AN ABSTRACT OF THE THESIS OF

Susan Ernst for the degree of Master of Science

in Forest Management presented on August 10, 1981.

Title: Volume and Value Equations for Young-Growth Red, White, and Grand Fir

Abstract approved: Signature redacted for privacy.

David W. Hann

Both public agencies and private industry are concerned with how timber is appraised for sale. An important part of the appraisal is estimating the lumber volume and value of standing timber. A system which accurately estimates the volume and value of young-growth true fir is needed.

This study uses existing data on three true fir species (red fir; *Abies magnifica* var. *shastensis* Lemm., white fir; *Abies concolor* (Dougl.)Lindl., and grand fir; *Abies grandis* (Gord. and Glend.)Lindl.) in northern California, southern Oregon, and Idaho to

develop equations which predict lumber volume and value. Lumber volume was originally separated into gross volume, defective volume, and recovery. Defective volume could not be modeled with the information available. Recovery and gross volume were modeled separately.

Two methods were used to model lumber value, the first predicted the volume of lumber found in each of three grades, and the second predicted an indexed value developed from the relative prices of the three grades.

The final equations which accurately predict lumber volume and value for both mill specific and non-mill specific users are given. Accuracy and bias statistics are also shown from testing on an independent data set.

Volume and Value Equations for Young-growth
Red, White, and Grand Fir

by

Susan Ernst

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed August 10, 1981

Commencement June 1982

APPROVED:

Signature redacted for privacy.

Assistant Professor of Forest Management in charge of major

Signature redacted for privacy.

Head of Department (Forest Management)

Signature redacted for privacy.

Dean of Graduate School

Date thesis is presented August 10, 1981

Typed by Susan Ernst for Susan Ernst

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

VOLUME AND VALUE EQUATIONS FOR YOUNG-GROWTH RED, WHITE, AND GRAND FIR

INTRODUCTION

True fir species make up approximately 13 percent of the commercial sawtimber volume in the west and over half of this volume is found in trees less than 29 inches diameter at breast height (D)(USDA Forest Service, 1977). The log grading system currently being used for appraisal and inventory purposes for true firs was developed from recovery information on old-growth timber (Wise and May, 1958). Because young-growth timber is generally smaller in size and less defective, this grading system does not adequately measure the value and volume of the young-growth resource.

Both public agencies and forest industry are concerned with how timber is appraised for sale. An important part of the appraisal is to determine the lumber selling value of the trees in order to estimate stumpage prices. Equations are used instead of discrete log grades since equations are easier and simpler to apply.

The objective of this study is to develop a system of equations which accurately predicts lumber volume and value recovery from standing young-growth true fir timber.

PROBLEM OVERVIEW

Past Work

Lane et al. (1970), Snellgrove et al. (1973), Plank and Snellgrove (1978) and Fahey (1980) have addressed the problem of accurately estimating the volume and value of a variety of species in the past. Their basic approach has been to develop two multiple regressions, one to predict the volume of the lumber recovered and one to predict the value of the lumber recovered. Lane et al. (1970) also predicted the amount of standard and better lumber recovered from each sample tree. Independent variables in these volume equations were separated into groups relating to gross volume (transformations of D and total tree height (H)) and defect (both scale deductions and surface indicators). Independent variables relating to quality (limb and knot size along with the number of clear faces) were also used in the value equations. Variables for each equation can be found in table 1. Stepwise and all possible combination screening procedures were used to select variables for these equations. The model with the lowest mean square residual and the highest r^2 was chosen. Residual plots were also checked for abnormalities and trends.

Table 1. Past volume and value equations.

Lane et al. (1970)

Volume or Value = B_0 - B_1 Basal Scar - B_2 H - B_3 Largest limb in the butt 16' -

B_4 D - B_5 % defect - B_6 D^2 + B_7 % defect^2 + B_8 DH + B_9 D^2H

Snellgrove et al. (1973)

Volume or Value = B_0 - B_1 % defect * D^2H + B_2 D - B_3 H +

B_4 Height to the first live limb - B_5 Largest limb in the butt 16' * D^2H -

B_6 number of limb and defect free faces in the butt 16' - B_7 % defect^2 * D^2H -

B_8 D^2 + B_9 $(H/D)^2$ + B_{10} D^2H

Plank and Snellgrove (1978)

Volume = B_0 + B_1 % defect * D^2H + B_2 Number of clear faces - B_3 H - B_4 D^2 -

B_5 % defect * D^2H + B_6 H^2 + B_7 H/D + B_8 $(H/D)^2$ + B_9 D^2H

Value = B_0 + B_1 % defect * D^2H + B_2 Number of clear faces - B_3 D - B_4 H -

B_5 % defect * D^2H + B_6 D^2 + B_7 H/D + B_8 D^2H

Fahey (1980)

Volume = B_0 + B_1 D^2H - B_2 D - B_3 H - B_4 Basal scar * D^2H -

B_5 %defect * D^2H - B_6 Crown ratio * D^2H - B_7 Taper * D^2H

Value = B_0 + B_1 D^2H - B_2 D - B_3 H - B_4 Basal scar * D^2H -

B_5 % defect * D^2H - B_6 Crown ratio * D^2H - B_7 Taper * D^2H - B_8 Knot size * D^2H

Volume related variables are: D, D^2, H, H^2, DH, D/H, $(D/H)^2$, D^2H, Crown ratio, and taper

Defect related variables are: % defect * D^2H, % defect^2 * D^2H, Basal scar length, and square root of basal scar length.

Quality related variables are: Largest limb in the butt 16', Number of limb and defect free faces in the butt 16', Height to the first live limb.

Since all of these equations have several independent variables which contain D and/or H, a high degree of multicollinearity can be expected. Because correlation between the independent variables can cause some of them to be statistically insignificant by themselves, stepwise screening techniques can lead to incorrect model forms. All the equations were transformed by $1/(D^2H)$ to equalize the variance, this is analogous to weighting each observation by $1/(D^2H)^2$. Underspecification of the model may also be a problem since mill and location differences were ignored by Lane et al. (1970), Plank and Snellgrove (1978) and, Fahey (1980).

Current Work

The basic approach in this paper is similar to past work in that two general models were developed, one for volume and one for value. Unlike past approaches, gross volume, defect volume, and recovery will be modeled independently and then combined to predict lumber volume in the following fashion:

Lumber Volume = (Gross Volume) * (1- Defect) * Recovery

Gross Volume = f(D, H)

Defect Volume = proportion of gross volume which cannot be cut into lumber because of defects

= f(D, surface indicators)

Recovery = proportion of net volume recovered in lumber

= f(D, H)

This approach will be used to assure proper model behavior for gross volume, defect volume, and recovery, both within and outside the data range. This approach should also reduce the negative effects of multicollinearity and separate milling differences from volume differences along with providing information not only on lumber volume but also on gross volume, defect volume, and recovery. Lumber volume will be predicted in cubic feet and then converted to board feet using a board foot/cubic foot lumber ratio.

