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

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed June 30, 1983

Commencement June 1984

AN ABSTRACT OF THE THESIS OF

Chris B. LeDoux for the degree of Doctor of Philosophy in Forest Engineering presented on June 30, 1983.

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

Abstract approved: Eldon D. Olsen

Eldon D. Olsen

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 (Pseudotugo 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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Typed by Frances Gallivan for ______ Chris B. LeDoux ______

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

A SIMULATION OF THE COMPARATIVE COSTS AND BENEFITS OF SKYLINE STRIP THINNING

INTRODUCTION

The effects of thinning on the yield of natural Douglas-fir (Pseudotsugo menziesii Franco) stands have recently been investigated 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 conventional 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.

REVIEW OF LITERATURE

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 (Alm, 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* Dougl.) 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* Dougl.) 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* Dougl.) 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.

Cable Systems - Commercial 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 (Pseudotsugo menziesii Franco) stand (Site III) with trees averaging 25.4 centimeters (10 inches) d.b.h. and stand volumes 61.23 m^3 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) report. 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 (Pseudotsugo 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 (36-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 an 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, lcaving 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:

(i) The development of a strip-thinning computer simulation model for mountainous (coastal) Douglas-fir (Pseudotsugo menziesii Franco) stands.

(ii) The development of a growth model that simulates stand release and spacing interactions for strip-thinned coastal Douglas-fir.

(iii) The validation of both models using existing data from coastal, strip-thinned plots.

(iv) The use of the above models to evaluate the costs and benefits associated with strip-thinning young Douglas-fir stands with cable-logging systems.

(v) The comparison of the costs and benefits of strip thinning with those derived from conventional thinning methods for the life of a stand.

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:

$$\text{Volume/log in ft}^3 = .00545\ D^2 L$$

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:

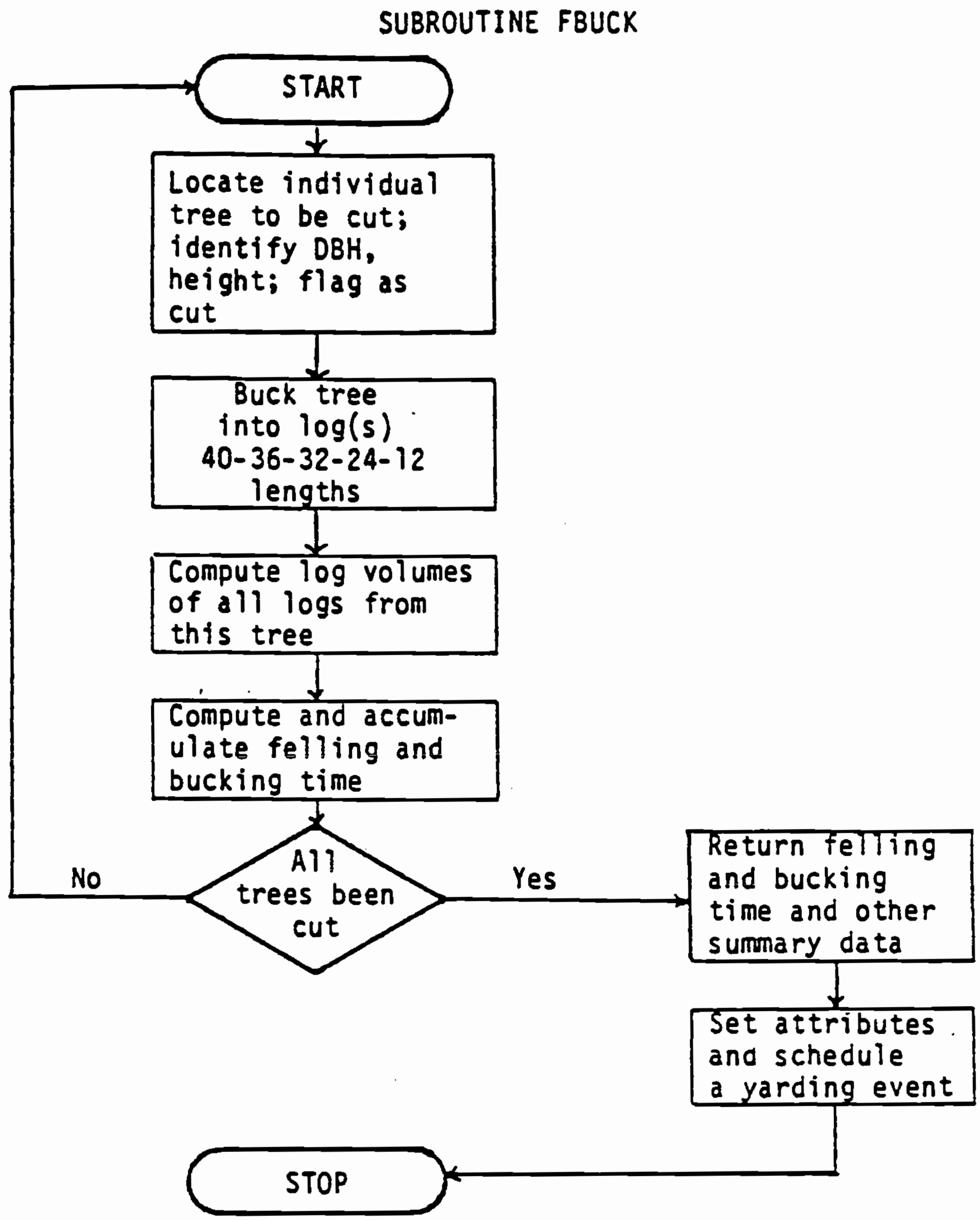

Figure 1. Flowchart of ROWTHIN's Felling and Bucking Routine.

Felling time/tree (minutes) = $.559 + .00419(DBH)^2$

Bucking and Limbing time/tree (minutes) =

$$.781 + .00681(DBH) + 1.123(NCUTS)$$

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)

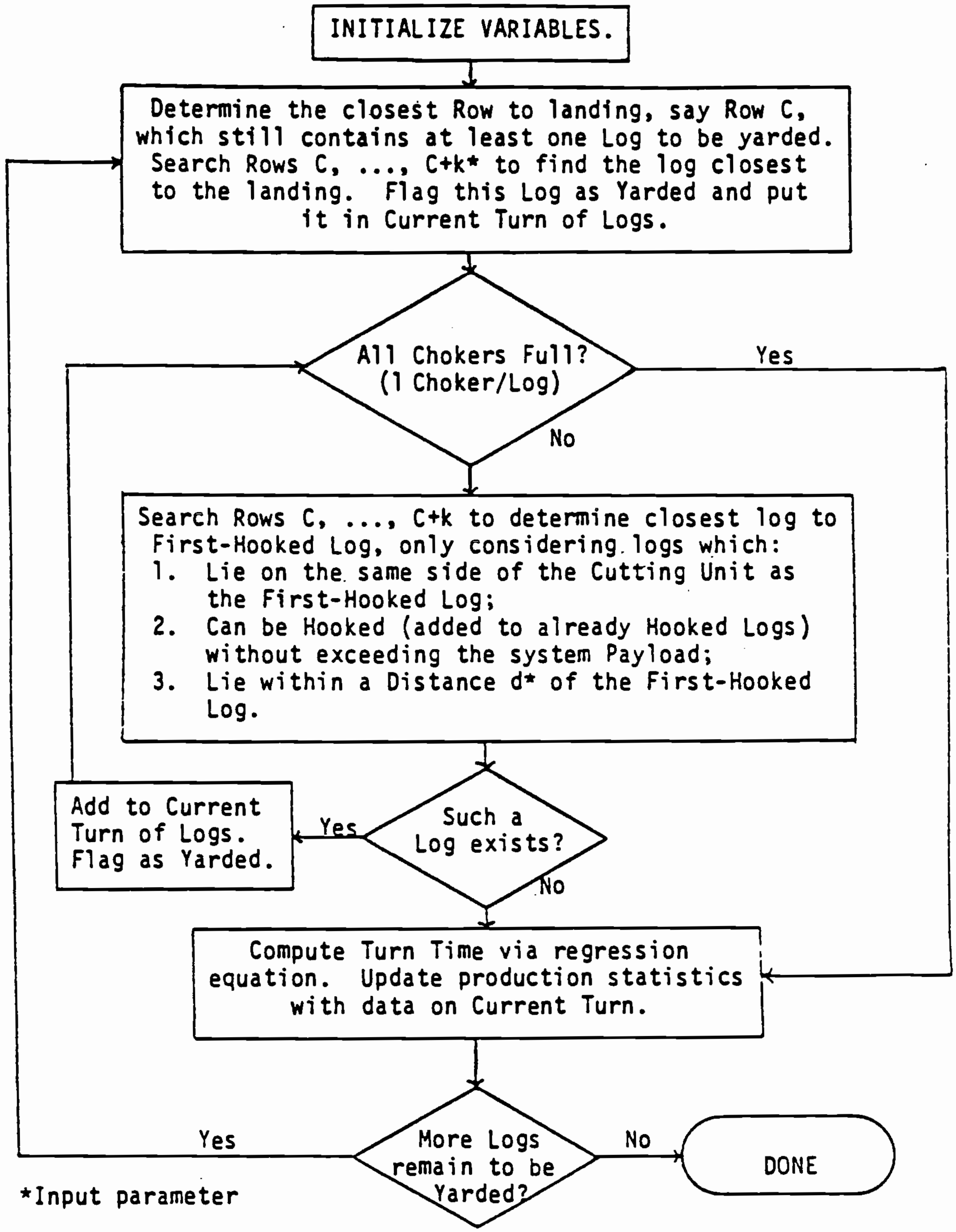

Figure 2. Flowchart of ROWTHIN's Yarding Routine.

$$\text{Total Turn Time Minutes (Delay Free)} = 3.814 + .00528(SYD) + .806(XLT) - .752(CREW) + .027(XLD) + .00149(XLA)$$

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

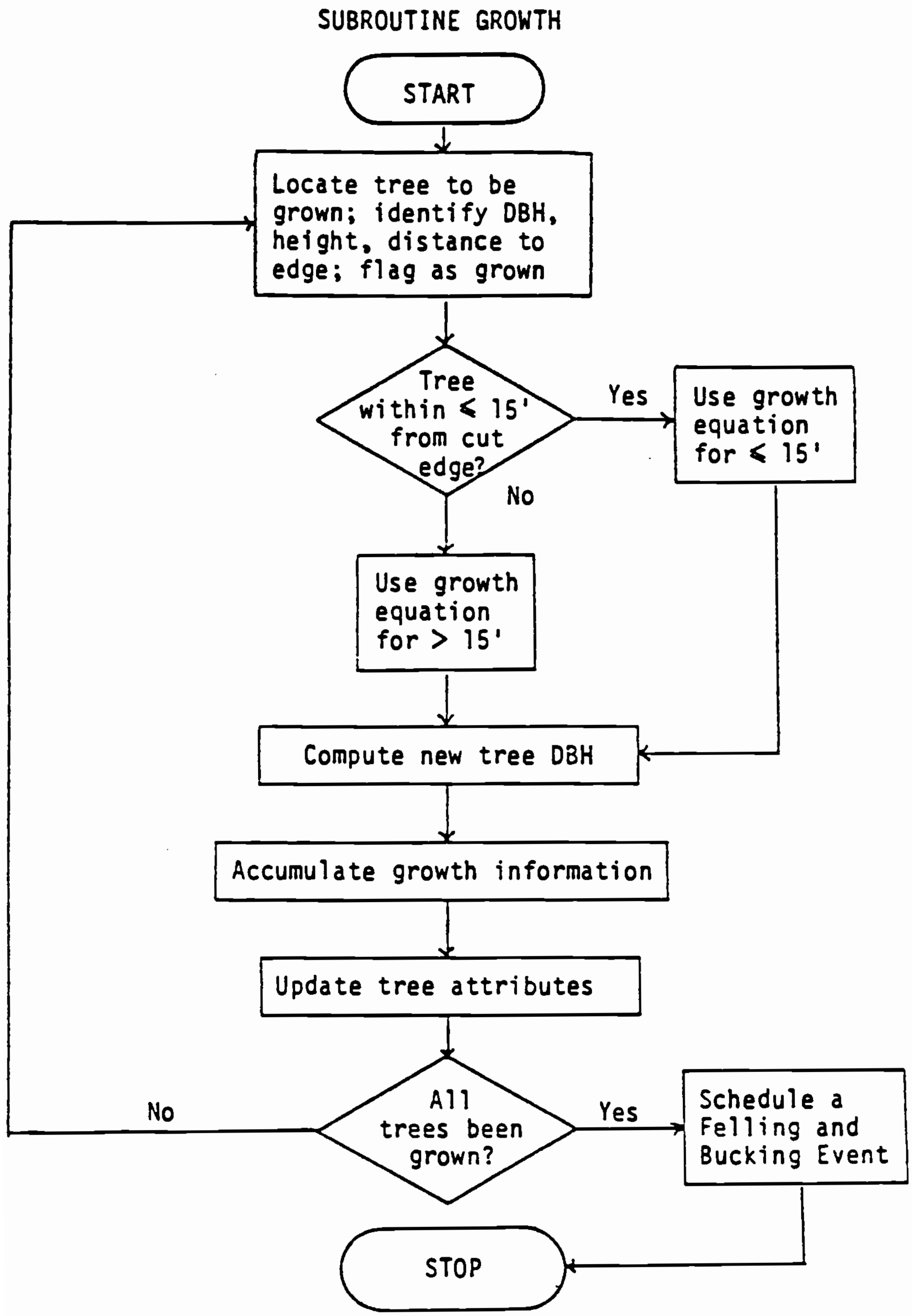

Figure 3. Flowchart of ROWTHIN's Growth Routine.

