASED ON THE AVERAGE STAND DIAMETER AND THE VOLUME CUT PER ENTRY.

DO 10 I=1,N

TREV(I)=TREV(I)*-.20.1066+(78.3930*DBH(I))**(2) *(.574-(.0191*DBH(I))))**10

TLCOST(I)=TREV(I)-TLCOST(I)

PMU(I)=TREV(I)/(*I+DISC)**ENTRY(I)

CPMU(I)=CPMU(I)+PMU(I)+CPMU(I)

CONTINUE

WRITE(6,700)

WRITE(6,701)

WRITE(6,702)

WRITE(6,703)

WRITE(6,704)

WRITE(6,705)

WRITE(6,706)

WRITE(6,707)

READ(5,104)(ENTRY(I),I=1,N)
READ(5,105)DBH(I),TVOL(I),TLCOST(I),TREV(I),PMU(I)

CONTINUE

STOP

END

READ(5,100)(ENTRY(I),I=1,N)
READ(5,101)DBH(I),I=1,N
READ(5,102)(TVOL(I),I=1,N)
READ(5,103)DISC,N

WRITE(6,100)(ENTRY(I),I=1,N)
WRITE(6,101)DBH(I),I=1,N
WRITE(6,102)(TVOL(I),I=1,N)
WRITE(6,103)DISC,N

FUNCTION TREV(I) COMPUTES THE POND VALUE PER ENTRY BASED ON THE AVERAGE STAND DIAMETER AND THE VOLUME CUT PER ENTRY.

DO 10 I=1,N

TREV(I)=TREV(I)*-.20.1066+(78.3930*DBH(I))**(2) *(.574-(.0191*DBH(I))))**10

TLCOST(I)=TREV(I)-TLCOST(I)

PMU(I)=TREV(I)/(*I+DISC)**ENTRY(I)

CPMU(I)=CPMU(I)+PMU(I)+CPMU(I)

CONTINUE

WRITE(6,700)

WRITE(6,701)

WRITE(6,702)

WRITE(6,703)

WRITE(6,704)

WRITE(6,705)

WRITE(6,706)

WRITE(6,707)

READ(5,104)(ENTRY(I),I=1,N)
READ(5,105)DBH(I),TVOL(I),TLCOST(I),TREV(I),PMU(I)

CONTINUE

STOP

END
### APPENDIX V

**Example Input Data for PNW**

<table>
<thead>
<tr>
<th></th>
<th>00001</th>
<th>00002</th>
<th>00003</th>
<th>00004</th>
</tr>
</thead>
<tbody>
<tr>
<td>00001</td>
<td>30.00</td>
<td>45.00</td>
<td>60.00</td>
<td>95.00</td>
</tr>
<tr>
<td>00002</td>
<td>9.18</td>
<td>16.71</td>
<td>23.98</td>
<td>28.06</td>
</tr>
<tr>
<td>00003</td>
<td>1663.00</td>
<td>2964.00</td>
<td>10253.00</td>
<td>6733.00</td>
</tr>
<tr>
<td>00004</td>
<td>.033</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example Input Data for PNW (continued)

The input data is defined as follows:

**Card 1**

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-10</td>
<td>F10.2</td>
<td>Age of first entry, years</td>
</tr>
<tr>
<td>11-20</td>
<td>F10.2</td>
<td>Age of second entry, years</td>
</tr>
<tr>
<td>21-30</td>
<td>F10.2</td>
<td>Age of third entry, years</td>
</tr>
<tr>
<td>31-40</td>
<td>F10.2</td>
<td>Age of fourth entry, years</td>
</tr>
<tr>
<td>41-50</td>
<td>F10.2</td>
<td>Age of fifth entry, years</td>
</tr>
</tbody>
</table>

**Card 2**

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-10</td>
<td>F10.2</td>
<td>Average diameter for first entry, inches</td>
</tr>
<tr>
<td>11-20</td>
<td>F10.2</td>
<td>Average diameter for second entry, inches</td>
</tr>
<tr>
<td>21-30</td>
<td>F10.2</td>
<td>Average diameter for third entry, inches</td>
</tr>
<tr>
<td>31-40</td>
<td>F10.2</td>
<td>Average diameter for fourth entry, inches</td>
</tr>
<tr>
<td>41-50</td>
<td>F10.2</td>
<td>Average diameter for fifth entry, inches</td>
</tr>
</tbody>
</table>