Tree value will be predicted by first predicting the volume of lumber produced in each of four grades and then summing the dollar value of the volume for each of the four grades. Or alternatively, a relative index of lumber grade prices will be developed and predicted using measurable independent variables. The basic models are:

Model 1: $\text{Value} = \sum_i (\text{Volume by grade}_i) * (\text{Value per grade}_i)$

$\text{Volume by grade}_i = f(D, \text{surface defect and quality indicators})$

$\text{Value per grade}_i =$ current value, in dollars of the i^{th} grade

Model 2: $\text{Value} = f(D, H, \text{surface defect and quality indicators})$

Gross volumes will be modeled separately for each species and/or mill type and tested using covariance techniques to see if models can be combined. Recovery, defect, and value models will be developed on each mill/species group and then a common model will be developed on all the data to provide the non-mill specific user with a predictive tool.

DATA

The data used in this project came from existing information on file with the Timber Quality Research Project, Pacific Northwest Forest and Range Experiment Station, Portland, OR. The data (table 2) are from four lumber recovery studies which have been conducted over the past ten years. These studies cover three true fir species (red fir; *Abies magnifica* var. *shastensis* Lemm., white fir; *Abies concolor* (Dougl.)Lindl., and grand fir; *Abies grandis* (Gord. and Glend.)Lindl.), three mill types (band, chip-n-saw, and quad-band), and two general locations (inland and coastal regions). The data were collected on all four studies in approximately the same way, trees were selected, diagramed, scaled, milled and the lumber was dried, planed, and graded.

Table 2. Summary of data available.

	Number of Trees		
	White Fir	Red Fir	Grand Fir
Martell, CA	55	0	0
Medford, OR	48	0	0
Burney, CA	275	65	0
Grangeville, ID	0	0	50

Field Work

The timber samples were selected from even-aged stands less than 140 years old (determined by increment boring) using a stratified sampling technique. Stratification was based on D (tree diameter outside bark at four and a half feet above ground on the uphill side of the tree) which ranged from six to thirty inches due to limitations of mill equipment. Presence of defect, the other basis for stratification, was determined by examination of the surface characteristics and physical condition of the first sixteen feet of the stem with a one foot stump and trim allowance. The sample was not selected to represent the current commercial mix of tree sizes and quality, instead it was chosen to be representative of available sizes and quality and to provide a base for predicting volume and value of similar trees.[1/] It was assumed that the commercial mix would be a subsample of the total sample. Industry personnel were invited to participate in selection and to examine the whole sample to make sure that it was "typical".

[1/] Pong, W. Y. Work Plan for a Young-Growth True Fir Recovery Study in the Southern Cascade Range of northern California. Project Study 31-01.

The first 16 feet of the standing trees were diagramed (Jackson et al., 1967; Pong and Jackson, 1972) for surface characteristics on specially designed diagraming forms (Appendix I). Information on the stem, crown, and environmental condition of each tree was also recorded. Additional stem characteristics were recorded after falling.

Falling of the trees was done according to normal industry practices in the area. Trees were bucked into log lengths according to mill specifications. All logs were tagged for identification by PNW personnel. All logs less than 25 percent sound or less than eight feet long were left in the woods.

Before sending the logs into the mill, check scalers for the U. S. Forest Service segment scaled the logs according to region procedures. Industry personnel were also given an opportunity to scale the logs at this time. After bucking, a short log scale was done by Forest Service check scalers on the mill length logs. Large and small end diameters were recorded for all logs.

Mill Work

A detailed description of the equipment used in each mill can be found in the Appendix II. A system of color coding and numbering was used in the mill to keep track of the output of each log. At the green chain, boards were graded, stamped sequentially, and photo tallied. A sample of rough green board thickness and widths were also taken at that point. Association grade inspectors supervised the grading of lumber on the green chain and all lumber was graded according to the National Forest Products Association Grading rules for dimension lumber.

Study lumber was dried according to schedules normally used by the mill for drying true fir lumber. Again a paint and numbering system was used to keep track of the lumber as it was planed. Hand, photo, and voice tallies were used on the infeed, and hand and photo tallies were used on the outfeed to record grade, length, width, and thickness of the surfaced dry lumber.

Several problems exist in the data, mainly due to trying to combine the four studies. First, since the studies were done over a ten year time span utilization standards have changed (i.e., in the first study, trees were harvested down to ten inches D and bucked to an eight inch top and while in the last study trees were harvested down to an eight inch D and a six inch top). Along with this, defect scaling has changed from Scribner scale to cubic scale with only the Scribner scale consistent throughout all studies.

Sample size is also a problem for screening variables and fitting models since one sample is nearly five times as large as the other four.

Validation Sample

A 20% sample of trees was set aside for model validation purposes. The trees in each study were ordered by D and a 20% systematic sample of each study was taken.

DATA ANALYSIS AND RESULTS

Gross Volume

Past Work

Historically, four approaches have been used to model total stem volume. These approaches vary not only in the form of the dependent and independent variables but also in the weights assigned to each observation. The first approach uses total stem volume as the dependent variable, various transformation of D and H for independent variables (with D^2H being the most common (Husch, 1963)), and a constant weight of one. The major problem with this approach is that the residuals have always been found to be heteroskedastic, indicating that a constant weight of one is inappropriate (Cunia, 1964). As a result the parameter estimates are not the best linear unbiased estimates.

The second approach uses the logarithm of total stem volume as the dependent variable, the logarithm of D and H for independent variables, and a constant weight of one. Wensel (1977) used this method in his work on red and white fir (and other species) of northern California. The advantage of this approach is that the resulting residuals are homogeneous (Furnival 1961). The major disadvantage is that the parameter estimations are biased because the model is fitted through the geometric rather than the arithmetic mean (Baskerville, 1972).

The third approach uses the total stem volume as the dependent variable with $1/(D^2H)^2$ as a weight for each observation. Independent variables are similar to the ones used in the first approach. Allen et al. (1974) used this model for small grand fir (and other species) of northern Idaho. This method also homogenizes the residuals and provides best linear unbiased estimates of parameters (Cunia, 1964; Furnival, 1961).

The final approach produces parameter estimates that are identical to those found in the third approach. The dependent variable is total stem volume divided by D^2H with a constant weight of one. Independent variables include a wide array of transformations of D and H. MacLean and Berger (1976) used this approach for red and white fir in California. The indices of fit from this approach are incorrect (Buse', 1973).

Table 3 summarizes a number of independent variables used for gross volume prediction. Several applications have used three or more independent variables, all transformations of D and H, but no one has discussed the problems of multicollinearity.

Table 3. Independent variables used to predict volume using transformed or weighted approaches.

Independent Variables	Reference
D^2H	Allen et al. (1974) MacLean and Berger (1976) Bruce and DeMars (1974) Furnival (1961), Cunia (1964)
DH^3, D^2, $1/H$, H^2/D, H/D	MacLean and Berger (1976)
D^2/H, D^3/H, D^3, D^3H	Bruce and DeMars (1974)

Current Work

The gross cubic volume less stump of each tree was calculated from long log or woods length measurements using Bruce's Butt log formula (Bruce in process for Forest Science)[2/] on all butt logs, Smalian's formula (Husch 1963)[3/] on all other logs, and a conical formula[4/] on all tops.