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:

$$\text{Annual Diameter Growth (DBH) per tree in inches} = .292\text{ E-02} - .175\text{ E-01 DIST*} + .201\text{ E-01 DBH*}$$

where,
- $n = 56$
- $R^2 = 57.6$
- $se = .460\text{ E-02}$
- DIST Limits = .32-11.0 feet
- DBH Limits = 5.0-23.0 inches

and where
- DIST = Distance to a cut edge, in feet
- DBH = 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:

$$\text{Annual Diameter Growth (DBH) per tree in inches} = -.203\text{ E-01} + .150\text{ E-01 DBH*}$$

where,
- $n = 18$
- $R^2 = 46.2$
- $se = .331\text{ E-02}$
- DBH Limits = 5.0-23.0 inches

and where
- DBH = 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.

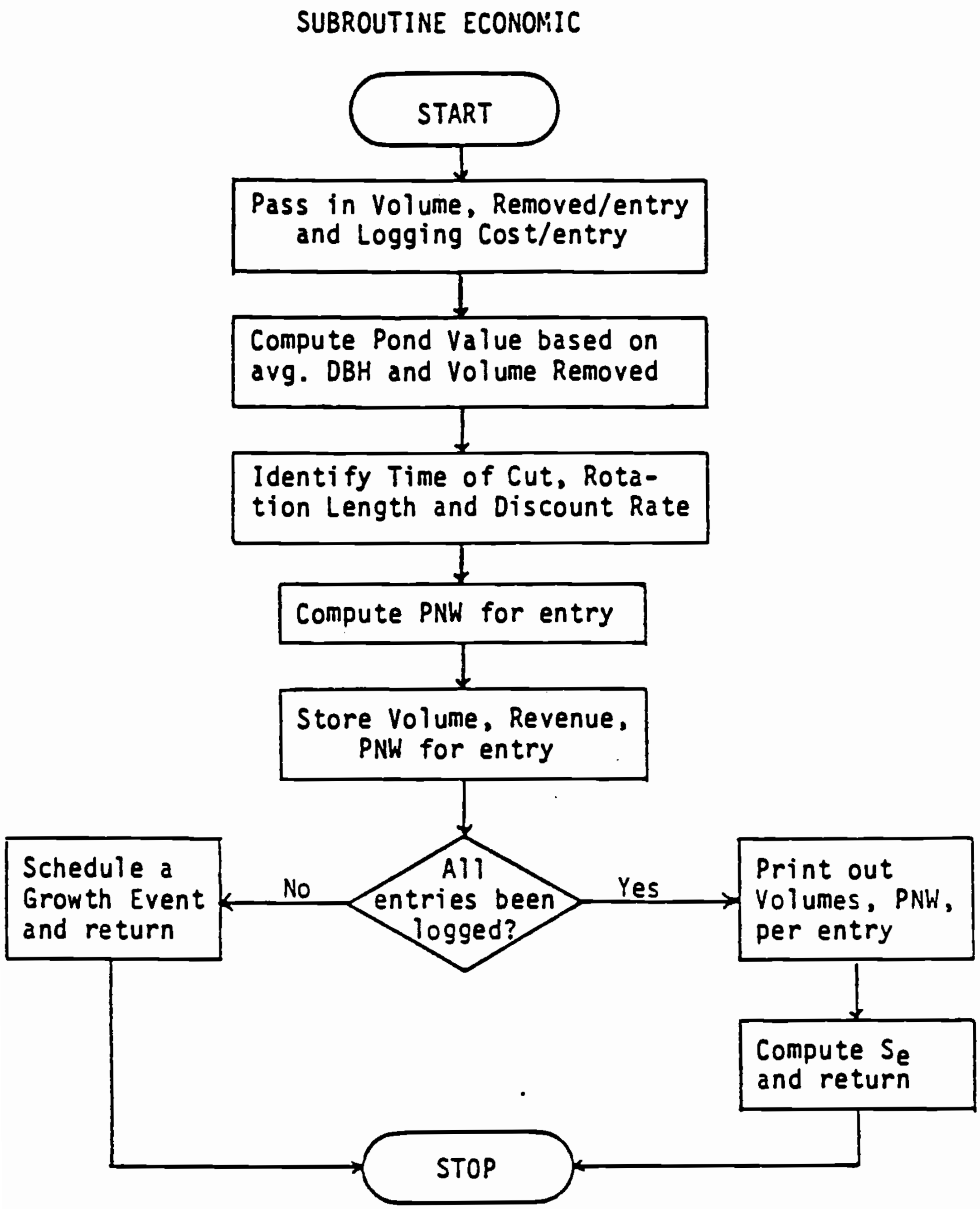

Figure 4. Flowchart of ROWTHIN's Economic Routine.

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.

Validation Test No. 1

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 m^3/hectare (9,594 ft^3/acre) — a mean of two runs. DFSIM, for the identical conditions and rotation length predicts a total per acre yield of 646 m^3/hectare (9,244 ft^3/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 m^3/hectare (14,946 ft^3/acre) (mean of two runs)) compared to DFSIM's 878 m^3/hectare (12,568 ft^3/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.

Validation Test No.	ROWTHIN	DFSIM	Error (Percent)
1a. 45-Year Rotation (No-Thinning Option)			
1. Total volume, m^3/hectare (ft^3/acre)	674 (9,649)	646 (9,244)	+4.38
2. Total volume, m^3/hectare (ft^3/acre)	667 (9,539)	646 (9,244)	+3.20
1b. 60-Year Rotation (No-thinning Option)			
1. Total volume, m^3/hectare (ft^3/acre)	1070 (15,314)	878 (12,568)	+21.85
2. Total volume, m^3/hectare (ft^3/acre)	1019 (14,578)	878 (12,568)	+16.01
2. 45-Year Rotation (Thinning Option)			
1. Total volume, m^3/hectare (ft^3/acre)	716 (10,240)	714 (10,223)	+0.17
2. Total volume, m^3/hectare (ft^3/acre)	724 (10,360)	714 (10,223)	+1.34
3. 60-Year Rotation (Thinning Option)			
1. Total volume, m^3/hectare (ft^3/acre)	1096 (15,687)	1029 (14,715)	+6.61
2. Total volume, m^3/hectare (ft^3/acre)	1141 (16,318)	1029 (14,715)	+10.89

would be beyond the scope of this research effort to develop a "senility" factor for ROWTHIN. It is for this reason, and based on Validation Tests 2 and 3, that the cost and benefit analysis is confined 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 m^3/hectare (4,178 ft^3/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 centimeteres (13.8 inches) and with a volume yield of 428 m^3/hectare (6,122 ft^3/acre). The total volume removed from a 45-year rotation is predicted by ROWTHIN to be 720 m^3/hectare (10,300 ft^3/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 m^3/hectare (10,223 ft^3/acre). Correcting the ROWTHIN results for mortality of 2.3 m^3/hectare (33 ft^3/acre) results in a total volume of 717 m^3/hectare (10,267 ft^3/acre), a .43% higher estimate compared to DFSIM.

Validation Test 2 and 3

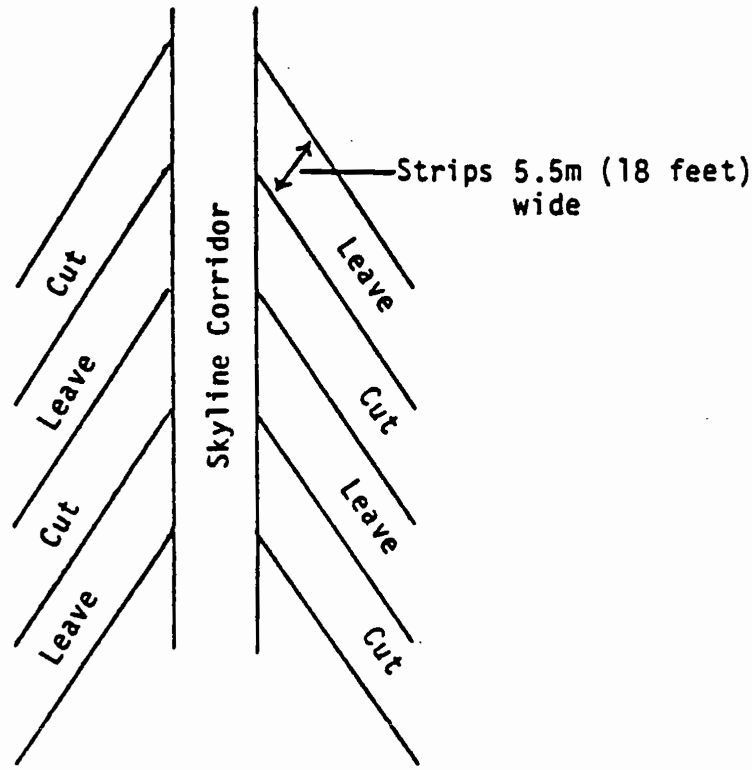

Figure 5. ROWTHIN Validation Removal Strategy.

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.

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 m^3 (16,907 ft^3) (a mean of two runs). The total volume for similar conditions is predicted by DFSIM to be 1,029 m^3/hectare (14,715 ft^3/acre). Correcting the ROWTHIN prediction for mortality of 63 m^3 (905 ft^3) results in a total volume of 1,119 m^3/hectare (16,002 ft^3/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 a 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.

Validation Test No.	Field Test	ROWTHIN	Error (Percent)
1. Logs per turn	2.4	2.5	+4.17
Volume per turn, m^3 (ft^3)	.83 (29.52)	.85 (30.30)	+2.64
Production rate, m^3/hr (ft^3/hr)	8.5 (300.71)	8.7 (308.18)	+2.48
2. Logs per turn	2.4	2.4	0
Volume per turn, m^3 (ft^3)	.83 (29.52)	.81 (28.95)	-1.93
Production rate, m^3/hr (ft^3/hr)	8.5 (300.71)	8.4 (299.46)	-0.42
3. Logs per turn	2.4	2.4	0
Volume per turn, m^3 (ft^3)	.83 (29.52)	.82 (28.99)	-1.80
Production rate, m^3/hr (ft^3/hr)	8.5 (300.71)	8.4 (299.86)	-0.28

ROWTHIN MODEL APPLICATIONS

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-m (18-ft) 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-m (18-ft) 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).

Simulation No.	Entry Age	Average DBH cm. (in.)	Volume Cut m^3/hectare (ft^3/acre)
1. Commercial Thinning (Remove 5.5m (18') strips, leave 5.5m (18') strips	30	29 (11.47)	292 (4,178)
Final Harvest	45	35 (13.80)	428 (6,122)
Total Volume Removed			720(10,300)
2. Commercial Thinning (Remove 5.5m (18') strips, leave 5.5m (18') strips	30	29 (11.47)	292 (4,177)
Final Harvest	60	44 (17.30)	890(12,730)
Total Volume Removed			1182(16,907)
3. Commercial Thinning (Remove 5.5m (18') strips, leave 11m (36') strip; remove 5.5m (18') strip from center at age 45; remove 2.7m (9') strip at age 60)	30	29 (11.57)	215 (3,082)
Commercial Thinning	45	32 (12.52)	222 (3,177)
Final Harvest	60	45 (17.91)	645 (9,236)
Total Volume Removed			1083(15,495)

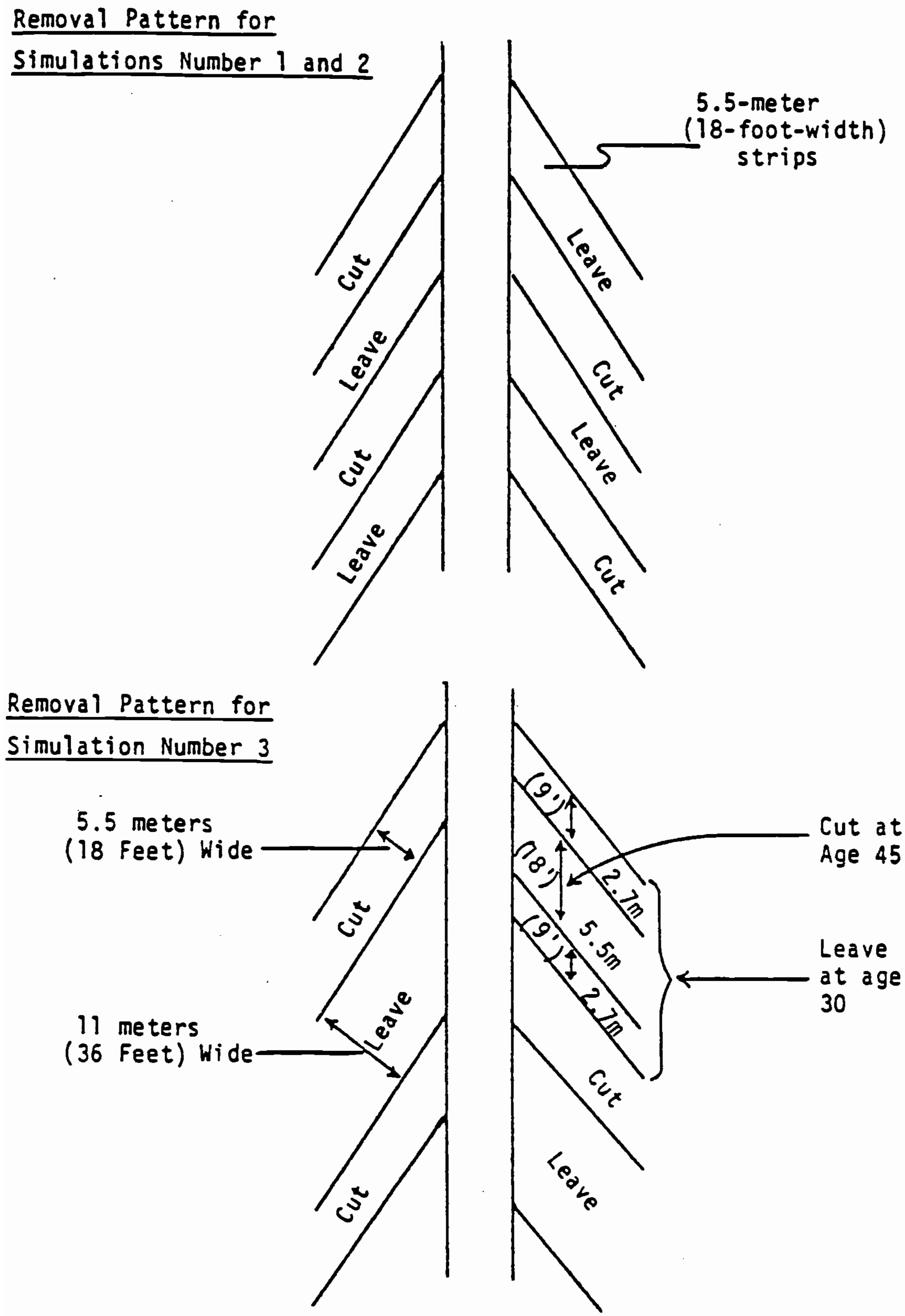

Figure 6. ROWTHIN Application Strategies.