**Card 3**

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-10</td>
<td>F10.2</td>
<td>Volume/acre for first entry, ft³</td>
</tr>
<tr>
<td>11-20</td>
<td>F10.2</td>
<td>Volume/acre for second entry, ft³</td>
</tr>
<tr>
<td>21-30</td>
<td>F10.2</td>
<td>Volume/acre for third entry, ft³</td>
</tr>
<tr>
<td>31-40</td>
<td>F10.2</td>
<td>Volume/acre for fourth entry, ft³</td>
</tr>
<tr>
<td>41-50</td>
<td>F10.2</td>
<td>Volume/acre for fifth entry, ft³</td>
</tr>
</tbody>
</table>

**Card 4**

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-6</td>
<td>F4.2</td>
<td>Discount rate, decimal</td>
</tr>
<tr>
<td>7</td>
<td>11</td>
<td>Number of entries into stand</td>
</tr>
</tbody>
</table>
**APPENDIX VI**

*Example Output from PHM*

<table>
<thead>
<tr>
<th></th>
<th>30.00</th>
<th>45.00</th>
<th>60.00</th>
<th>95.00</th>
<th>1.80</th>
</tr>
</thead>
<tbody>
<tr>
<td>00002</td>
<td>9.18</td>
<td>16.71</td>
<td>23.98</td>
<td>26.00</td>
<td>12.00</td>
</tr>
<tr>
<td>00003</td>
<td>1663.00</td>
<td>2964.00</td>
<td>10253.00</td>
<td>1173.62</td>
<td>3823.09</td>
</tr>
<tr>
<td>00004</td>
<td>30.00</td>
<td>9.18</td>
<td>1463.04</td>
<td>1014.37</td>
<td>1143.34</td>
</tr>
<tr>
<td>00005</td>
<td>45.00</td>
<td>16.71</td>
<td>2964.00</td>
<td>1173.62</td>
<td>3823.09</td>
</tr>
<tr>
<td>00006</td>
<td>60.00</td>
<td>23.98</td>
<td>10253.00</td>
<td>1929.43</td>
<td>19068.10</td>
</tr>
</tbody>
</table>
Example Output from PNW (continued)

The output from PNW is detailed line by line as follows:

Lines 1 through 4 echo the input data. Lines 5 through 6 are blank. Lines 7 through 14 summarize the results of a specific analysis. Units are on a per/acre basis.
APPENDIX VII

Derivation of Cumulative Growth Formulas
from Annual Growth Formulas

\[ DBH(0) \text{ is given} \]

\[ DBH(1) = A + B \cdot DIST + C \cdot DBH(0) \]

\[ DBH(2) = A + 2 \cdot B \cdot DIST + C \cdot [A + B \cdot DIST + C \cdot DBH(0)] \]

\[ = A + C \cdot (1 + A + B \cdot DIST + C \cdot DBH(0)) \]

\[ DBH(3) = A + 3 \cdot B \cdot DIST + C \cdot DBH(2) \]

\[ = A + 3 \cdot B \cdot DIST + C \cdot [A + 2 \cdot B \cdot DIST + C \cdot (1 + A + B \cdot DIST + C \cdot DBH(0))] \]

\[ = A + 3 \cdot B \cdot DIST + C \cdot [A + 2 \cdot B \cdot DIST + C \cdot DBH(0) + C \cdot DBH(0)] \]

By induction:

\[ DBH(n) = A + n \cdot B \cdot DIST + C \cdot [A + (n-1) \cdot B \cdot DIST + \cdots + C \cdot DBH(0)] \]

\[ = A + n \cdot B \cdot DIST + C \cdot \left\{ \frac{C^n - 1}{C-1} \right\} DBH(0) \]

For \( \leq 15' \) equation:

\[ A = .290 \ldots \cdot 10^{-2} \]

\[ B = -.01755 \ldots \]

\[ C = 1.0201006 \]