The six equations in table 4 were chosen for testing because they have been successfully used on young-growth red, white, and grand fir.

2/ $Vol = .005454 * (.25D_s^2 + .75D_l^2) * L$

where D_s = small end diameter, D_l = large end diameter, and L = log or top length.

3/ $Vol = .005454 * ((D_l^2 + D_s^2)/2) * L$

4/ $Vol = .005454 * D_l^2H/3 * L$

Table 4. Gross volume model forms for young-growth white, red, and grand fir.

Equation	Weight	Citation
1) $VOL/D^2H = B_0 + B_1(1/H) + B_2(H^2/D)$	1	MacLean & Berger (1976)
2) $VOL/D^2H = B_0 + B_1(H/D)$	1	MacLean & Berger (1976)
3) $VOL/D^2H = B_0 + B_1(1/H^2) + B_2(D/H^2) + B_3(D/H) + B_4(D)$	1	Bruce & DeMars (1974)
4) $VOL = B_0 + B_1D^2H$	1	Husch (1968)
5) $\ln(VOL) = B_0 + B_1\ln(D) + B_2\ln(H)$	1	Wensel (1977)
6) $VOL = B_0 + B_1D^2H$	$1/(D^2H)^2$	Allen et al. (1974)

After the validation sample was removed, regression coefficients were estimated on each data group for each of the six models using the linear least squares regression package SPSS (Nie et al., 1975). The four models (1,2,3,6) with similar dependent variables were compared using mean square residuals (MSR). Table 5 shows the MSR's for each mill/species group for these four models. Visual inspection shows that Model 3 had the lowest MSR in four out of five data groups, but Model 1 had equally as low MSRs in two groups and lower in the other. The differences in MSRs between models among groups were small enough enough that it was felt that one model form could be used equally well for all data sources.

Table 5. Mean square residuals for Models 1,2,3 and 6

Mill/species	Model Number 1	2	3	6
Burney/White	.00024*	.00025	.00024*	.00025
Burney/red	.00020	.00022	.00019*	.00020
Medford/white	.00018*	.00018*	.00019	.00018*
Martell/white	.00025*	.00026	.00025*	.00029
Grangeville/grand	.00024	.00024	.00022*	.00025

*Lowest MSR for each mill/species group.

The two best overall transformed models were then compared to the logarithmic and untransformed models using Furnival's Index (Furnival,1971). Table 6 lists Furnival's Index for the logarithmic, untransformed, and two best transformed models for each of the data groups. Visual inspection again shows the transformed models to be the best fitting models throughout the data sets.

Table 6. Furnival's Indicies for transformed, untransformed, and logarithmic model forms.

Mill/Species	Model Number 1	3	4	5
Burney/White	3.93*	3.93*	5.51	9.12
Burney/Red	3.23	3.07*	5.02	7.69
Medford/White	3.52*	3.72	4.13	8.41
Martell/White	6.39*	6.39*	11.17	15.56
Grangeville/Grand	2.93	2.69*	4.31	6.58

*Lowest Furnival's Index for each mill/species group.

Both of the transformed models were tested for multicollinearity using Brex (Mitchell and Hann, 1979). Model 3 with five variables proved to have a high degree of multicollinearity (with a Variance Inflation Factor (VIF) of 130) while Model 1 with only two variables was found to have practically no correlation between the independent variables (with a VIF of 1.8). A normal probability plot of the residuals of Model 1 showed the data to be normally distributed (figure 1). Therefore Model 1 was fitted to each mill/species group and the coefficients are shown in table 7.

Table 7. Coefficients for best fitting gross volume equation for individual mill/species group.

Mill/Species	Number of Observations	Constant	1/H	H^2/D
Grangeville/white	40	.00187	.0216	.000000756
Medford/white	39	.00159	.0274	.000000185
Martell/white	44	.00056	.0490	.00000175
Burney/White	223	.00156	.0029	.0000009
Burney/Red	52	.00216	-.0186	.00000023

Model 1 was then used to test for differences in slopes and intercepts between species/mill data groups. First the three white fir groups were tested, then the combined white fir versus the red fir, and finally the combined red and white fir versus the grand fir. Table 8 contains the F-test values for the comparison of slopes and intercepts.

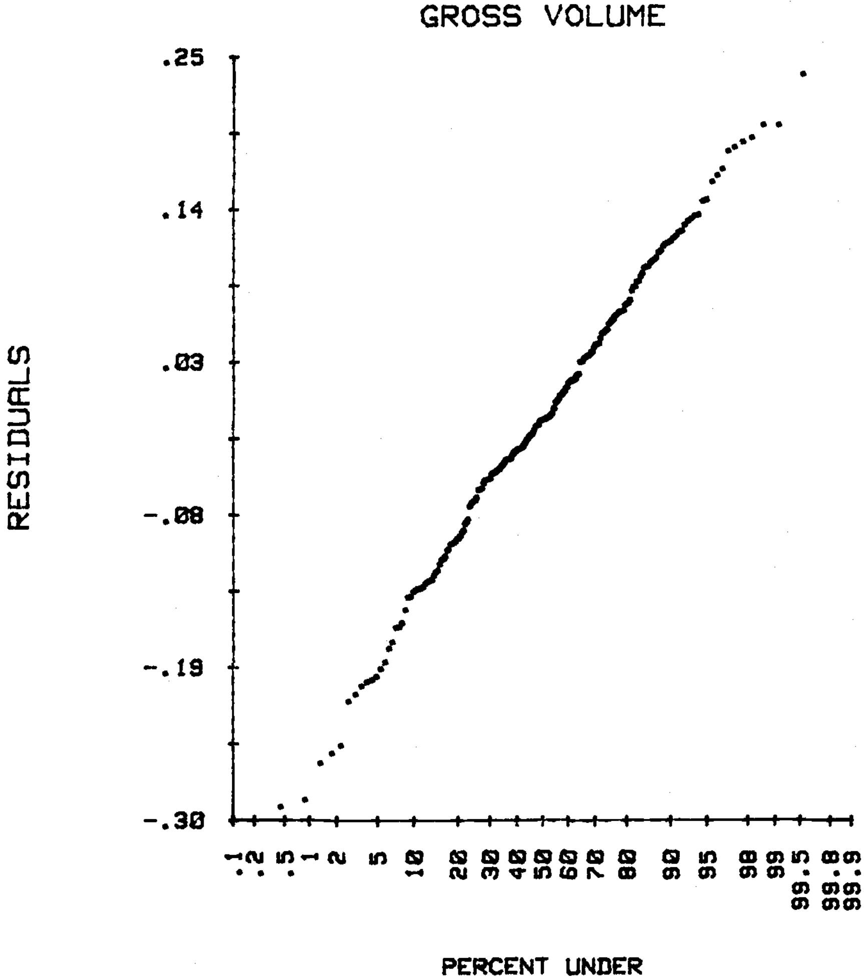


Figure 1. Normal probability plot of residuals from Model 1.

Table 8. F-test values for comparison of slopes and intercepts for combinations of sources.