Table 4. Summary of growth and yield for three DFSIM simulations (DBH is of material cut).

Simulation No.	Entry Age	Average DBH cm. (in.)	Volume Cut m^3/hectare (ft^3/acre)
1. Commercial Thinning (d/D ratio = .71, 365 trees/hectare (148 stems/acre) removed)	30	23 (9.18)	116 (1,663)
Final Harvest	45	46 (18.23)	598 (8,560)
Total Volume Removed			714(10,223)
2. Commercial Thinning (d/D ratio = .71, 365 trees/hectare (148 stems/acre) removed)	30	23 (9.18)	116 (1,663)
Final Harvest	60	56 (22.02)	912(13,052)
Total Volume Removed			1028(14,715)
3. Commercial Thinning (d/D ratio = .71, 365 trees/hectare (148 stems/acre) removed at age 30; 148 trees/hectare (60 stems/acre) removed ate age 60)	30	23 (9.18)	116 (1,663)
Commercial Thinning (d/D ratio = .87)	45	42 (16.71)	207 (2,964)
Final Harvest	60	61 (23.98)	716(10,253)
Total Volume Removed			1040(14,880)

Table 5. Cumulative present net worth comparison for ROWTHIN and DFSIM simulations.

Simulation No.	Total Logging Cost \$/Ha (\$/acre)	Total Pond Value \$/Ha (\$/acre)	Cumulative Present Net Worth per Ha (per acre)
ROWTHIN			
1. Commercial thinning at age 30, final cut at age 45	10,568 (4,277)	25,172 (10,187)	4,545 (1,840)
2. Commercial thinning at age 30, final cut at age 60	13,163 (5,327)	50,119 (20,283)	7,057 (2,856)
3. Commercial thinning at age 30 and age 45, final cut at age 60	12,681 (5,132)	45,881 (18,568)	6,501 (2,631)
DFSIM			
1. Commercial thinning at age 30, final cut at age 45	9,968 (4,034)	32,676 (13,224)	6,050 (2,452)
2. Commercial thinning at age 30, final cut at age 60	10,385 (4,203)	57,898 (23,431)	8,151 (3,299)
3. Commercial thinning at age 30 and age 45, final cut at age 60	10,178 (4,119)	59,437 (24,054)	9,068 (3,670)

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 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 ROWTHIN 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).

Simulation Number	Entry Age (yrs)	Average DBH cm. (in.)	Volume Cut m /Ha (ft /ac)	Cumulative Present Net Worth $/Hectare ($/acre)
DFSIM				
1a. Commercial thinning, d/D = .71	30	23 (9.18)	116 (1,663)	
Final Cut	45	46 (18.23)	598 (8,560)	6,058 (2,452)
b. Commercial thinning, d/D = 90	30	25 (10.08)	138 (1,972)	
Final Cut	45	44 (17.48)	553 (7,906)	5,416 (2,192)
c. Commercial thinning, d/D = 1.15	30	32 (12.88)	234 (3,349)	
Final Cut	45	37 (14,69)	349 (4,994)	3,862 (1,563)
ROWTHIN				
1. Commercial thinning (remove 5.5m (18') strips, leave 5.5m (18') strips	30	29 (11.47)	292 (4,178)	
Final Cut	45	35 (13.80)	428 (6,122)	4,546 (1,840)

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 = $(1{,}386)(1.03)^{30} = 3{,}364.19$

Table 7. Detailed data for comparison of ROWTHIN and DFSIM simulation number one (DBH is of material cut).

Simulation Number	Entry Age	Avg. DBH cm. (in.)	Volume Removed m^3/Ha (ft^3/acre)	Total Logging Costs \$/Ha(\$/ac)	Total Pond Value \$/Ha(\$/ac)	Present Net Worth \$/Ha(\$/ac)	Cumulative Present Net Worth \$/Ha(\$/ac)
ROWTHIN							
1. Commercial thinning at age 30, final cut at age 45	30	28 (11.73)	10,514 (4,255)	4,820 (1,951)	9,464 (3,830)	1,912 (774)	1,912 (774)
Final Cut	45	35 (13.82)	14,776 (5,980)	5,747 (2,326)	15,708 (6,357)	2,634 (1,066)	4,546 (1,840)
DFSIM							
1. Commercial thinning at age 30, final cut at age 45	30	23 (9.18)	4,109 (1,663)	2,510 (1,016)	2,873 (1,163)	150 (61)	150 (61)
Final Cut	45	46 (18.23)	21,151 (8,560)	7,457 (3,018)	30,635 (12,061)	5,908 (2,391)	6,058 (2,452)

- 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.