For \( > 15' \) equation:

\[ A = -2.03 \ldots \cdot 10^{-2} \]

\[ B = 0 \]

\[ C = 1.015 \ldots \]

The above cumulative growth formulas were used throughout this analysis and were derived with generous assistance from David A. Butler, Dept. of Statistics, Oregon State University.
Derivation of Annual Growth Formulas

The strip-thinned stand is interesting because it demonstrates both release and lack of release in a relatively small area. The trees close to the edge of a strip respond with improved diameter growth, while trees at 3-4.6m (10-15 ft) from a cut edge respond with little, if any, diameter growth (McCreary and Perry, 1983). In order to develop prediction functions that would model these conditions, approximately 140 strip-thinned trees were carefully remeasured (LeDoux, 1982). For each tree, we recorded its diameter (DBH) at time of treatment, its annual diameter response over a period of nine years, and its distance from the closest cut edge. The true form of the growth function is likely something like the graph in Figure 7, where annual diameter growth drops off sharply out to about 3-4.6m (10-15 ft) from a cut edge and then stabilizes, resulting in little (if any) growth.

Of all the combinations of attempts to produce statistically sound equations, we found the most successful combination to be a scenario involving two linear regression equations. Equation number one would grow trees within distance from the edge-limits of A and B, while equation two would grow trees beyond distance to cut edge B and within the limit of C.

Accordingly, the field measurements were sorted by computer for trees in two groups: those within 4.6m (15 ft) from a cut edge, and those beyond 4.6m (15 ft) from the edge. You now have two groups of approximately 70 trees each. Each of these two
Figure 7. Graph of Theoretical Growth Response to Distance to Cut Edge.
groups was then randomly dichotomized into two additional samples. We now have two groups of approximately 35 trees that have distances of less than 4.6m (15 ft) to an edge and also two groups that have distances beyond 4.6m (15 ft). One of each group was used to develop the annual growth equations shown on page 25. The second group of each was used to test the equations' ability to predict against observed field measurements. All statistical tests were sound. The specific step-by-step procedure and results are available (LeDoux, 1982).

Figure 8, involving the use of annual and cumulative growth equations, was developed to compare the annual diameter response of a 30-year-old 29-cm (11.47-inch) DBH Douglas-fir tree when growing .9m (3 ft) from the edge versus 4.8m (16 ft) from the edge. The projections suggest that the trees respond similarly for 10 to 20 years, at which time the growth of a tree 4.8m (16 ft) in from an edge really falls behind. Figure 9 was developed to compare how different-diameter trees would respond .9m (3 ft) in from an edge. Clearly, the larger the tree, the more response observed. Admittedly, the results thus far are strictly correlative and not cause-and-effect. It is the intent here to develop statistically rigorous prediction equations, based on field data, for the purpose of an integrated systems analysis. It is not the intent to suggest a biological oversimplification of strip-thinned trees' diameter growth response to distance to cut edge and DBH at time of thinning. The method does give us sound analytical tools with which to make diameter-growth predictions for strip-thinned trees within some
reasonable limits. For limits of the equations, see page 25.
The procedure used here will result in two equations that do not
necessarily intersect at point B. This lack of intersection could
result in artifacts of diameter growth response. Potential users
are cautioned to use the equations within the limits specified.
Conditions

Tree DBH of 11.47 inches at age 30

Figure 8. Comparison of annual growth response of a 30-year-old tree close to an edge and deep within a leave strip.
Conditions

Tree DBH of 11.47, 8.8, and 6.6 inches at Age 30. Tree is 3 feet from a cut edge.

Figure 9. Comparison of Annual Growth Response of 3 Different Diameter 30-Year-Old Trees Close to a Cut Edge.
Logging costs were segmented into felling, bucking, limbing, yarding, and haul and loading components. A general equation was derived for each component by simulating the respective activity for a weighted average of logs recovered from thinning. The costs/unit were regressed against average log diameter. Detailed data used are given below (DBH should be in inches in these equations).