	Sources Compared					
	All White fir combined		Combined White fir vs. Red fir		Combined White and Red vs. Grand fir	
	F-test	Df	F-test	Df	F-test	Df
Slopes	1.84	304	1.42	357	.81	396
Intercepts	1.97	306	1.20	358	151.50	397

The significant F-value at the .05 level for 250 observations is 3.03.

No significant differences were found between the white fir and red fir equations. But a statistically significant difference was found in the intercepts between the red and white fir combined equation and the grand fir equation. Due to the nature of the samples it is impossible to know if this difference is due to species or location since the grand fir sample was the only one outside of the coastal region of southern Oregon and northern California.

The final gross volumes are estimated using one equation for the red and white fir in the coastal region and one equation for grand fir in the inland region of Idaho. The final gross cubic volume equations are

1)for red and white fir:

$$VOL = D^2H(.00159412 + .0025682(1/H) + .000000811(H^2/D))$$

2)for grand fir:

$$VOL = D^2H(.00187129 + .021574(1/H) + .000000755(H^2/D))$$

Defect

Past Work

In the past defect volumes have been estimated by cruisers or scalers based on scars, conks, and other surface indicators of defect. More recently in an effort to reduce the subjectivity in these estimates, attempts have been made to quantify these surface characteristics in predictive equations. Aho (1974), Aho and Simonski (1975), and Aho and Roth (1978) have produced several regression equations which use the presence or absence of surface defect indicators to predict cubic and Scribner board foot percent deductions. They used the all possible combinations procedure to screen 11 independent variables and found the presence or absence of forks, crook, dead tops, trunk injuries, cankers, basal injuries, frost cracks, Indian paint fungus (Echinodontium tinctorium (ET)), and D to be statistically significant. Unfortunately these equations for red, white and grand fir have been developed mainly for old-growth trees, in specific areas, and generally in areas with ET which was not found in any of the sample areas. The equations also cannot predict if the defect volume will actually affect the volume of lumber produced.

Barger and Ffolliott (1970) used the model: percent correction to gross volume is equal to the percent occurrence of defect multiplied by the percent scaling deduction, where the percent scaling deductions were predetermined. Hann and Bare (1978) used a similar approach to predict the average cull proportion for a tree of given characteristics. Their model is the average proportion cull is equal to the probability of cull multiplied by the fraction cull given that the tree has some cull. Nonlinear techniques were used to estimate the probability of cull and linear techniques the fraction cull. Independent variables which were used to estimate the probability of cull were D, H and number of forks and D, H, sweep, forks, and porcupine damage for the fraction cull. Average cull was predicted in both cubic foot and board foot deductions.

Current Work

Since sectioning into short pieces was used in past equations to estimate the volume of defect and trees cannot be sectioned and then sawn, no way exists to directly measure the volume of lumber lost due to defect. Therefore the best available estimate of this volume is a defect scale, either from a scaler or from an equation. The only consistent defect estimate available on all four studies is Scribner scale. Unfortunately, Scribner scale is based on a diagram log rule which uses a sawkerf and shrinkage factor of one-quarter inch, board sizes of one-inch by eight inches or larger, and logs with no taper for diagramming. Since none of these conditions are met in the production of lumber from young-growth true fir, Scribner scale estimates of defect are not highly correlated with the lumber volume actually lost due to defect. Therefore alternative attempts were made to calculate the volume of lumber lost due to defect.

The first attempt to calculate the volume of lumber lost due to defect was to match sound and unsound logs of the same end diameters and length within each study. The volume of lumber produced from the unsound log was then subtracted from that produced from the sound log (or average of sound log matches). These differences were summed for all logs of any given tree. Logs were used instead of trees with the hope that, with a much greater number of logs than trees, more matches would be found. Unfortunately, only 60 of the 119 defective logs had matches of one or more sound logs, and some of the unsound logs produced more lumber than the sound log (or sound log average).

The next approach was to compare the lumber volume of unsound logs to a regression equation which predicted the lumber volume of the sound logs, using both end diameters and the log length as independent variables and Plank and Johnson's (1975) empirical log rule as the model form. Sound log regression equations were estimated for each mill/species group, and butt logs were separated from non-butt logs to further reduce variation.

This method was proposed as a way to eliminate the problem of no matches while keeping the effects of individual surface indicators separate. But the problem of unsound logs producing more lumber than the sound logs was not solved. This problem is mainly due to the use of Scribner scale measurements to separate sound and unsound logs along with natural variation in milling.

Therefore for the purposes of predicting lumber volume, defect will not be modeled separately but it will be included in the recovery equation as additional variation. Fortunately only small rates of defect were found (table 9) so combining defect and recovery is not a serious deviation from the original approach.

Table 9. Scribner scale defect percentages for each mill/species.

Mill/species	Percent Defect
Grangeville/white	1.8
Medford/white	0.7
Martell/white	1.5
Burney/White	1.4
Burney/Red	1.0