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APPENDICES

APPENDIX I

Computer Code Listing for ROWTHIN

```
      PROGRAM MAIN(INPUT,OUTPUT,TAPE7,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION NSET(2000)
      COMMON QSET(2000)
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/  TDAT(2,0:40,40,3),NSTR(2),NTR(2,0:40),LR,
     1UYD,UXD,WUV,XMDL,SP,NCA,YE,SLOPE,CSLOPE,NCREW,
     2BFVLT,BFVLG,XLA,CFTTN,CH,SPC,L,A,B,NTREES,SYD,STRLP,
     3K,WT,THETA,BTIME,PNW(0:5),LSIZE(5),ISTR,
     4LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
     6INDST(2,500),ISTW(2,40),KENTR(2,0:40),NENTR,KKENTR,
     7YTIME,FTIME,NLOGS,LSTEM,TAPER,DIAM,DBH,ANGLE,COSANG,
     8SINANG,XLEN,NLT,RCAP,ISLOG,INHLOG,TVOL(0:5),HLCOST,TCOST(0:5),
     9TREV(0:5),TNREV(0:5),YCOST,BCOST,FCOST,KTIME(0:5),DISCT,
     1NSTEMS,TDBH,AVGDBH,PONDVAL,TTHETA,CTHETA,STHETA,WCOR,XDBH(0:5)
      EQUIVALENCE (NSET(1),QSET(1))
C
C     INITIALIZE CARD READER AND LINE PRINTER
      NCRDR=5
      NPRNT=6
C
C     START THE SIMULATION
C
      CALL GASP
      STOP
      END


C*****SUBROUTINE INTLC READS AND INITIIALIZES VARIABLES
C
      SUBROUTINE INTLC
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/  TDAT(2,0:40,40,3),NSTR(2),NTR(2,0:40),LR,
     1UYD,UXD,WUV,XMDL,SP,NCA,YE,SLOPE,CSLOPE,NCREW,
     2BFVLT,BFVLG,XLA,CFTTN,CH,SPC,L,A,B,NTREES,SYD,STRLP,
     3K,WT,THETA,BTIME,PNW(0:5),LSIZE(5),ISTR,
     4LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
     6INDST(2,500),ISTW(2,40),KENTR(2,0:40),NENTR,KKENTR,
     7YTIME,FTIME,NLOGS,LSTEM,TAPER,DIAM,DBH,ANGLE,COSANG,
     8SINANG,XLEN,NLT,RCAP,ISLOG,INHLOG,TVOL(0:5),HLCOST,TCOST(0:5),
     9TREV(0:5),TNREV(0:5),YCOST,BCOST,FCOST,KTIME(0:5),DISCT,
     1NSTEMS,TDBH,AVGDBH,PONDVAL,TTHETA,CTHETA,STHETA,WCOR,XDBH(0:5)
C
C     VARIABLE DEFINITIONS
C
```

```
C      ANGLE=STEM ANGLE RELATIVE TO STRIP, DEGREES
C      AVGDBH=AVERAGE DBH OF STEMS IN ENTRY
C      BCOST=BUCKING COST PER HOUR
C      BFVLG=BOARD FOOT VOLUME PER LOG
C      BFVLT=BOARD FOOT VOLUME PER TURN
C      BTIME=TOTAL BUCKING/LIMBING TIME FOR TREES IN AN ENTRY(MINUTES)
C      CFTTN=CUBIC FOOT VOLUME PER TURN
C      CFVLG= CUBIC FOOT VOLUME PER LOG
C      CH=CARRIAGE HEIGHT
C      COSANG=COSINE OF STEM ANGLE
C      CSLOPE=CHORDSLOPE OF SKYLINE CORRIDOR
C      DBH=STEM DIAMETER BREAST HEIGHT, INCHES
C      DIAM=BUTT END LOG DIAMETER, INCHES
C      DISCT=YEARLY DISCT FACTOR
C      EDGE1(LR,ISTR)=NEAR EDGE OF THE LEAVE-STRIP BLOCK CONTAINING
C      THE INDICATED STRIP
C      EDGE2(LR,ISTR)=FAR EDGE OF THE LEAVE-STRIP BLOCK CONTAINING
C      THE INDICATED STRIP
C      FCOST=FELLING COST PER HOUR
C      FTIME=TOTAL FELLING TIME FOR TREES IN AN ENTRY(MINUTES)
C      HLCOST=HAULING AND LOADING COST PER CUBIC FOOT
C      ICH=TREE CHARACTERISTIC
C      ILFLG=1 IF PREVIOUS STRIP A LEAVE STRIP; =0 IF PREVIOUS STRIP
C      A CUT STRIP
C      ILTYPE=INDEX FOR THE ITH LOG TYPE
C      INDST(LR,MTHRE)=INDEX OF STRIP CONTAINING THE POINT WHICH
C         IS (3*MTHRE) FEET FROM L1 OR L2.
C      INHLOG=NUMBER OF CLOSEST LOG TO FIRST HOOKED LOG
C      ISLOG=NUMBER OF CLOSEST LOG TO CORRIDOR(ALONG L1 AXIS)
C      ISTR=STRIP NUMBER
C         ISTR=0:  CORRIDOR
C      ISTW(LR,ISTR)=WIDTH OF INDICATED STRIP
C      ITR=TREE NUMBER WITHIN STRIP
C      KENTR(LR,ISTR)=ENTRY AT WHICH INDICATED STRIP IS HARVESTED
C      KKENTR=CURRENT ENTRY NO.
C      KTIME(KKENTR)=TIME OF ENTRY (YEARS FROM SEEDLING)
C      LOGTAB(LSTEM,ILTYPE)=NUMBER OF LOGS OF TYPE ILTYPE FROM A
C            STEM OF THE INDICATED SIZE
C      LR= LEFT - RIGHT INDICATOR; 1= LEFT SIDE,
C           2= RIGHT SIDE OF CORRIDOR
C      LSIZE(ILTYPE)=SIZE IN FEET OF LOG TYPE I
C      LSTEM=STEM LENGTH IN 4 FOOT UNITS
C      LSTR=NO. OF LAST LEAVE STRIP HAVING BOTH EDGES LOCATED
C      NCA=NUMBER OF CHOKERS AVAILABLE FOR YARDING
C      NCREW=NUMBER OF WORKERS ON THE RIGGING
C      NCUTS=NUMBER OF CUTS IN A STEM
C      NENTR=TOTAL NUMBER OF ENTRIES INTO CUTTING UNIT
C      NLOGS=NUMBER OF LOGS IN A STRIP
C      NLT=NUMBER OF LOGS PER TURN
C      NSTEMS=TOTAL NUMBER OF STEMS HARVESTED IN AN ENTRY
C      NSTR(LR)=NO. STRIPS ON LEFT/RIGHT SIDE OF CORRIDOR
```

```
C     NTR(LR,ISTR)=NO. OF TREES WITHIN INDICATED STRIP
C     NTREES=NUMBER OF TREES IN THE CUTTING UNIT
C     PONDVAL=POND VALUE OF LOGS DELIVERED TO THE MILL
C     RCAP=REMAINING SYSTEM CAPACITY, LBS
C     SINANG=SINE OF STEM ANGLE
C     SP=SYSTEM PAYLOAD OF YARDER
C     SPC=SPATIAL DISTRIBUTION COEFFICIENT
C     SLOPE=PERCENT SIDESLOPE OF TERRAIN
C     TAPER=TAPER RATE (INCHES PER LINEAL FOOT)
C     TCOST(KKENTR)=TOTAL COST PER ENTRY
C     TDAT(LR,ISTR,ITR,ICH)=TREE DATA
C        ICH=1:  L-DISTANCE  (X-DISTANCE IF ISTR=0)
C            2:  L'-DISTANCE  (Y-DISTANCE IS ISTR=0)
C            3:  DBH
C     TDBH=TOTAL SUM OF DBH'S OVER STEMS IN EACH ENTRY
C     THETA=STRIP ANGLE
C     TNREV(5)=TOTAL NET REVENUE PER ENTRY
C     TREV(5)=TOTAL REVENUE PER ENTRY
C     TVOL(5)=TOTAL VOLUME HARVESTED IN AN ENTRY
C     UXD=SKYLINE ROAD WIDTH
C     UYD=SKYLINE ROAD LENGTH
C     WCOR=CORRIDOR WIDTH
C     WUV=WEIGHT PER UNIT VOLUME
C     XLA=LEAD ANGLE OF LOG
C     XLEN=LOG LENGTH IN FEET
C     XMDL=MAXIMUM LATERAL DISTANCE PERMITTED
C        (STRAIGHT YARDING OR PRE-BUNCHING)
C     YE= YARDER AND CREW EFFICIENCY
C     YCOST=YARDING COST PER HOUR
C     YTIME=TOTAL YARDING TIME FOR TREES IN AN ENTRY
C     ZLOG(ILOG,ICH)=LOGS ARRAY WHERE: ILOG=LOG NUMBER,
C           ICH=1:  L-DISTANCE  (X-DISANCE IF ISTR=0)
C           ICH=2:  L'-DISTANCE  (Y-DISTANCE IF ISTR=0)
C           ICH=3:  BUTT LOG DIAMETER
C           ICH=4:  LOG LENGTH      (0.0 MEANS LOG ALREADY YARDED)
C           ICH=5:  LEAD ANGLE
C           ICH=6:  LOG VOLLUME IN CUBIC FEET
C
C
C     INITIALIZE VARIABLES
C
      DO 5 LR=1,2
         DO 6 ISTR=0,40
            NTR(LR,ISTR)=0
6        CONTINUE
5     CONTINUE
      DO 7 KKENTR=0,5
         TVOL(KKENTR)=0.0
7     CONTINUE
C
C
```

```
C     INPUT INITIAL CONDITIONS
C
      READ(5,101) BCOST,CH,CSLOPE,DISCT,FCOST
      READ(5,101) HLCOST,SP,SPC,SSLOPE,TAPER
      READ(5,101) THETA,UXD,UYD,WCOR,WUV
      READ(5,101) XMDL,YE,YCOST
      READ(5,102) NENTR,NSTR(1),NSTR(2)
      READ(5,102) ((ISTW(LR,ISTR),ISTR=1,NSTR(LR)),LR=1,2)
      READ(5,102) ((KENTR(LR,ISTR),ISTR=1,NSTR(LR)),LR=1,2)
      READ(5,102) (KTIME(KKENTR),KKENTR=0,NENTR)
      READ(5,102) ((LOGTAB(LSTEM,ILTYPE),ILTYPE=1,5),LSTEM=1,60)
      READ(5,102) (LSIZE(ILTYPE),ILTYPE=1,5)
      READ(5,102) NCA,NCREW,NTREES
101   FORMAT(1X,10F7.2)
102   FORMAT(1X,10I7)
C
C     ECHO INPUTS
C
      WRITE(6,101) BCOST,CH,CSLOPE,DISCT,FCOST
      WRITE(6,101) HLCOST,SP,SPC,SSLOPE,TAPER
      WRITE(6,101) THETA,UXD,UYD,WCOR,WUV
      WRITE(6,101) XMDL,YE,YCOST
      WRITE(6,102) NENTR,NSTR(1),NSTR(2)
      WRITE(6,102) ((ISTW(LR,ISTR),ISTR=1,NSTR(LR)),LR=1,2)
      WRITE(6,102) ((KENTR(LR,ISTR),ISTR=1,NSTR(LR)),LR=1,2)
      WRITE(6,102) (KTIME(KKENTR),KKENTR=0,NENTR)
      WRITE(6,102) ((LOGTAB(LSTEM,ILTYPE),ILTYPE=1,5),LSTEM=1,60)
      WRITE(6,102) (LSIZE(ILTYPE),ILTYPE=1,5)
      WRITE(6,102) NCA,NCREW,NTREES
C     DO PRELIMINARY CALCULATIONS AND CHECKS
      TTHETA=TAN(THETA)
      CTHETA=COS(THETA)
      STHETA=SIN(THETA)
      WRITE(6,101)TTHETA,CTHETA,STHETA,WCOR
      DO 300 LR=1,2
C
C     DO CHECKS ON INPUT VARIABLES
C
      IF ((CH.LT.0.0) .OR. (DISCT.LE.0.0) .OR. (DISCT.GE.1.0)
     1.OR. (TAPER.LT.0.0) .OR. (SP.LE.0.0) .OR. (UXD.LE.0.0)
     1.OR. (UYD.LE.0.0) .OR. (WCOR.LT.0.0) .OR. (WUV.LE.0.0)
     1.OR. (XMDL.LT.0.0) .OR. (YE.LT.1.0) .OR. (NENTR.LT.1)
     1.OR. (NENTR.GT.5) .OR. (NSTR(1).LE.0) .OR. (NSTR(2).LE.0)
     1.OR. (NSTR(1).GT.40) .OR. (NSTR(2).GT.40)
     1.OR. (NTREES.LT.1) .OR. (NTREES.GT.1000)) THEN
         WRITE(6,*) 'INPUT PARAMETER(S) OUT OF RANGE.'
         STOP
      ENDIF
C     CHECK THAT STRIP WIDTHS ARE MULTIPLES OF THREE
         DO 100 ISTR=1,NSTR(LR)
            IF (ISTW(LR,ISTR).NE.ISTW(LR,ISTR)/3*3) THEN
```

```
              WRITE(6,*) 'STRIP WIDTHS NOT MULTIPLES OF THREE'
              STOP
           ENDIF
100     CONTINUE
C     COMPUTE INDST(.,.)
        ISTR=1
        ICUMW=ISTW(LR,1)
        MTHREMX=INT((UYD*TTHETA+UXD/2.)*CTHETA/3)+1
        DO 200 MTHRE=1,MTHREMX
150        IF (MTHRE*3.LE.ICUMW) THEN
              INDST(LR,MTHRE)=ISTR
           ELSE
              ISTR=ISTR+1
              IF (ISTR.GT.NSTR(LR)) THEN
                 WRITE(6,*) 'NOT ENOUGH STRIPS.
                 STOP
              ENDIF
              ICUMW=ICUMW+ISTW(LR,ISTR)
              GOTO 150
           ENDIF
200     CONTINUE
        IF (ISTR.LT.NSTR(LR)) THEN
           WRITE(6,*) 'TOO MANY STRIPS.
           STOP
      ENDIF
  300 CONTINUE
      KKENTR=-1
      KENTR(1,0)=0
      KENTR(2,0)=0
C
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
```

```
C
C*****SUBROUTINE SPACE SCATTERS TREES ON THE CUTTING UNIT
C
      SUBROUTINE SPACE
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/  TDAT(2,0:40,40,3),NSTR(2),NTR(2,0:40),LR,
     1UYD,UXD,WUV,XMDL,SP,NCA,YE,SLOPE,CSLOPE,NCREW,
     2BFVLT,BFVLG,XLA,CFTTN,CH,SPC,L,A,B,NTREES,SYD,STRLP,
     3K,WT,THETA,BTIME,PNW(0:5),LSIZE(5),ISTR,
     4LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
     6INDST(2,500),ISTW(2,40),KENTR(2,0:40),NENTR,KKENTR,
     7YTIME,FTIME,NLOGS,LSTEM,TAPER,DIAM,DBH,ANGLE,COSANG,
     8SINANG,XLEN,NLT,RCAP,ISLOG,INHLOG,TVOL(0:5),HLCOST,TCOST(0:5),
     9TREV(0:5),TNREV(0:5),YCOST,BCOST,FCOST,KTIME(0:5),DISCT,
     1NSTEMS,TDBH,AVGDBH,PONDVAL,TTHETA,CTHETA,STHETA,WCOR,XDBH(0:5)
C
C
C      COMPUTE THE FOLLOWING:
C
C      S=APPROXIMATE LENGTH OF A CELL SIDE
C      K=NUMBER OF COLUMNS WITHIN GRID
C      L=NUMBER OF ROWS WITHIN GRID
C      A=WIDTH OF CELL
C      B=LENGTH OF A CELL
C      C=X-COORDINATE OF LOG (I,J)
C      D=Y-COORDINATE OF LOG (I,J)
C      DST=DISTANCE TO L1 OR L2
C      DSTN=DISTANCE TO L1' OR L2'
C
      S=SQRT(UYD*UXD/NTREES)
      K=(IFIX(UXD/S))/2*2
      IF (UXD/S-FLOAT(K).GE.1) K=K+2
      L=IFIX(FLOAT(NTREES)/K+.5)
      A=UXD/K
      B=UYD/L
      DO 100 I=1,K
         DO 110 J=1,L
            R3=RNORM(1,1)
            R4=RNORM(2,2)
            C=-(K+1)*A/2.+A*I
            D=-(B/2)+(B*J)
            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 (C.LE.0.) THEN
```

```
            LR=1
          ELSE
            LR=2
         ENDIF
          DL=ABS(C+(3.-2.*LR)*(D*TTHETA+UXD/2.))*CTHETA
          DLP=ABS(C-(3.-2.*LR)*D/TTHETA)*STHETA
          IF (ABS(C).LE.UCOR/2.) THEN
            ISTR=0
            IF ((ISTR.LT.0) .OR. (ISTR.GT.NSTR(LR))) THEN
              WRITE(6,*) 'STRIP INDEX OUT OF RANGE.'
              STOP
            ENDIF
          ELSE
            ISTR=INDST(LR,INT(DL/3.)+1)
          ENDIF
          ITR=NTR(LR,ISTR)=NTR(LR,ISTR)+1
          IF (ITR.GT.75) THEN
            WRITE(6,*) 'TOO MANY TREES FOR ONE STRIP.
      WRITE(6,102)LR,ISTR,ITR
  102 FORMAT(2X,5I10)
            STOP
          ENDIF
          IF (ISTR.EQ.0) THEN
            TDAT(LR,ISTR,ITR,1)=C
            TDAT(LR,ISTR,ITR,2)=D
          ELSE
            TDAT(LR,ISTR,ITR,1)=DL
            TDAT(LR,ISTR,ITR,2)=DLP
          ENDIF
          TDAT(LR,ISTR,ITR,3)=RNORM(3,3)
110     CONTINUE
100   CONTINUE
      NTREE=K*L
      WRITE(6,105)NTREES,NTREE
  105 FORMAT(2X,"NO. TREES SPECIFIED =",I5," NO. TREES CREATED =",I5)
C
C     SORT LOGS IN EACH STRIP BY DISTANCE TO L1' OR L2', OR Y-DISTANCE
C     IF CORRIDOR STRIP
C
      DO 1500 LR=1,2
        DO 1400 ISTR=1,NSTR(LR)
1100      IFL=0
          DO 1300 ITR=1,NTR(LR,ISTR)-1
            IF (TDAT(LR,ISTR,ITR,2).GT.TDAT(LR,ISTR,ITR+1,2)) THEN
              IFL=1
              DO 1200 ICH=1,3
                TEMP=TDAT(LR,ISTR,ITR,ICH)
                TDAT(LR,ISTR,ITR,ICH)=TDAT(LR,ISTR,ITR+1,ICH)
                TDAT(LR,ISTR,ITR+1,ICH)=TEMP
1200          CONTINUE
            ENDIF
```

```
1300        CONTINUE
            IF (IFL.EQ.1) GOTO 1100
1400      CONTINUE
1500  CONTINUE
C
C     SCHEDULE HARVEST EVENT
C
      ATRIB(1)=TNOW
      ATRIB(2)=2.0
      CALL FILEM(1)
      RETURN
      END


C
C*****SUBROUTINE HARVEST SERVES AS A CONTROL MODULE FOR ENTRYS
C     INTO CUTTING UNIT
      SUBROUTINE HARVEST