**Felling, Bucking, Limbing**

Felling, bucking, and limbing time was estimated using equations developed by Adams (1967) and average-weighted logs to produce the following data:

<table>
<thead>
<tr>
<th>Dollars/Ft$^3$</th>
<th>Average Log DBH</th>
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<tbody>
<tr>
<td>.075</td>
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<td>.052</td>
<td>14</td>
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<tr>
<td>.045</td>
<td>16</td>
</tr>
</tbody>
</table>

When regressed, the following equation emerged:

\[
\text{Felling, Limbing & Bucking Cost/Ft}^3 \text{ by DBH} = .102 - .00360 \text{ (Avg DBH)}
\]

\[
R^2 = 96.0\%
\]

DBH Limits = 20cm-40cm (8 in.-16 in.)
Yarding Cost

Yarding cost equations were developed similarly to felling, bucking, and limbing costs. Cycle times were estimated for conventional thinning, using an equation developed by Aulerich (1975). The THIN model (LeDoux and Butler, 1981) was used to develop the following estimates:

<table>
<thead>
<tr>
<th>Dollars/Ft^3</th>
<th>Average Log DBH</th>
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<tbody>
<tr>
<td>.59</td>
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<tr>
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<td>.11</td>
<td>26</td>
</tr>
<tr>
<td>.09</td>
<td>28</td>
</tr>
</tbody>
</table>

When regressed, the following equation emerged:

\[
\text{Yarding Cost/Ft}^3 \text{ by DBH for Schield Bantam Conventional Thinning} = .574 -.019 \text{(Avg DBH)}
\]

\[
R^2 = 77.6\%
\]

DBH Limits = 23cm-61cm (9 in.-24 in.)

A yarding cost equation was also developed to estimate yarding cost for strip thinning using an equation developed by Aulerich (1975).
The ROWTHIN model was used to develop the following estimates:

When regressed, the following equation emerged:

\[
\text{Yarding Cost/Ft}^3 = .572 - .024 \text{ (Avg DBH)} \\
R^2 = 99.3\% \\
\text{Limits} = 25\text{cm-}45\text{cm (10 in.-18 in.)}
\]

The equations for yarding cost include set-up costs.

**Loading and Hauling Costs**

Loading and hauling costs were developed similarly to those previously (above), using data from Dykstra and Garland (1977) and Schneider (1978). The following estimates were derived:

When regressed, the following equation emerged:

\[
\text{Loading and Hauling Cost/Ft}^3 = .196 - .00588 \text{ (Avg DBH)}
\]
$R^2 = 94.1\%$

DBH: 20 cm - 61 cm (8 in. - 24 in.)

Limits

The foregoing equations were used throughout this analysis.
APPENDIX IX

Pond Values

Pond value is defined as the value a mill would pay for logs received at the mill gate. Pond value was derived by taking a weighted average of logs recovered from thinning or regeneration harvesting of a stand of known diameter distribution. Log values were assigned diameter premiums using values from the Oregon Department of Revenue, Timber Tax Division, of January 1980 for Northwest Oregon. 1/

Logs from second-growth Douglas-fir are assumed to fall into one of five classes: 2/

- No. 4 Mill Sawlogs - Less than 6 inches in diameter (15 cm)
- No. 3 Mill Sawlogs - Less than 12 inches in diameter (30 cm)
- No. 2 Mill Sawlogs - Less than 16 inches in diameter (40 cm)
- Special Mill Grade - Less than 24 inches in diameter (60 cm)
- No. 3 Peeler Logs - Over 24 inches in diameter (60 cm).

Average log values for second-growth Douglas-fir as of January 1980 for Northwest Oregon, as listed in Table 1:

TABLE 1. LOG VALUES FOR SECOND-GROWTH DOUGLAS-FIR IN NORTHWEST OREGON, 1980.

<table>
<thead>
<tr>
<th>Log Class</th>
<th>Log Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 4 Mill Sawlogs</td>
<td>215 F/Mbf</td>
</tr>
</tbody>
</table>

1/ Specifically, the counties from the Columbia River to the southern end of Lane County and from the Cascade Divide to the coast.