Recovery

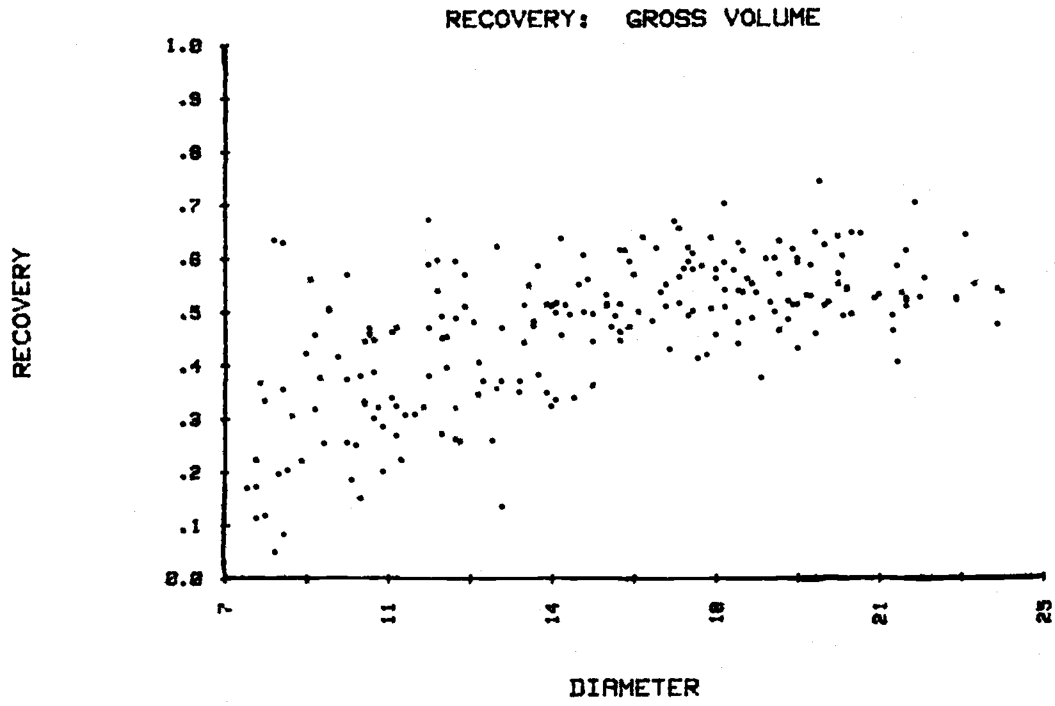
Past Work

Recovery is defined as the cubic volume of lumber which is produced from a cubic foot of wood. The cubic volume of lumber is calculated from rough green dimensions which are width, thickness, and length measurements taken before the lumber is dried and planed. Recovery has been modeled on a tree (Hann and Bare, 1978) and log basis in the past and factors which affect log or tree recovery are mill type and equipment, processing decisions, product sizes, and log or tree characteristics. The specific log characteristics which tend to reduce the recovery are sweep or crook, small end diameters, presence of defect, taper, and bucking length (USDA Forest Service, 1973). Quadratic model forms have been used in the past to predict recovery. The independent variable in these equations has been small end diameter (D_s) for logs or D for trees. For logs, the small end diameter is the most widely used variable because it was the major measurement which was recorded in the mill on the scale record. Most of the equations for recovery were developed on Scribner or some other board foot scale system, and recoveries were usually based on the net scale so defect was not included. Log lengths or H were also not used since they varied only slightly and the whole range of lengths were included in any one small end diameter class. Quadratic model forms were used because recovery has a curvilinear relationship with D_s.

Current Work

In this study recovery was based on gross tree volume in cubic rather than board foot measurements. The recovery for each tree was calculated by dividing the actual lumber volume in cubic feet by the predicted gross volume less stump volume in cubic feet. This ratio was then used as the dependent variable in the recovery equations.

An attempt was made to reduce variation due to the varying top sizes (i.e. six or eight inches) by eliminating the top volumes from gross volumes using merchantable tree volumes from tarif tables. Unfortunately, this increased rather than decreased the variation within the seven to ten inch D range (figure 2). Therefore the original calculation of recovery was used for further analysis.



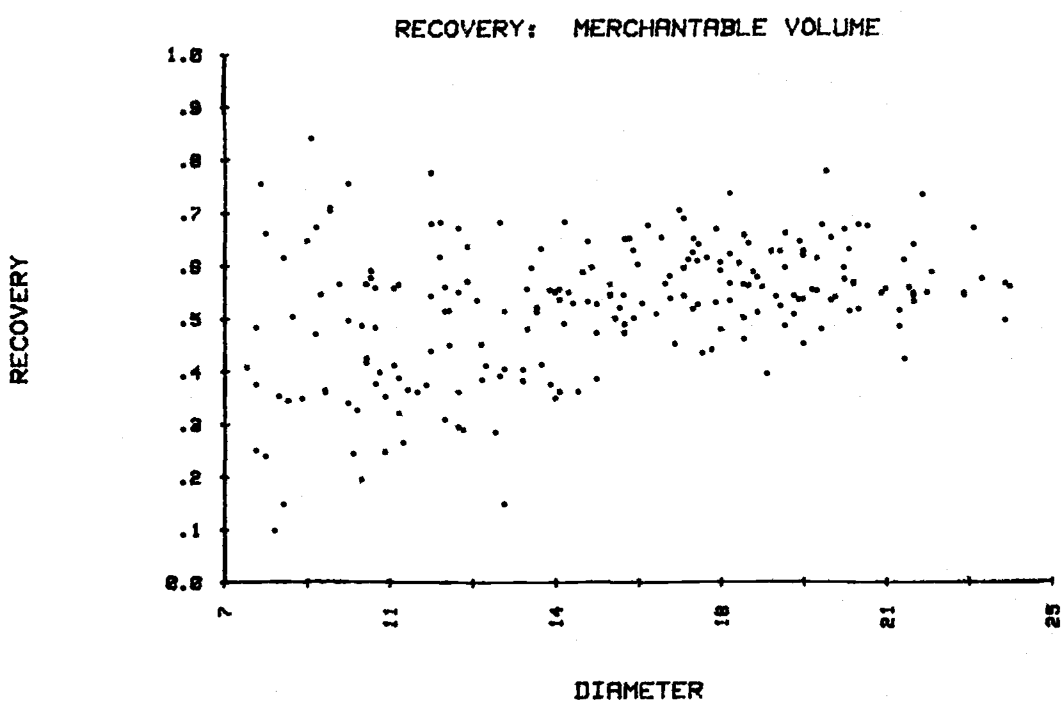


Figure 2. Comparison of recovery based on gross volume and merchantable volume.

Two basic approaches to modeling recovery were tried on each mill/species data group. The first approach was to solve a nonlinear model using the linear all possible combinations REX (Grosenbaugh, 1967). The following nonlinear model was proposed as a way to relate D, H, and the presence or absence of basal scars, lightning scars, frost cracks, conks, and other trunk scars (I) to recovery.

$$\text{Recovery} = B_1 H^{B_2} + B_3 D^{B_4} H^{B_5} + B_6 I\ H^{B_7} + B_8\ I\ \ D^{B_9} H^{B_{10}}$$

The first term $(B_1 H^{B_2})$ and the third term $(B_6 I\ H^{B_7})$ relate height and defect to the asymptote or upper limit of the recovery curve. The second and fourth terms in the model relate height, diameter, and defect to the shape or steepness of the curve. Initial parameter estimates were provided for the exponential parameters $(B_2, B_4, B_5, B_7, B_9, B_{10})$. These estimates covered a range of values (table 10) and the best combination of values within these ranges was chosen by solving the model through all possible combinations regression. Based on this "best combination of values" the ranges for parameter estimates were refined to smaller and smaller intervals until further refinements no longer increased the r^2 and decreased the MSR.

Table 10. Initial parameter ranges.

Parameters	Initial estimates for each parameter
B_4, B_9	0, -1, -2, -3
B_2, B_5, B_7, B_{10}	0, 1, 2, 3

Attempts were made to force not only 1/D and $1/D^2$ into the model but also estimates of B_2, B_4, and B_5 found by fitting the regression to trees with no defect indicators. Neither of these attempts improved upon the fit found by varying all the parameters on all the data in each mill/species group. The final equations for each mill/species group and all the data combines are shown in table 11.

Table 11. Final equations from the non-linear solution.

Mill/species	Equation
Grangeville/grand	REC = .678 - 2.416/D - .00052*I*H/D + .000044*I*H**2
Martell/white	REC = .793 - 22.440/D**1.5 - .0345*I*H**.5 + .00245*I*H**2/D**1.5
Burney/white	REC = .607 - 41.985/D**2.4 -.0860*I - .00000120*I*H/D**2
Burney/red	REC = .610 - 23.980/D**2 -.310*I + .050*I*H/D
All data	REC = .628 - 6.751/D**1.5 - .203*I + .00763*I*H/D**.5

The second approach was to model recovery on each mill/species group with a linear regression using characteristics of the tree as independent variables ($1/D$, $1/D^2$, D, D^2, H/D, H/D^2, crook, and defect indicators). Stepwise regression was used as a screening technique.

Table 12. Final equations from the linear solution.