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/  TDAT(2,0:40,40,3),NSTR(2),NTR(2,0:40),LR,
     1UYD,UXD,WUV,XMDL,SP,NCA,YE,SLOPE,CSLOPE,NCREW,
     2BFVLT,BFVLG,XLA,CFTTN,CH,SPC,L,A,B,NTREES,SYD,STRLP,
     3K,WT,THETA,BTIME,PNU(0:5),LSIZE(5),ISTR,
     4LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
     6INDST(2,500),ISTW(2,40),KENTR(2,0:40),NENTR,KKENTR,
     7YTIME,FTIME,NLOGS,LSTEM,TAPER,DIAM,DBH,ANGLE,COSANG,
     8SINANG,XLEN,NLT,RCAP,ISLOG,INHLOG,TVOL(0:5),HLCOST,TCOST(0:5),
     9TREV(0:5),TNREV(0:5),YCOST,BCOST,FCOST,KTIME(0:5),DISCT,
     1NSTEMS,TDBH,AVGDBH,PONDVAL,TTHETA,CTHETA,STHETA,WCOR,XDBH(0:5)
      IF (KKENTR.LT.NENTR) THEN
         KKENTR=KKENTR+1
         TDBH=0.0
         TVOL(KKENTR)=0.0
         NSTEMS=0.0
         YTIME=FTIME=BTIME=0.0
         FBCOST=XHLCOST=YCOST=0.0
        IF(KKENTR .EQ. 0)THEN
            NLOGS=0
            LR=1
            ISTR=0
            CALL FBUCK
            LR=2
            CALL FBUCK
            CALL YARD.
         ELSE
            DO 40 LR=1,2
               STRMID=-UXD/TTHETA/2.
               DO 50 ISTR=1,NSTR(LR)
                  XWIDTH=ISTW(LR,ISTR)/STHETA/2.
```

```
                  STRMID=STRMID+XWIDTH
                  IF(KKENTR .EQ. KENTR(LR,ISTR))THEN
                     IF (STRMID.LT.0.0) THEN
                        SYD=0.0
                     ELSE
                        SYD=STRMID
                     ENDIF
                     STRLP=SYD*STHETA/TTHETA
                     NLOGS=0
                     CALL FBUCK
                     CALL YARD
                  ENDIF
                  STRMID=STRMID+XWIDTH
   50          CONTINUE
  40        CONTINUE
         ENDIF
         IF (NSTEMS.EQ.0) THEN
            WRITE(6,*) 'NO STRIPS YARDED DURING ENTRY',KKENTR
            AVGDBH=0
         ELSE
            AVGDBH=TDBH/NSTEMS
         ENDIF
C
C        SCHEDULE AN ECON EVENT
C
         ATRIB(2)=3.0
         ATRIB(1)=TNOW
         CALL FILEM(1)
         RETURN
      ELSE
C
C        END SIMULATION
C
         MSTOP=-1
         RETURN
      ENDIF
      END


C
C*****SUBROUTINE FBUCK CUTS UP LOGS IN A STRIP BY USER DEFINED
C     BUCKING RULES
C
      SUBROUTINE FBUCK
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/  TDAT(2,0:40,40,3),NSTR(2),NTR(2,0:40),LR,
     1UYD,UXD,WUV,XMDL,SP,NCA,YE,SLOPE,CSLOPE,NCREW,
     2BFVLT,BFVLG,XLA,CFTTN,CH,SPC,L,A,B,NTREES,SYD,STRLP,
     3K,WT,THETA,BTIME,PNW(0:5),LSIZE(5),ISTR,
```

```
     4LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
     6INDST(2,500),ISTW(2,40),KENTR(2,0:40),NENTR,KKENTR,
     7YTIME,FTIME,NLOGS,LSTEM,TAPER,DIAM,DBH,ANGLE,COSANG,
     8SINANG,XLEN,NLT,RCAP,ISLOG,INHLOG,TVOL(0:5),HLCOST,TCOST(0:5),
     9TREV(0:5),TNREV(0:5),YCOST,BCOST,FCOST,KTIME(0:5),DISCT,
     1NSTEMS,TDBH,AVGDBH,PONDVAL,TTHETA,CTHETA,STHETA,WCOR,XDBH(0:5)
      DO 400 ITR=1,NTR(LR,ISTR)
         DL=TDAT(LR,ISTR,ITR,1)
         DLP=TDAT(LR,ISTR,ITR,2)
         DBH=DIAM=TDAT(LR,ISTR,ITR,3)
        TDBH=TDBH+DBH
         NSTEMS=NSTEMS+1
         LSTEM=(2.985+(DBH-4.0)/TAPER)/4.0
         IF (LSTEM.LE.0) GOTO 400
         IF (LSTEM.GT.60) THEN
            WRITE(6,*) 'STEM LENGTH TOO LONG',LSTEM,DIAM,LR,ISTR,ITR
            STOP
         ENDIF
         ANGLE=RNORM(4,4)
         COSANG=COS(ANGLE)
         SINANG=SIN(ANGLE)
         DO 300 ILTYPE=1,5
            XLEN=LSIZE(ILTYPE)
            COSANGL=COSANG*XLEN
            SINANGL=SINANG*XLEN
            NCUTS=0
            DO 200 LOGI=1,LOGTAB(LSTEM,ILTYPE)
               NLOGS=NLOGS+1
               NCUTS=NCUTS+1
               ZLOG(NLOGS,1)=DL
               ZLOG(NLOGS,2)=DLP
               ZLOG(NLOGS,3)=DIAM
               ZLOG(NLOGS,4)=XLEN
               ZLOG(NLOGS,5)=ANGLE
               DIAMC=DIAM-XLEN*TAPER/2.0
               VOL=ZLOG(NLOGS,6)=3.14159*DIAMC*DIAMC/4.0/144.0*XLEN
               TVOL(KKENTR)=TVOL(KKENTR)+VOL
               DL=DL+COSANGL
               DLP=DLP+SINANGL
               DIAM=DIAM-XLEN*TAPER
200         CONTINUE
300      CONTINUE
         FTIME=FTIME+(.5599+.00419*DBH)*.80
         BTIME=BTIME+(.7815*DBH+1.123*NCUTS)*.80
400   CONTINUE
      RETURN
      END


C
C*****SUBROUTINE YARD YARDS THE LOGS IN A STRIP
```

```
C
      SUBROUTINE YARD
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/  TDAT(2,0:40,40,3),NSTR(2),NTR(2,0:40),LR,
     1UYD,UXD,WUV,XMDL,SP,NCA,YE,SLOPE,CSLOPE,NCREW,
     2BFVLT,BFVLG,XLA,CFTTN,CH,SPC,L,A,B,NTREES,SYD,STRLP,
     3K,WT,THETA,BTIME,PNW(0:5),LSIZE(5),ISTR,
     4LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
     6INDST(2,500),ISTW(2,40),KENTR(2,0:40),NENTR,KKENTR,
     7YTIME,FTIME,NLOGS,LSTEM,TAPER,DIAM,DBH,ANGLE,COSANG,
     8SINANG,XLEN,NLT,RCAP,ISLOG,INHLOG,TVOL(0:5),HLCOST,TCOST(0:5),
     9TREV(0:5),TNREV(0:5),YCOST,BCOST,FCOST,KTIME(0:5),DISCT,
     1NSTEMS,TDBH,AVGDBH,PONDVAL,TTHETA,CTHETA,STHETA,WCOR,XDBH(0:5)
C
C      SORT LOGS BY L1P DISTANCE
C
100   IFL=0
      DO 150 ILOG=1,NLOGS
         IF(ZLOG(ILOG,2) .GT. ZLOG(ILOG+1,2))THEN
            DO 10 J=1,6
               Z=ZLOG(ILOG,J)
               ZLOG(ILOG,J)=ZLOG(ILOG+1,J)
               ZLOG(ILOG+1,J)=Z
10          CONTINUE
            IFL=1
         ENDIF
150   CONTINUE
      IF(IFL .EQ. 1) GO TO 100
      ISLOG=1
C     DETERMINE FIRST UNYARDED LOG IN LOG ARRAY
40    IF ((ZLOG(ISLOG,4).EQ.0.0) .AND. (ISLOG.LE.NLOGS)) THEN
         ISLOG=ISLOG+1
         GOTO 40
      ENDIF
      IF(ISLOG .GT. NLOGS) GO TO 60
C     DO FIRST LOG COMPUTATIONS
      DL=ZLOG(ISLOG,1)
      DLP=ZLOG(ISLOG,2)
      XLEN=ZLOG(ISLOG,4)
      ZLOG(ISLOG,4)=0.0
      WT=ZLOG(ISLOG,6)*WUV
      RCAP=SP-WT
      NLT=1
      XLD=ABS(DLP-STRLP)
      IF(NCA .EQ. 1) GO TO 50
      ILLOG=MIN(ISLOG+15,NLOGS)
C     SORT FOR CLOSEST ELIGIBLE LOG TO FIRST-HOOKED LOG
90    XMIN=1E99
       DO 80 ILOG=ISLOG,ILLOG
```

```
          IF ((ZLOG(ILOG,4).NE.0) .AND. (ZLOG(ILOG,6)*WUV.LE.RCAP)) THEN
             DISTSQR=(ZLOG(ILOG,1)-DL)**2+(ZLOG(ILOG,2)-DLP)**2
             IF(DISTSQR .LT. XMIN)THEN
                XMIN=DISTSQR
                INHLOG=ILOG
             ENDIF
          ENDIF
30     CONTINUE
       IF(SQRT(XMIN).LE. XMDL)THEN
          NLT=NLT+1
          RCAP=RCAP-WT
          ZLOG(INHLOG,4)=0
          IF(NLT .LT. NCA) GO TO 90
       ENDIF
50     NLE=NLE+NLT
C      COMPUTE TURN TIME AND COLLECT TURN STATS HERE
C
      XLT=NLT
       YTIME= (3.8149+.005287*SYD+.80662*XLT-.75233*NCREW
     1+.02733*XLD+.0014982*ANGLE)
       WT=SP-RCAP
      IF(KKENTR .EQ. 2)THEN
       CALL COLCT(YTIME,1)
       CALL COLCT(XLT,2)
       CALL COLCT(SYD,3)
       CALL COLCT(XLD,4)
       CALL COLCT(WT,5)
      ENDIF
       GO TO 40
C      COLLECT STRIP STATS HERE
60     RETURN
       END


C
C*****SUBROUTINE ECON COMPUTES PRESENT NET WORTH PER ENTRY
C
      SUBROUTINE ECON
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/  TDAT(2,0:40,40,3),NSTR(2),NTR(2,0:40),LR,
     1UYD,UXD,WUV,XMDL,SP,NCA,YE,SLOPE,CSLOPE,NCREW,
     2BFVLT,BFVLG,XLA,CFTTN,CH,SPC,L,A,B,NTREES,SYD,STRLP,
     3K,WT,THETA,BTIME,PNW(0:5),LSIZE(5),ISTR,
     4LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
     6INDST(2,500),ISTW(2,40),KENTR(2,0:40),NENTR,KKENTR,
     7YTIME,FTIME,NLOGS,LSTEM,TAPER,DIAM,DBH,ANGLE,COSANG,
     8SINANG,XLEN,NLT,RCAP,ISLOG,INHLOG,TVOL(0:5).HLCOST,TCOST(0:5),
     9TREV(0:5),TNREV(0:5),YCOST,BCOST,FCOST,KTIME(0:5),DISCT,
     1NSTEMS,TDBH,AVGDBH,PONDVAL,TTHETA.CTHETA,STHETA,WCOR,XDBH(0:5)
```

```
      XDBH(KKENTR)=AVGDBH
      PONDVAL=(-20.1061+78.393*AVGDBH)/1000.
      FBCOST=((.1026-.0036*XDBH(KKENTR))*TVOL(KKENTR))*.80
      XHLCOST=(.196930-.00588*XDBH(KKENTR))*TVOL(KKENTR)
      YCOST=(.572260-.0246983*XDBH(KKENTR))*TVOL(KKENTR)
      TCOST(KKENTR)=FBCOST+XHLCOST+YCOST
      TREV(KKENTR)=TREV(KKENTR)+TVOL(KKENTR)*PONDVAL
      TNREV(KKENTR)=TREV(KKENTR)-TCOST(KKENTR)
      PNW(KKENTR)=TNREV(KKENTR)*((1.0-DISCT)**KTIME(KKENTR))
C
C     SCHEDULE GROWTH EVENT
C
      ATRIB(1)=TNOW
      ATRIB(2)=4.0
      CALL FILEM(1)
      RETURN
      END


C
C*****SUBROUTINE GROWTH GROWS TREES BETWEEN ENTRIES
C
      SUBROUTINE GROWTH
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /UCOM1/  TDAT(2,0:40,40,3),NSTR(2),NTR(2,0:40),LR,
     1UYD,UXD,WUV,XMDL,SP,HCA,YE,SLOPE,CSLOPE,NCREW,
     2BFVLT,BFVLG,XLA,CFTTN,CH,SPC,L,A,B,NTREES,SYD,STRLP,
     3K,WT,THETA,BTIME,PNW(0:5),LSIZE(5),ISTR,
     4LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
     6INDST(2,500),ISTW(2,40),KENTR(2,0:40),NENTR,KKENTR,
     7YTIME,FTIME,NLOGS,LSTEM,TAPER,DIAM,DBH,ANGLE,COSANG,
     8SINANG,XLEN,NLT,RCAP,ISLOG,INHLOG,TVOL(0:5),HLCOST,TCOST(0:5),
     9TREV(0:5),TNREV(0:5),YCOST,BCOST,FCOST,KTIME(0:5),DISCT,
     1NSTEMS,TDBH,AVGDBH,PONDVAL,TTHETA,CTHETA,STHETA,WCOR,XDBH(0:5)
      DO 500 LR=1,2
         ICUMW=0.0
         EDG1=0.0
         ILFLG=0
         LSTR=0
         DO 400 ISTR=1,NSTR(LR)
            IF (KKENTR.LT.KENTR(LR,ISTR)) THEN
C LEAVE STRIP
               IF (ILFLG.EQ.0) THEN
C CUT STRIP / LEAVE STRIP BOUNDARY
                  ILFLG=1
                  EDG1=ICUMW
               ENDIF
               EDGE1(LR,ISTR)=EDG1
            ELSE
```

```
C CUT STRIP
              IF (ILFLG.EQ.1) THEN
C LEAVE STRIP / CUT STRIP BOUNDARY
                 ILFLG=0
                 DO 350 JSTR=LSTR+1,ISTR-1
                    EDGE2(LR,JSTR)=ICUMU
350              CONTINUE
                 LSTR=ISTR
              ENDIF
           ENDIF
           ICUMU=ICUMU+ISTU(LR,ISTR)
400     CONTINUE
        DO 450 JSTR=LSTR+1,NSTR(LR)
           EDGE2(LR,JSTR)=ICUMU
450     CONTINUE
500   CONTINUE
      N=KTIME(KKENTR+1) - KTIME(KKENTR)
      C11=.00292245
      C12=-.0175524
      C13=.0201006
      C21=-.0203446
      C22=.0150499 .
      B1N=(1+C13)**N
      B2N=(1+C22)**N
      D1=(B1N-1)/C13
      D2=C21*(B2N-1)/C22
      DO 900 LR=1,2
         DO 800 ISTR=1,NSTR(LR)
            IF (KKENTR.LT.KENTR(LR,ISTR)) THEN
               EDG1=EDGE1(LR,ISTR)
               EDG2=EDGE2(LR,ISTR)
               DO 700 ITR=1,NTR(LR,ISTR)
                  DIST1=TDAT(LR,ISTR,ITR,1)-EDG1
                  DIST2=EDG2-TDAT(LR,ISTR,ITR,1)
                  IF ((DIST1.LT.15.) .OR. (DIST2.LT.15.)) THEN
                     TDAT(LR,ISTR,ITR,3)=(AMIN1(DIST1,DIST2)*C12
     1               +C11)*D1 + B1N*TDAT(LR,ISTR,ITR,3)
                  ELSE
                     TDAT(LR,ISTR,ITR,3)=D2 + B2N*TDAT(LR,ISTR,ITR,3)
                  ENDIF
700            CONTINUE
            ENDIF
800      CONTINUE
900   CONTINUE
C
C     SCHEDULE A HARVEST EVENT
C
      ATRIB(1)=TNOW
      ATRIB(2)=2.0
      CALL FILEM(1)
      RETURN
```

```
      END
C
C*****SUBROUTINE OTPUT OUTPUTS SIMULATION RESULTS
C
      SUBROUTINE OTPUT
      COMMON /GCOM1/ ATRIB(25),JEVNT,MFA,MFE(100),MLE(100),MSTOP,
     1NCRDR,NNAPO,NNAPT,NNATR,NNFIL,NNQ(100),NNTRY,NPRNT,PPARM(50,4),
     2TNOW,TTBEG,TTCLR,TTFIN,TTRIB(25),TTSET
      COMMON /GCOM6/ EENQ(100),IINN(100),KKRNK(100),MMAXQ(100),
     1QQTIM(100),SSOBV(25,5),SSTPV(25,6),VVNQ(100)
      COMMON /UCOM1/  TDAT(2,0:40,40,3),NSTR(2),NTR(2,0:40),LR,
     1UYD,UXD.WUV,XMDL,SF,NCA,YE,SLOPE,CSLOPE,NCREW,
     2BFVLT,BFVLG,XLA,CFTTN,CH,SPC,L,A,B,NTREES,SYD,STRLP,
     3K,WT,THETA,BTIME,PNW(0:5),LSIZE(5),ISTR,
     4LOGTAB(60,5),ZLOG(100,6),EDGE1(2,0:40),EDGE2(2,0:40),
     6INDST(2.500),ISTW(2,40),KENTR(2,0:40),NENTR,KKENTR,
     7YTIME,FTIME,NLOGS,LSTEM,TAPER,DIAM,DBH,ANGLE,COSANG,
     8SINANG,XLEN,NLT,RCAP,ISLOG,INHLOG,TVOL(0:5),HLCOST,TCOST(0:5),
     9TREV(0:5),TNREV(0:5),YCOST,BCOST,FCOST,KTIME(0:5),DISCT,
     1NSTEMS,TDBH,AVGDBH,PONDVAL,TTHETA,CTHETA,STHETA,WCOR,XDBH(0:5)
      WRITE(6,700)
  700 FORMAT(//,2X,65("*"),/,2X,"***",59X,"***",
     1/,2X,"***",5X,"ENTRY",6X,"AVE",
     24X,"VOLUME",3X,"LOGGING",5X,"POND",5X,"ENTRY",
     31X,"***",/,2X,"***",6X,"AGE",7X,"DBH",
     45X,"CUT",6X,"COST",6X,"VALUE",6X,"PNW",2X,"***",/,
     52X,65("*"))
      DO 20 I=0,NENTR
      WRITE(6,104)KTIME(I),XDBH(I),TVOL(I),TCOST(I),TREV(I),PNW(I)
  104 FORMAT(5X,I9,5F10.2)
   20 CONTINUE
      PRH=(SSOBV(5,1)*60.0)/(WUV*SSOBV(1,1))
      WRITE(6,9120)PRH
 9120 FORMAT(1X,34HHOURLY PRODUCTION RATE FOR YARDING,F10.4)
      RETURN
      END
```