2/ Log classes are from Official Log Scaling and Grading Rules for Columbia River Scaling Bureau; January 1, 1982.
To derive the average unit revenue per thousand cubic feet of volume removed as a function of mean stand diameter, the following procedure was used to weight the various trees which would be removed in thinning or final harvests (Sessions, 1979).

A. For a given diameter (DBH) distribution, the stand was divided into five intervals having equal probability.

B. The diameter of a tree corresponding to the midpoint of each interval was selected to model the interval.

C. Each of the five trees was scaled by the Girard and Bruce formula: \( V = 1.53D^2 - 4D - 8 \), which approximates the Columbia River Scaling Rule (Dilworth, 1970).

D. Each log was multiplied by its corresponding value.

E. The cubic volume of each tree was calculated by assigning each tree a linear taper based on its diameter and the mean height of the stand.

F. The sum of the log values were then divided by the sum of the cubic volumes to give an estimate of the pond value of the stand per unit volume of the stand cut.

Values were computed for Site 112 (Kings) Douglas-fir, ages 40 to 160, based on mean diameters from Bulletin 201 (McArdle, 1961).

<table>
<thead>
<tr>
<th>Type of Log</th>
<th>Price per Mbf</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 3 Mill Sawlogs</td>
<td>230 $/Mbf</td>
</tr>
<tr>
<td>No. 2 Mill Sawlogs</td>
<td>265 $/Mbf</td>
</tr>
<tr>
<td>Special Mill Grade</td>
<td>300 $/Mbf</td>
</tr>
<tr>
<td>No. 3 Peeler Logs</td>
<td>330 $/Mbf</td>
</tr>
</tbody>
</table>
A linear regression model was fitted to the data with an $R^2$ of 97% providing the following relationship between stand value and mean stand diameter:

Stand Value ($/Mcf) = -20.106 + 78.393 \times \text{Mean Stand Diameter (in)}

DBH Limits = 15cm-64cm (6 in.-22 in.).
### Logging Equipment

The logging equipment used for this study is, unless otherwise stated:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Equipment Description</th>
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</thead>
<tbody>
<tr>
<td>Skyline yarding</td>
<td>Schielf Bantam yarder</td>
</tr>
<tr>
<td>Falling, bucking, limbing</td>
<td>Stihl 048 w/32&quot; bar saw</td>
</tr>
<tr>
<td>Decking and Loading</td>
<td>Bantam C266L hydraulic loader</td>
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<tr>
<td>Hauling</td>
<td>Peerless long-log truck</td>
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</table>
**APPENDIX XI**

**Bucking Rules**

<table>
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<th>Log lengths desired (in feet)</th>
<th>40&quot;</th>
<th>36</th>
<th>32</th>
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</tbody>
</table>

1 Log lengths desired in feet
2 Merchantable stem length in four foot sections, for example, a value of 12 represents a 48 foot merchantable stem.

The desired bucking strategy, for example, a merchantable stem of 48 feet would be cut into one 48 foot log.
APPENDIX XII

Stand Conditions

The standard conditions for this study are, unless otherwise stated:

- **Harvest unit geometry**: Rectangular
- **Cutting unit length**: 598 feet (182.0 meters) horizontal distance
- **Cutting unit width**: 120 feet (36.5 meters) horizontal distance
- **Cutting unit slope**: 20 percent
- **Yarding direction**: Uphill
- **Yarding system**: Skyline rigged in shotgun configuration
- **Discount rate**: 3 percent
- **Trees per acre**: 296 stems
- **Site index**: 112 (Kings)
- **Stand origin**: Natural
- **Average stand DBH**: 11.2 inches (27 cm)
- **Maximum stand DBH**: 20.6 inches (52 cm)
- **Minimum stand DBH**: 4.9 inches (12 cm)
- **Standard error of mean (DBH)**: 3.5 inches (9 cm)
- **Taper rates (inches/lineal foot)**: .14
- **Stand age**: 30 years
Stand Conditions (continued)

Initial Conditions for DFSIM and ROWTHIN:

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Stand</th>
<th>Avg. Trees</th>
<th>d/D</th>
<th>Ratio</th>
<th>Random Seed</th>
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