Grangeville/grand	REC = .706 - 2.973/D + .0330*H/D**2
Martell/white	REC = .295 + 10.047/D - 177.580/D**2 + .0140*I - .0980*Crook + .666*H/D**2
Burney/white	REC = .674 - 1.735/D - 18.950/D**2 - .0550*I + .175*H/D**2
Burney/red	REC = .545 - 31.097/D**2 - .0170*I + .244*H/D**2
All data	REC = .664 - 2.624/D - 13.702/D**2 - .0363*I + .222*H/D**2

The Medford/white data group had no relationship between recovery and any of the tested independent variables, therefore no mill specific recovery equation was developed for that data set.

The best two or three equations from each method of modeling for each of the remaining four mill/species data groups were subjectively compared to see if one common model form could be used for a general recovery equation. Since no general model form could be found in this manner, all the data (including the Medford/white data) was combined and a general model form was developed for each of the two modeling approaches. While this does provide the non-mill specific user with a recovery equation it should be cautioned that this equation may be underspecified, more biased and inaccurate, and it may not fit all the mills equally. The best model for each of the mill/species groups and for the overall data was chosen by comparing r^2 and MSR values (table 13).

Table 13. Statistics on all final recovery equations.

Mill/species		r^2	MSE
Grangeville/grand	Linear	.578	45.6
	Nonlinear*	.632	39.8
Martell/white	Linear*	.600	71.5
	Nonlinear	.550	80.6
Burney/white	Linear*	.462	103.9
	Nonlinear	.459	104.1
Burney/red	Linear	.410	93.8
	Nonlinear*	.467	84.3
All data	Linear	.355	105.9
	Nonlinear*	.358	105.2

*Indicates the final equation for each data group.

Testing for normality was done through a normal probability plot (figure 3). The final equation for Martell/white has a positive coefficient on the defect indicator variable, this occurs because that mill was cutting dunnage from the defective material during the mill study. Dunnage is material in the form of cants used for securing cargo in ship holds. All of the equations had positive coefficients on the taper variables where taper was expressed as a height over diameter squared. This is because the highly tapered logs produced less lumber than more even logs.

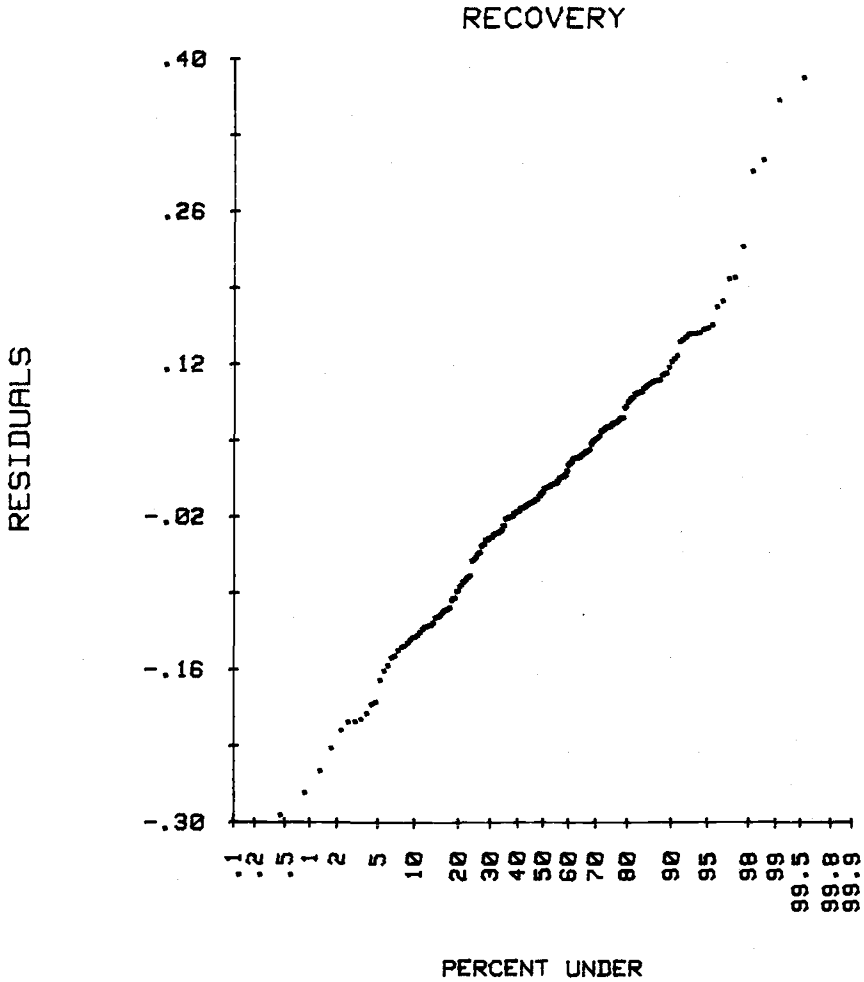


Figure 3. Normal probability plot of residuals from the general recovery equation.

Lumber Volume

The original model for predicting lumber volume was:

Lumber Volume = (Gross volume) * (1 - Defect) * Recovery.

This was reduced to the model:

Lumber Volume = Gross volume * Recovery

due to the problems of calculating a dependent variable for defect. Since both gross volume and recovery have been predicted separately, they were multiplied together to predict the lumber volume. The product of gross volume and recovery was regressed against the actual lumber volume and the regression was forced through the origin to provide a final correction factor for any bias that may have occured in the estimate of lumber volume. The final volume equation was transformed by $1/(D^2H)$ to equalize the variance. The final parameter estimates for the correction factors are shown in table 14. The coefficient for the Medford/white data set represents the average recovery over the diameter range for that mill/species group.

Table 14. Final coefficients for lumber volume (cubic) where:
Lumber Volume = B_0 * gross vol * recovery.

Mill/species	B_0
Grangeville/grand	1.0103
Martell/white	1.0157
Medford/white*	.5030
Burney/white	.9897
Burney/red	1.0198
All data	1.0075

*Indicates that no recovery equation was used.

Board foot/Cubic foot

Next board foot/cubic foot of lumber ratios (Fahey and Woodfin, 1976) were estimated for each mill/species group and for all the data combined to enable the user to convert the cubic feet of rough green lumber to board feet of finished lumber. This ratio can also be estimated in any other mill by calculating the ratio of the rough green cubic volume of lumber (actual sizes) and the surface dry board foot of lumber (nominal sizes). The ratios for each mill/species and all data are given in table 15. These ratios are constants instead of functions because graphs showed the ratios to be stable over diameter.

Table 15. Board foot/cubic foot ratios.*

Mill/species	Ratio
Grangeville/grand	13.512
Martell/white	13.713
Medford/white	12.620
Burney/white	14.103
Burney/red	14.034
All data	13.844

*Note: One board foot of lumber in nominal sizes could be expressed as 1" by 12" by 1' which in actual sizes is .75" by 11.5" by 1'. In this example the board foot per cubic foot ratio would be $1/(.75*11.5/144) = 16.842$.