APPENDIX II

Example Input Data for ROWTHIN

```
GEN,LEDOUX,TESTRUN,2,8,1983,1,7*
STA,5*
LIM,4,4,300,2, ,2000*
COL,1,YTIME,2,NLT,3,SYD,4,XLD,5,WT*
PRI,1,HVF,2*
PAR,1,0.0,-10.0,10.0,1.0*
PAR,2,0.0,-10.0,10.0,1.0*
PAR,3,11.2,4.9,20.6,3.5*
PAR,4,17.0,16.0,18.0,1.0*
INI,0,YES,YES,0, ,YES*
SEE,11327,43989,48275,53985*
FIN*
      1.10   22.00   30.00     .03    1.00
      1.123000.00     1.40   19.00     .14
      0.79  120.00  598.00   12.00   46.00
     45.00    1.60    1.12
         2      26      26
        18      18      18      18      18      18      18      18      18      18
        18      18      18      18      18      18      18      18      18      18
        18      18      18      18      18      18      18      18      18      18
        18      18      18      18      18      18      18      18      18      18
        18      18      18      18      18      18      18      18      18      18
        18      18
         2       1       2       1       2       1       2       1       2       1
         2       1       2       1       2       1       2       1       2       1
         2       1       2       1       2       1       2       1       2       1
         2       1       2       1       2       1       2       1       2       1
         2       1       2       1       2       1       2       1       2       1
         2       1
        30      30      60      60
         0       0       0       0       0       0       0       0       0       0
         0       0       0       0       1       0       0       0       0       1
         0       0       0       0       1       0       0       0       1       0
         0       0       0       1       0       0       0       1       0       0
         0       1       0       0       0       1       0       0       0       0
         1       0       0       0       0       1       0       0       0       0
         1       0       0       0       1       0       0       1       1       0
         0       1       0       1       0       1       0       0       1       0
         0       1       1       0       0       1       0       1       0       0
         1       1       0       0       0       2       0       0       0       0
```

41	1	0	1	0	1	1	0	0	2	0
42	2	0	0	0	1	0	2	0	1	0
43	1	1	0	1	0	2	0	0	1	0
44	0	2	0	1	1	1	1	0	1	1
45	2	1	0	0	0	3	0	0	0	0
46	2	0	1	0	1	2	1	0	0	1
47	3	0	0	0	1	1	2	0	1	0
48	2	1	0	1	0	3	0	0	1	0
49	2	1	1	0	0	3	0	1	0	[illegible]
50	3	1	0	0	0	4	0	0	0	[illegible]
51	3	0	1	0	1	3	1	0	0	[illegible]
52	4	0	0	0	1	3	0	1	1	[illegible]
53	3	1	0	1	0	4	0	0	1	[illegible]
54	3	1	1	0	0	4	0	1	0	0
55	4	1	0	0	0	5	0	0	0	0
56	4	0	1	0	1	4	1	0	0	[illegible]
57	5	0	0	0	1	4	0	1	1	0
58	4	1	0	1	0	3	0	0	1	0
59	4	1	1	0	0	5	0	1	0	0
60	5	1	0	0	0	6	0	0	0	[illegible]
[illegible]	40	36	32	24	12					
[illegible]	3	3	510							

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:

Columns	Format	Description
1-7	F7.2	Bucking Cost/ft^3
8-14	F7.2	Carriage Height, ft
15-21	F7.2	Chordslope, percent
22-28	F7.2	Discount rate, decimal
29-35	F7.2	Felling Cost/ft^3

Card 14

Card 14 contains the following data:

Columns	Format	Description
1-7	F7.2	Hauling and Loading Cost/ft^3
8-14	F7.2	Yarding System Payload, lbs
15-21	F7.2	Spatial Distribution Coefficient
22-28	F7.2	Percent Sideslope
29-35	F7.2	Taper Rate, inches/lineal foot

Card 15

Card 15 contains the following data:

Columns	Format	Description
1-7	F7.2	Corridor Angle, Radians
8-14	F7.2	Skyline Block Width, ft
15-21	F7.2	Skyline Block Length, ft
22-28	F7.2	Skyline Corridor Width, ft
29-35	F7.2	Weight/Unit Volume, lbs/ft^3

Card 16

Card 16 contains the following data:

Columns	Format	Description
1-7	F7.2	Maximum Distance for Hooking Turns
8-14	F7.2	Yarding Efficiency
15-21	F7.2	Yarding Cost/ft^3

Card 17

Card 17 contains the following data:

Columns	Format	Description
1-7	I7	Number of entries into unit
8-14	I7	Number of strips on left side of skyline block
15-21	I7	Number of strips on right side of skyline block

Cards 18 - 23

Cards 18-23 contain the following data:

Columns	Format	Description
1-70	10I7	Cut-and-leave strip widths

Cards 24 - 29

Cards 24-29 contain the following data:

Columns	Format	Description
1-70	10I7	Entry schedule, 1 = first entry, 2 = second entry

Card 30

Card 30 contain the following data:

Columns	Format	Description
1-7	I7	Entry age for skyline corridor
8-14	I7	Entry age for first entry
15-21	I7	Entry age for final cut

Cards 31 - 60

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

Card 61

Card 61 contains the following data:

Columns	Format	Description
1-70	10I7	Log lengths desired, ft.

Card 62

Card 62 contains the following data:

Columns	Format	Description
1-7	I7	Number of chokers flown
8-14	I7	Number on rigging crew
15-21	I7	Number of trees per skyline block

APPENDIX III.

Example Output from ROWTHIN

```
1
GEN,LEDOUX,TESTRUN,2,8,1983,1,7*
                                              **GASP INPUT ERROR TYPE 180 **
STA,5*
LIN,4,4,300,2, ,2000*
COL,1,YTIME,2,NLT,3,SYD,4,XLD,5,WT*
PRI,1,HVF,2*
PAR,1,0.0,-10.0,10.0,1.0*
PAR,2,0.0,-10.0,10.0,1.0*
PAR,3,11.2,4.9,20.6,3.5*
PAR,4,17.0,16.0,18.0,1.0*
INI,0,YES,YES,0, ,YES*
SEE,11327,43989,48275,53985*
FIN*
    1.10  22.00  30.00    .03   1.00
    1.123000.00   1.40  19.00    .14
     .79 120.00 598.00  12.00  46.00
   45.00   1.60   1.12
       2     26     26
      18     18     18     18     18     18     18     18     18     18
      18     18     18     18     18     18     18     18     18     18
      18     18     18     18     18     18     18     18     18     18
      18     18     18     18     18     18     18     18     18     18
      18     18     18     18     18     18     18     18     18     18
      18     18
       2      1      2      1      2      1      2      1      2      1
       2      1      2      1      2      1      2      1      2      1
       2      1      2      1      2      1      2      1      2      1
       2      1      2      1      2      1      2      1      2      1
       2      1      2      1      2      1      2      1      2      1
       2      1
      30     30     60
       0      0      0      0      0      0      0      0      0      0
```

1031	0	0	0	0	1	0	0	0	0	1
1035	0	0	0	0	1	0	0	0	1	0
1036	0	0	0	1	0	0	0	1	0	0
1037	0	1	0	0	0	1	0	0	0	0
1038	1	0	0	0	0	1	0	0	0	0
1039	1	0	0	0	1	0	0	1	1	0
1040	0	1	0	1	0	1	0	0	1	0
1041	0	1	1	0	0	1	0	1	0	0
1042	1	1	0	0	0	2	0	0	0	0
1043	1	0	1	0	1	1	0	0	2	0
1044	2	0	0	0	1	0	2	0	1	0
1045	1	1	0	1	0	2	0	0	1	0
1046	0	2	0	1	1	1	1	0	1	1
1047	2	1	0	0	0	3	0	0	0	0
1048	2	0	1	0	1	2	1	0	0	1
1049	3	0	0	0	1	1	2	0	1	0
1050	2	1	0	1	0	3	0	0	1	0
1051	2	1	1	0	0	3	0	1	0	0
1052	3	1	0	0	0	4	0	0	0	0
1053	3	0	1	0	1	3	1	0	0	1
1054	4	0	0	0	1	3	0	1	1	0
1055	3	1	0	1	0	4	0	0	1	0
1056	3	1	1	0	0	4	0	1	0	0
1057	4	1	0	0	0	5	0	0	0	0
1058	4	0	1	0	1	4	1	0	0	1
1059	5	0	0	0	1	4	0	1	1	0
1060	4	1	0	1	0	5	0	0	1	0
1061	4	1	1	0	0	5	0	1	0	0
1062	5	1	0	0	0	6	0	0	0	0
1063	40	36	32	24	12					
1064	3	3	510							
1065	1.01	.70	.71	12.00						
1066 1										
1067										
1068										