Value

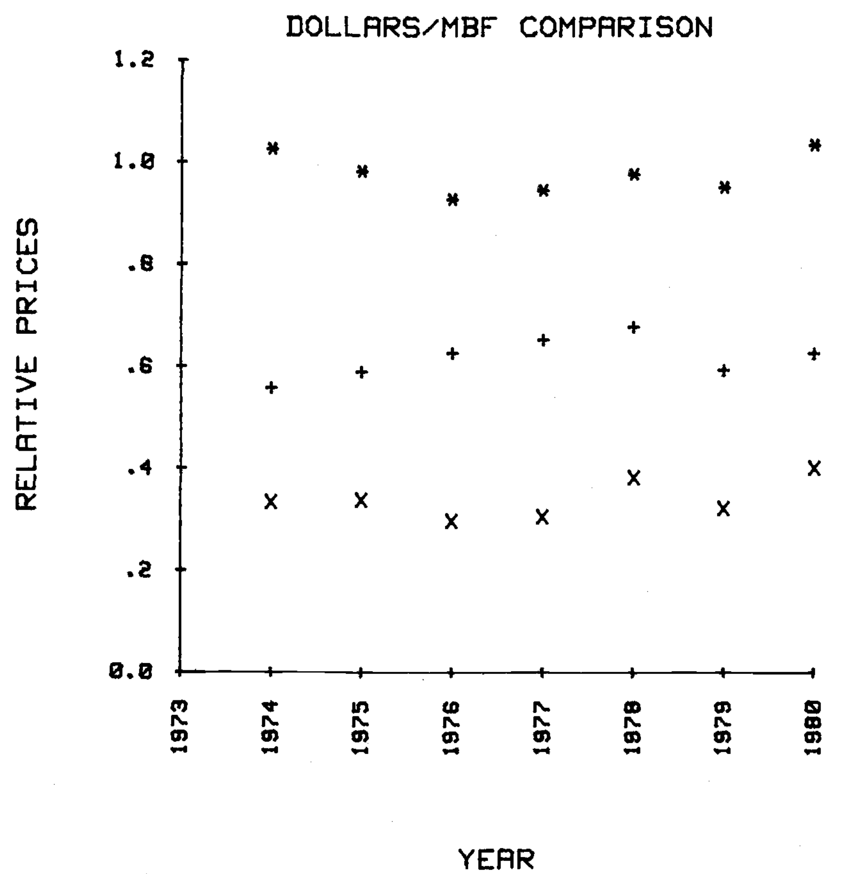
Past Work

Historically, softwood lumber value has been predicted by summing the dollar value of all the lumber produced from a tree and predicting that value using volume and quality related independent variables (table 1). The problem with these value equations have been that the prices are built into the equation coefficients and when prices change these coefficients must be re-estimated. To avoid this problem, attempts were made to predict separate lumber grades (Plank and Snellgrove, 1976) but with little success. Strub (1980) used the logistic function to predict the volume of studs in each of three grades. Hardwood lumber volumes have been successfully separated into volume by grade. Hanks (1976) developed systems of equations for a variety of hardwood species using D^2, H, and D^2H in various combinations as independent variables. Marden (1965) proposed equations with 15 or so independent variables to predict volumes which were calculated in non-production settings. Hardwood lumber is graded on the basis of the number and size of clear cuttings while softwood lumber is graded on the basis of strength properties using knot size and location as indicators of strength, along with manufacturing defects such as raised grain, etc. Therefore it may be harder to separate softwood grades than hardwood grades.

Current Work

The first approach to modeling value was to predict the board foot volume of surfaced dry lumber found in each lumber grade. The volumes in each grade could then be multiplied by the appropriate dollars per thousand board feet ($/MBF) and summed to equal the total value of each tree. Several grades of lumber were produced by the mills, but only four are actually used to sell lumber, the additional grades were recorded only for the studies and are not generally used. A comparison of the values in $/MBF for each of the remaining four grades showed two of the four to be approximately the same over the last seven years. This comparison was done by indexing all the $/MBF by the value of the highest grade (Standard and Better) for each of the seven years. The results of this comparison are shown in figure 4. Based on this comparison, the volumes of the top two grades were combined. This left only three grades of lumber; Standard and Better (which includes the Common grades), Utility, and Economy.

The volume by grade approaches in the past have all predicted the actual volumes without forcing these volumes to sum to the total volume of lumber produced. In this study, the variation within grades is greater than the variation around the total lumber volume so it was felt that for accurate value estimation, the volumes by grade should be forced to sum to the total lumber volume. Therefore



* Common
\+ Utility
x Economy

Figure 4. Comparison of relative prices of Common, Utility, and Economy lumber grades to the price of Standard and better over the past 7 years.

the volumes by grade will be put on a proportional basis so they sum to one and are not greater than or less than the total lumber volume. They were also made cumulative, i.e. the proportion of volume of Utility is found by subtracting the proportion of volume of Standard and Better (Std and Btr) from the proportion of volume of Utility and Better (Util and Btr). This way the volume in only two grades has to be predicted, the volume in the third grade is found by subtracting the volume in the first two from 1.0.

The logistic function was used to model the proportional volumes in Std and Btr and Util and Btr because it can be constrained between 0 and 1, the natural limits of the proportional volumes. Taper, D^2, I, and the size of the largest limb in the butt sixteen feet (K) were screened as independent variables using the likelihood ratio estimator (Gallant, 1975) to test the hypothesis that the coefficients are not zero. None of the variable coefficients proved to be significantly different from zero for three of the data groups. For the Burney/white and Burney/red data sets and all the data combined, D^2 was significant. Table 16 lists the average proportional volumes by grade and the nonlinear equation parameters.

Table 16. Nonlinear parameter estimates and average proportional volumes.

	Std and Btr	Util and Btr	Econ and Btr
Grangeville/grand	.857	.886	1.0
Martell/white	.713	.793	1.0
Medford/white	.780	.848	1.0

Burney/white Std and Btr = $1.0/(1.0 + e^{(-(.317 + .00151*D**2))})$

Util and Btr = $1.0/(1.0 + e^{(-(1.295 + .00314*D**2))})$

Burney/red Std and Btr = $1.0/(1.0 + e^{(-(.203 + .00250*D**2))})$

Util and Btr = $1.0/(1.0 + e^{(-(1.146 + .00508*D**2))})$

All data Std and Btr = $1.0/(1.0 + e^{(-(.574 + .00137*D**2))})$

Util and Btr = $1.0/(1.0 + e^{(-(1.532 + .00355*D**2))})$

The second approach to modeling value was to calculate an indexed dependent variable for value. The indexed value was found by multiplying the volume of lumber in each grade by its average relative price and then summing the volume by grade times the relative prices. The average relative price over the seven year time span was .6188 for Utility and .3319 for Economy. This provides an estimate which only has to multiplied by the current price of Standard and Better to obtain the current value of the tree. Stepwise linear regression was then used to test predicted lumber volume, knot size, defect, and taper as independent variables. Only lumber volume was significant in any of the data groups and $1/(D^2H)^2$ was used as a weight to equalize the variance. Table 17 shows the coefficients for the indexed value equations.

Table 17. Coefficients for the linear indexed value equation: Indexed Value = $B_0 + B_1$ Lumber volume (Bd Ft).