SIMULATION PROJECT NUMBER 0 BY LEDOUX

DATE 2/ 6/ 1983 RUN NUMBER 1 OF 1

```
                                         GASP IV VERSION 01JAN76


NNCLT=     5    NNSTA=     0    NNHIS=     0    NNPRM=     4    NNPLT=     0    NNSTR=     4 NNTRY=   300
NNATR=     2    NNFIL=     1    NNSET=  2000    NNEQD=     0    NNEQS=     0    NFLAG=     0
IIFOF=     Y    IIPOS=     Y    IISUM=     Y    IIPIR=     Y

COLCT NO.  1    LLABC=YTIME
COLCT NO.  2    LLABC=NLT
COLCT NO.  3    LLABC=SYD
COLCT NO.  4    LLABC=XLD
COLCT NO.  5    LLABC=WT

PRIORITY FILE   1=HVF ( 2)

PARAMETER SET     1 =     0.               -.1000E+02       .1000E+02       .1000E+01
PARAMETER SET     2 =     0.               -.1000E+02       .1000E+02       .1000E+01
PARAMETER SET     3 =      .1120E+02        .4900E+01       .2060E+02       .3500E+01
PARAMETER SET     4 =      .1700E+02        .1600E+02       .1800E+02       .1000E+01

MSTOP=     0    JJCLR=     Y    JJBEG=     Y    TTBEG=     0.            TTFIN=      .1000E+21
JJFIL=     Y
IISED= 11327          43989            48275            53985
1                          **GASP FILE STORAGE AREA DUMP AT TIME  0.        **


                           MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA =  1


                                       PRINTOUT OF FILE NUMBER   1
                                           THOU =  0.
                                           QQTIM=  0.

                                              FILE CONTENTS
```

```
ENTRY   1    =     0.                .1000E+01
1                                             **INTERMEDIATE RESULTS**


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


*********************************************************************
***                                                               ***
***     ENTRY      AVE    VOLUME   LOGGING     FOND     ENTRY ***
***      AGE       DBH     CUT      COST      VALUE      PNU  ***
*********************************************************************
           30     11.89   1264.62    573.42   1153.37    232.56
           30     11.70   5756.70   2646.12   5166.29   1010.60
           60     17.27  20359.66   5569.79  27148.57   3470.01
HOURLY PRODUCTION RATE FOR YARDING  580.6017
1                                            **GASP SUMMARY REPORT**

                               SIMULATION PROJECT NUMBER   0  BY  LEDOUX

                               DATE  2/  8/ 1983       RUN NUMBER    1 OF    1

                               CURRENT TIME =  0.



PARAMETER SET      1 =     0.              -.1000E+02       .1000E+02       .1000E+01
PARAMETER SET      2 =     0.              -.1000E+02       .1000E+02       .1000E+01
PARAMETER SET      3 =      .1120E+02       .4900E+01       .2060E+02       .3500E+01
PARAMETER SET      4 =      .1700E+02       .1600E+02       .1800E+02       .1000E+01
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN	STD DEV	SD OF MEAN	CV	MINIMUM	MAXIMUM	OBS
YTIME	.5446E+01	.1261E+01	.6719E-01	.2315E+00	.2500E+01	.9057E+01	352
NLT	.1827E+01	.8242E+00	.4393E-01	.4512E+00	.1000E+01	.3000E+01	352
SYD	.2677E+03	.1761E+03	.9386E+01	.6579E+00	0.	.5614E+03	352
XLD	.3562E+02	.2488E+02	.1326E+01	.6986E+00	.4903E-01	.1265E+03	352
WT	.2424E+04	.1844E+04	.9830E+02	.7608E+00	.6813E+02	.9371E+04	352

1

**GASP FILE STORAGE AREA DUMP AT TIME 0. **

MAXIMUM NUMBER OF ENTRIES IN FILE STORAGE AREA = 1

PRINTOUT OF FILE NUMBER 1

TNOW = 0.

QQTIM= 0.

THE FILE IS EMPTY

Example Output from ROWTHIN (continued)

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 133 are GASP IV output. Lines 134 through 141 show detailed descriptive statistics for a simulation run. Lines 142 through 152 are GASP IV output.

APPENDIX IV

Computer Code Listing for PNW

```
      PROGRAM MAIN(INPUT,OUTPUT,TAPE7,TAPE5=INPUT,TAPE6=OUTPUT)
C
C
C       PROGRAM PNW COMPUTES TOTAL LOGGING COST, TOTAL REVENUE,
C       AND DETERMINES THE PRESENT NET WORTH FOR EACH USER DEFINED
C       ENTRY.  THE USER INPUTS THE FOLLOWING STAND ATTRIBUTES ON
C       A PER ENTRY BASIS FOR THE NUMBER OF ENTRIES OF INTEREST.
C
C       USER DEFINED INPUTS:
C
C         1. AVERAGE STAND DIAMETER IN INCHES, DBH(I).
C         2. AVERAGE VOLUME REMOVED PER ACRE, IN CUBIC FEET TVOL(I).
C         3. THE TIME OF EACH ENTRY. AGE IN YEARS FROM 0, ENRTY(I).
C         4. THE DISCOUNT RATE CHOSEN, DISCT.
C         5. THE NUMBER OF ENTRYS CONSIDERED FOR EACH ANALYSIS,N
C
C
C       VARIABLE DEFINITIONS:
C
C       ENTRY(I)= AGES OF ENTRYS FROM 0.
C       DBH(I)= AVERAGE STAND DIAMETER FOR EACH ENTRY,INCHES.
C       TVOL(I)=VOLUME IN CUBIC FEET PER ACRE FOR EACH ENTRY.
C       TREV(I)=TOTAL REVENUE FOR EACH ENTRY, POND VALUE,DOLLARS.
C       TLCOST(I)=TOTAL LOGGING COST PER ENTRY,DOLLARS.
C       TNREV(I)=TOTAL NET REVENUE PER ENTRY,DOLLARS.
C       PNW(I)=PRESENT NET WORTH FOR EACH ENTRY, DOLLARS.
C       CPNW(I)=CUMULATIVE PRESENT NET WORTH FOR EACH ENTRY.
C       N=NUMBER OF ENTRYS CHOSEN TO EVALUATE, INTEGER.
C       DISCT=DISCOUNT RATE CHOSEN FOR THE ANALYSIS.
C
C
C       DIMENSION ARRAYS, IF MORE THAN FIVE ENTRYS ARE SCHEDULED
C       THE ARRAY DIMENSIONS MUST BE CHANGED ACCORDINGLY.
C
      DIMENSION ENTRY(5),DBH(5),TVOL(5).TREV(5).TLCOST(5),CPNW(5)
      DIMENSION TNREV(5).PNW(5)
C
C       INITIALIZE COMPUTATIONAL ARRAYS.
C
      TLCOST(1)=TLCOST(2)=TLCOST(3)=TLCOST(4)=TLCOST(5)=0.0
      TREV(1)=TREV(2)=TREV(3)=TREV(4)=TREV(5)=0.0
      TNREV(1)=TNREV(2)=TNREV(3)=TNREV(4)=TNREV(5)=0.0
      PNW(1)=PNW(2)=PNW(3)=PNW(4)=PNW(5)=0.0
      CPNW(1)=CPNW(2)=CPNW(3)=CPNW(4)=CPNW(5)=0.0
C
C       READ IN USER DEFINED INPUT CONDITIONS.
      X=1.0
      Y=1.0
C
```

```
      READ(5,100)(ENTRY(I),I=1,5)
      READ(5,101)(DBH(I),I=1,5)
      READ(5,101)(TVOL(I),I=1,5)
      READ(5,103)DISCT,N
C
C      ECHO OUT INPUT CONDITION.
C
  100 FORMAT(2X,5F10.2)
  101 FORMAT(2X,5F10.2)
  102 FORMAT(2X,5F10.2)
  103 FORMAT(2X,F4.2,I1)
      WRITE(6,100)(ENTRY(I),I=1,5)
      WRITE(6,101)(DBH(I),I=1,5)
      WRITE(6,102)(TVOL(I),I=1,5)
      WRITE(6,103)DISCT,N
C
C      COMPUTE TOTAL LOGGING COST FOR EACH OF N USER SPECIFIED
C      ENTRYS.  THE TOTAL COST FUNCTION COMPUTES FELLING, BUCKING
C      LIMBING,YARDING, LOADING AND HAULING COST BY AVERAGE
C      DIAMETER OF THE MATERIAL CUT AND BY THE TOTAL VOLUME
C      REMOVED.
C
C
C

      DO 10 I=1,N
      TLCOST(I)=((.1026-(.0036*DBH(I)))*X+(.574-(.0191*DBH(I)))*Y+
     1(.19693-(.00588*DBH(I))))*1.0*(TVOL(I))
C
C      FUNCTION TREV(I) COMPUTES THE POND VALUE PER ENTRY BASED
C      ON THE AVERAGE STAND DIAMETER AND THE VOLUME CUT PER
C      ENTRY.
C
      TREV(I)=TREV(I)+(-20.1061+(78.3930*DBH(I)))*TVOL(I)/1000.0
      TNREV(I)=TREV(I)-TLCOST(I)
      PNW(I)= TNREV(I)/((1.0+DISCT)**ENTRY(I))
      CPNW(I)=CPNW(I)+PNW(I)+CPNW(I)
   10 CONTINUE
      WRITE(6,700)
  700 FORMAT(//,2X,65("*"),/,2X,"***",59X,"***",
     */,2X,"***",5X,"ENTRY",6X,"AVE",
     *4X,"VOLUME",3X,"LOGGING",5X,"POND",5X,"ENTRY",
     *1X,"***",/,2X,"***",6X,"AGE",7X,"DBH",
     *5X,"CUT",6X,"COST",6X,"VALUE",6X,"PNW",2X,"***",/,
     *2X,65("*"))
                .
      DO 20 I=1,N
      WRITE(6,104)ENTRY(I),DBH(I),TVOL(I),TLCOST(I),TREV(I),PNW(I)
  104 FORMAT(5X,6F10.2)
   20 CONTINUE
      STOP
      END
```

APPENDIX V

Example Input Data for PNW

00001	30.00	45.00	60.00	95.00	1.00
00002	9.18	16.71	23.98	28.00	12.00
00003	1663.00	2964.00	10253.00	6733.00	6000.00
00004	.033				

Example Input Data for PNW (continued)

The input data is defined as follows:

Card 1

Columns	Format	Description
1-10	F10.2	Age of first entry, years
11-20	F10.2	Age of second entry, years
21-30	F10.2	Age of third entry, years
31-40	F10.2	Age of fourth entry, years
41-50	F10.2	Age of fifth entry, years

Card 2

Columns	Format	Description
1-10	F10.2	Average diameter for first entry, inches
11-20	F10.2	Average diameter for second entry, inches
21-30	F10.2	Average diameter for third entry, inches
31-40	F10.2	Average diameter for fourth entry, inches
41-50	F10.2	Average diameter for fifth entry, inches

Card 3

Columns	Format	Description
1-10	F10.2	Volume/acre for first entry, ft^3
11-20	F10.2	Volume/acre for second entry, ft^3
21-30	F10.2	Volume/acre for third entry, ft^3
31-40	F10.2	Volume/acre for fourth entry, ft^3
41-50	F10.2	Volume/acre for fifth entry, ft^3

Card 4

Columns	Format	Description
1-6	F4.2	Discount rate, decimal
7	I1	Number of entries into stand

APPENDIX VI

Example Output from PNW

```
      30.00     45.00     60.00     95.00      1.00
       9.18     16.71     23.98     28.00     12.00
    1663.00   2964.00  10253.00   6733.00   6000.00
 .033


******************************************************************
***                                                            ***
***      ENTRY      AVE     VOLUME    LOGGING      POND    ENTRY ***
***       AGE       DBH      CUT       COST       VALUE     PNW  ***
******************************************************************
          30.00      9.18   1663.00   1016.37   1163.34     60.55
          45.00     16.71   2964.00   1173.62   3823.09    700.62
          60.00     23.98  10253.00   1929.43  19068.10   2909.00
```

<u>Example Output from PNW</u> (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

$$DBH(0) = \text{Given}$$

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

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

$$= A+C\cdot A+B\cdot DIST+B\cdot C\cdot DIST+C^2DHB(0)$$

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

$$= A+B\cdot DIST+A\cdot C+A\cdot C^2+B\cdot C\cdot DIST+B\cdot C^2\cdot DIST+C^3DBH(0)$$

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

By induction:

$$DBH(n) = A[1+C+\ldots+C^{n-1}]+B\cdot DIST[1+C+\ldots C^{n-1}]+C^nDBH(0)$$

$$\frac{1-C^n}{1-C} = \frac{C^n-1}{C-1}$$

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

For $\leq$ 15' equation: $A = .290\ldots E\text{-}02$

$B = -.01755\ldots$

$C = 1.0201006$

For > 15' equation: $A = -2.03\ldots E\text{-}02$

$B = 0$

$C = 1.015\ldots$

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) in 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

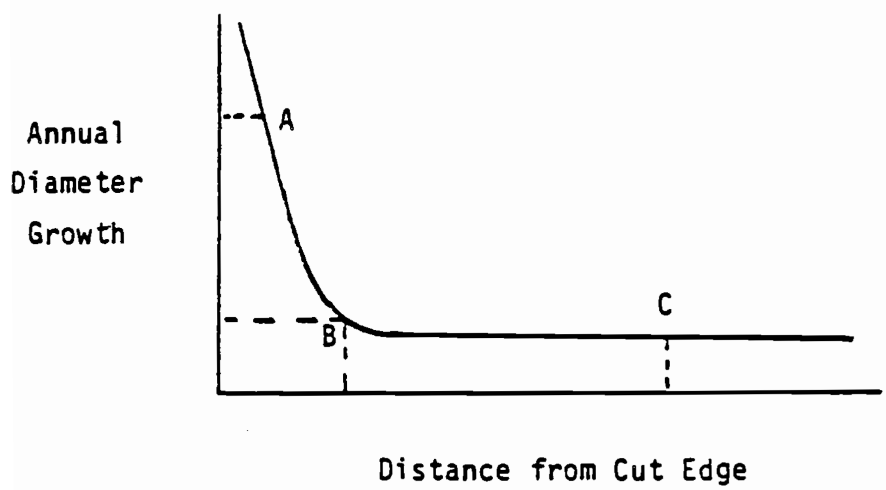

Figure 7. Graph of Theoretical Growth Response to Distance to Cut Edge.

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 rigorour 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.

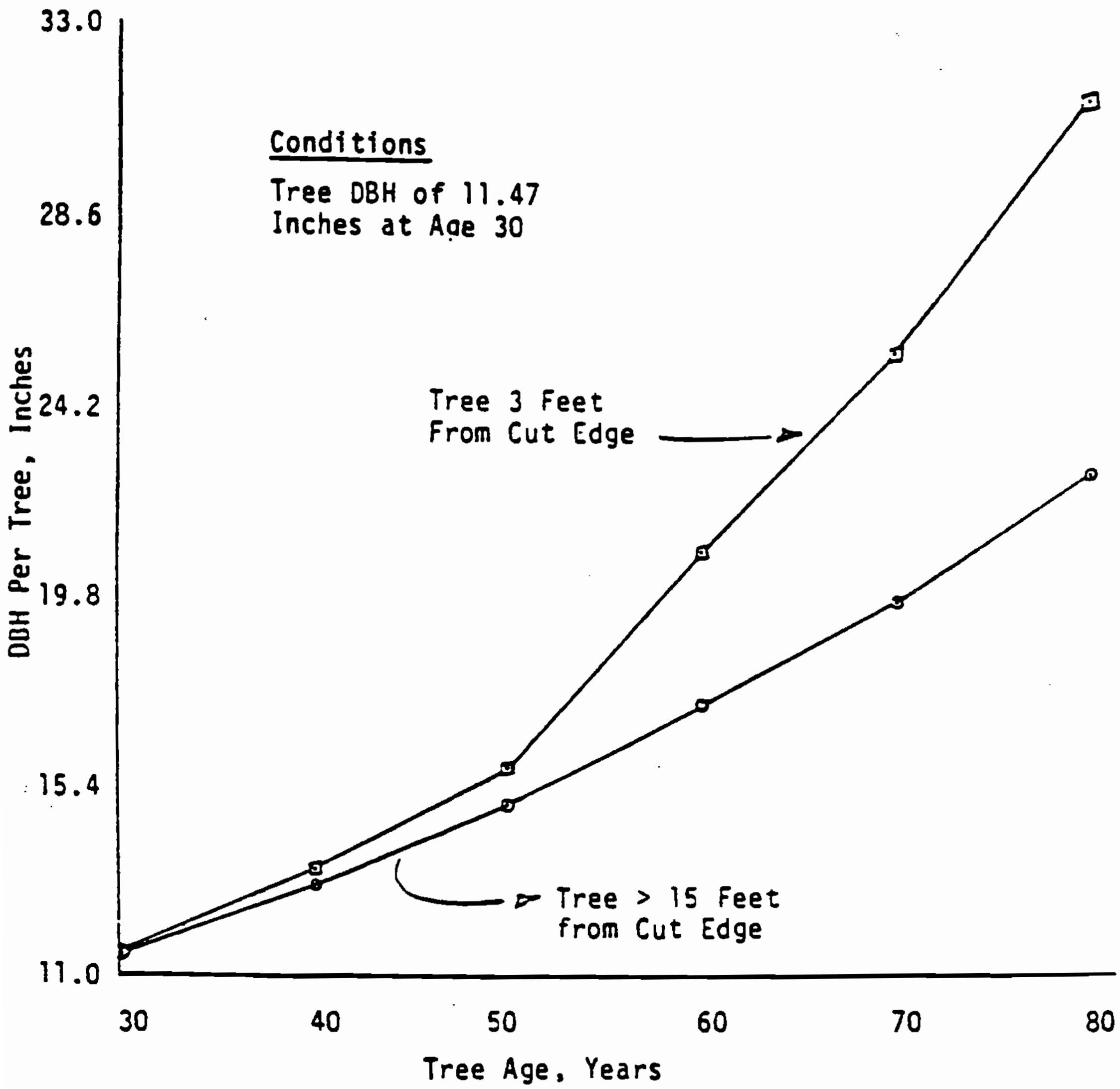

Figure 8. Comparison of Annual Growth Response of a 30-Year-Old Tree Close to an Edge and Deep Within a Leave Strip.

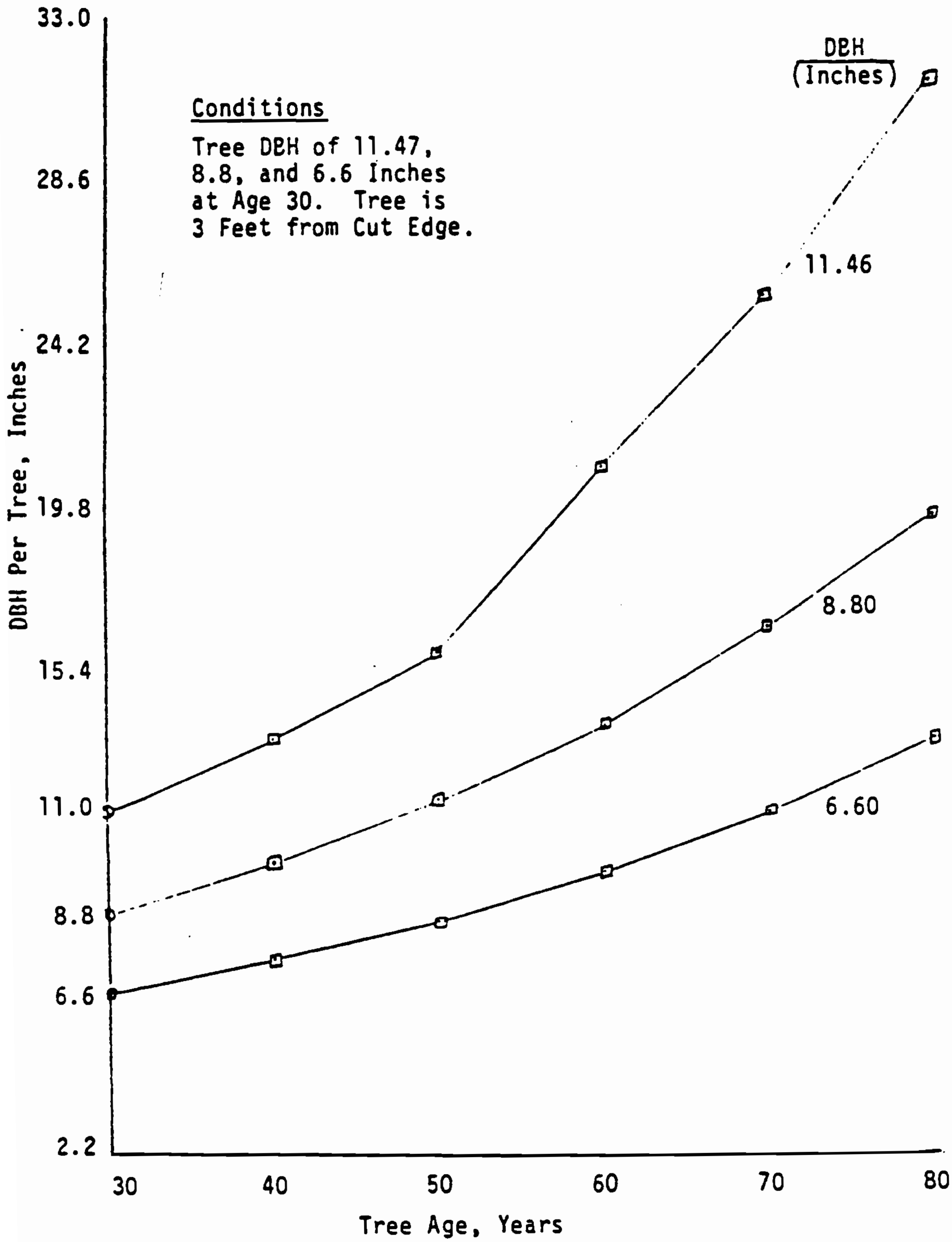

Figure 9. Comparison of Annual Growth Response of 3 Different Diameter 30-Year-Old Trees Close to a Cut Edge.

APPENDIX VIII

Logging Cost Equations

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:

Dollars/Ft^3	Average Log DBH
.075	8
.064	10
.061	12
.052	14
.045	16

When regressed, the following equation emerged:

Felling, Limbing & Bucking Cost/Ft^3 by DBH

$$\$/Ft^3 = .102 - .00360\ (\text{Avg DBH})$$

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:

Dollars/Ft^3	Average Log DBH
.59	8
.36	10
.30	12
.23	14
.21	16
.19	18
.17	20
.15	22
.13	24
.11	26
.09	28

When regressed, the following equation emerged:

Yarding Cost/Ft^3 by DBH for Schield Bantam Conventional Thinning

$$\$/Ft^3 = .574 - .019\ (\text{Avg DBH})$$

$$R^2 = 77.6\%$$

$$\text{DBH Limits} = 23\text{cm}-61\text{cm}\ (9\ \text{in.}-24\ \text{in.})$$

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:

Dollars/Ft^3	Average Log DBH
.28	11.54
.29	11.73
.14	17.32
.15	17.27

When regressed, the following equation emerged:

Yarding Cost/Ft^3 by DBH for Schield Bantam Strip Thinning

$\$/Ft^3 = .572$

$-.024$ (Avg DBH)

$R^2 = 99.3\%$

DBH Limits = 25cm-45cm (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:

Dollars/Ft^3	Average Log Diameter
.153	8
.133	10
.129	12
.115	14
.102	16
.091	18
.079	20
.067	22
.055	24

When regressed, the following equation emerged:

Loading and Hauling Cost/Ft^3 by DBH

$\$/Ft^3 = .196$

$-.00588$ (Avg DBH)

R^2 = 94.1%

DBH Limits = 20cm-61cm (8 in.-24 in.)

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:[2/]

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

No. 4 Mill Sawlogs	215 F/Mbf

[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.

No. 3 Mill Sawlogs	230 $/Mbf
No. 2 Mill Sawlogs	265 $/Mbf
Special Mill Grade	300 $/Mbf
No. 3 Peeler Logs	330 $/Mbf

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 = 1.53 D**2 - 4*D - 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 2. POND VALUE AS A FUNCTION OF MEAN STAND DIAMETER.

Mean Stand DBH (inches)	Age (years)	Bf/Cf Ratio	Pond Value ($/mcf)
6.6	40	1.93	414.95
10.40	60	3.46	795.80
13.70	80	4.15	1099.75
16.20	100	4.58	1374.00
18.40	120	4.94	1482.00
20.20	140	5.11	1533.00
22.00	160	5.29	1587.00

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* Mean Stand Diameter (in)

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

APPENDIX I

Logging Equipment

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

Skyline yarding	=	Schield Bantam yarder
Felling, bucking, limbing	=	Stihl 048 w/32" bar saw
Decking and Loading	=	Bantam C266L hydraulic loader
Hauling	=	Peerless long-log truck

APPENDIX XI

Bucking Rules

	40[1]	36	32	24	12		40[1]	36	32	24	12
1[2]	0	0	0	0	0	31	2	0	1	0	1
2	0	0	0	0	0	32	2	1	0	0	1
3	0	0	0	0	1	33	3	0	0	0	1
4	0	0	0	0	1	34	1	2	0	1	0
5	0	0	0	0	1	35	2	1	0	1	0
6	0	0	0	1	0	36	3	0	0	1	0
7	0	0	0	1	0	37	2	1	1	0	0
8	0	0	1	0	0	38	3	0	1	0	0
9	0	1	0	0	0	39	3	1	0	0	0
10	1	0	0	0	0	40	4	0	0	0	0
11	1	0	0	0	0	41	3	0	1	0	1
12	1[3]	0	0	0	0	42	3	1	0	0	1
13	1	0	0	0	1	43	4	0	0	0	1
14	0	0	1	1	0	44	3	0	1	1	0
15	0	1	0	1	0	45	3	1	0	1	0
16	1	0	0	1	0	46	4	0	0	1	0
17	0	1	1	0	0	47	3	1	1	0	0
18	1	0	1	0	0	48	4	0	1	0	0
19	1	1	0	0	0	49	4	1	0	0	0
20	2	0	0	0	0	50	5	0	0	0	0
21	1	0	1	0	1	51	4	0	1	0	1
22	1	0	0	2	0	52	4	1	0	0	1
23	2	0	0	0	1	53	5	0	0	0	1
24	0	2	0	1	0	54	4	0	1	1	0
25	1	1	0	1	0	55	4	1	0	1	0
26	2	0	0	1	0	56	5	0	0	1	0
27	0	2	0	1	1	57	4	1	1	0	0
28	1	1	0	1	1	58	5	0	1	0	0
29	2	1	0	0	0	59	5	1	0	0	0
30	3	0	0	0	0	60	6	0	0	0	0

[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.

[3] The desired bucking strategy, for example, a merchantable stem of 48 feet would buck into one 40 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:

DFSIM

Simulation Number	Stand Age	Avg. DBH	Trees Per Acre	d/D Ratio
1-8	30	11.2	296	1.0

ROWTHIN

Simulation Number	Stand Age	Avg. DBH	Trees Per Acre	d/D Ratio	Random Seed
1	30	11.2	296	1.0	48275
2	30	11.2	296	1.0	53985
3	30	11.2	296	1.0	48275
4	30	11.2	296	1.0	53985
5	30	11.2	296	1.0	48275
6	30	11.2	296	1.0	53985
7	30	11.2	296	1.0	49275
8	30	11.2	296	1.0	53985