Mill/species	B_0	B_1
Grangeville/grand	-2.350	.956
Martell/white	-3.318	.860
Medford/white	2.368	.903
Burney/white	-3.201	.854
Burney/red	-6.989	.872
All data	-4.081	.874

The first and second equations were compared on the original data sets using bias (measured by the average residual (R)) and accuracy (measured by the MSR) as criteria. The specific first approach equations were compared to specific second approach equations for Burney/white and Burney/red (table 18). These specific first approach equations were more biased and less accurate than the corresponding second equations. The general first and second equations were also compared across all data groups (table 19). Again the first approach equation was less accurate than the second equation in all five data groups, and it was also more biased in four out of five of the groups.

Table 18. Bias and Accuracy statistics for Burney/white and Burney/red by modeling approach for the mill/species specific equations.

Mill/species	Approach	R	MSR
Burney/white	First	-13.410	4044.6
	Second	.013	3612.4
Burney/red	First	-1.36	1899.9
	Second	.031	1762.9

Table 19. Bias and Accuracy statistics by mill, species, and modeling approach for the general equations.

Mill/species	Approach	R	MSR
Grangeville/grand	First	43.8	3923.8
	Second	40.6	1385.1
Martell/white	First	-87.4	28198.4
	Second	-56.4	6272.7
Medford/white	First	-29.6	6465.9
	Second	-23.9	2976.8
Burney/white	First	10.9	3933.2
	Second	4.3	3783.5
Burney/red	First	-14.5	2236.4
	Second	-10.7	1785.5
All data	First	-7.9	6647.7
	Second	-0.012	4901.4

Prediction of volume in each grade was not expected to produce good results, this is mainly due to the way lumber is graded. Dimension lumber (two-inch thickness) is graded on strength properties characterized by knot size in relation to board width, the number of knots within certain size classes which again depend on the board width, location of the knots on the board surface, soft rots, spiked knots, etc. The other major grade deductions are for raised grain, torn or chipped grain, and other manufacturing defects, which cannot be predicted for the surface characteristics which were measured in these four studies. Boards (one-inch lumber), on the other hand are graded for appearance rather than strength properties. The final difficulty in predicting volumes by grade has to do with the individual mill markets. Any given mill will cut a slightly different mix of lumber products and grades from the same quality logs depending on its orders. Also the chip market has a definite influence on the production of low quality lumber, if the chip market exists, it may be more profitable for the mill to chip low quality material than to dry and plane it.

VALIDATION

Validation involves testing the accuracy of the estimated models and parameters on an independent data set (table 20), one which was not used to estimate parameters.

Table 20. Summary of validation data available.

	Number of Trees		
	White Fir	Red Fir	Grand Fir
Martell, CA	10	0	0
Medford, OR	9	0	0
Burney, CA	52	14	0
Grangeville, ID	0	0	9

No statistical test is available but various statistics can be calculated which reflect the bias and precision of the model. Among these statistics are the average residual which estimates the magnitude and direction of the bias and the mean square residual which estimates accuracy (a combination of precision and bias). These statistics were calculated for the lumber volume models (specific and general) and the lumber value first and second approach models.

The average residual or average bias per tree for cubic foot predictions of lumber volume ranged from -6.225 to .751 cubic feet. The mill specific equations were generally less biased and more accurate than the general equation. In absolute terms the accuracy of both the general and specific equations was approximately the same.

The average residual for the prediction of indexed lumber value ranged from -26.66 to 31.96 board feet of Standard and Better lumber. Overall the specific equations were less biased than the general equations and generally more accurate. The specific equations (both approaches) for Burney/white and Burney/red were more accurate and less biased than the corresponding general equations.

The statistics for accuracy (mean square residual) and bias (average residual) for both lumber volume and lumber value are presented in tables 21 and 22, respectively.

A comparison of the past volume and value equations by Lane et al. (1970), Snellgrove et al. (1973), and Plank and Snellgrove (1978) with the current general volume and value equations are presented in table 23.

Table 21. Validation of Lumber Volume (in cubic feet) prediction system by mill, species, and equation type.

Mill/species		R	MSR
Grangeville/grand	(s)*	-.441	4.39
	(g)**	.751	4.46
Martell/white	(s)	-3.190	136.04
	(g)	-6.225	164.84
Medford/white	(s)	-.810	15.21
	(g)	-.817	15.27
Burney/white	(s)	-.244	24.02
	(g)	.680	23.87
Burney/red	(s)	-1.560	15.69
	(g)	-.818	13.35
All data		-.383	34.86

*(s) = specific equation
**(g) = general equation

Table 22. Validation for Lumber Value prediction system by mill, species, and equation type.

Mill/species	model type	R	MSR
Grangeville/grand	Second (s)*	-.11	836.6
	Second (g)**	26.87	1656.2
	First (s)	31.96	2110.4
Martell/white	Second (s)	13.43	3016.3
	Second (g)	-27.45	4244.8
	First(g)	-21.28	3689.1
Medford/white	Second (s)	13.96	1375.7
	Second (g)	13.46	3025.0
	First (g)	20.39	1655.5
Burney/white	Second (s)	8.49	4290.9
	Second (g)	27.36	5250.5
	First (s)	-3.60	4367.9
	First (g)	30.53	5513.1
Burney/red	Second (s)	7.11	716.3
	Second (g)	-14.19	1928.4
	First (s)	-26.66	815.6
	First (g)	-19.13	1898.6
All data	Second	15.34	6081.1
	first	19.54	6494.2

*(s) = specific equation
**(g) = general equation

Table 23. Comparison of past volume and value equations using estimated minus actual divided by actual.

Reference	Volume/Value	% error	# of trees
Lane et al. (1970)	Value	5.7	168
	Value	-4.6	45
	Value	1.0	158
Snellgrove et al.(1973)	Value	-6.5	99
	Volume	-2.7	99
Plank and Snellgrove (1978)	Value	-2.7	100
	Volume	.9	100
Current Study (general linear equations)	Value	-3.3	94
	Volume	1.7	94

SUMMARY

Lane et al. (1970), Snellgrove et al. (1973), Plank and Snellgrove (1978) and Fahey (1980) have addressed the problem of accurately estimating the volume and value of a variety of species in the past. Their basic approach was to develop two multiple regressions, one to predict the volume of the lumber recovered and one to predict the value of the lumber recovered. The basic approach in this paper is similar to past work in that two general models were developed, one for volume and one for value. Unlike past approaches, gross volume, defect volume, and recovery were modeled independently and then combined to predict lumber volume.

The data used in this project came from existing information on file with the Timber Quality Research Project, Pacific Northwest Forest and Range Experiment Station, Portland, OR. The data are from four lumber recovery studies which have been conducted over the past ten years. Data was collected both on standing timber in the field and logs and lumber during processing. A subsample of this data was reserved for validation of the equations.

Four historical methods of modeling gross volume were reviewed and equations which were developed on young-growth red, white, and grand fir were tested for goodness of fit. MacLean and Berger's (1976) white fir equation fit the data the best.

The major problem with defect was finding a dependent variable. Neither Scribner scale deductions nor any of the attempts to calculate the volume of defect were able to relate defect to loss in lumber volume. Fortunately only small rates of defect were found (table 9) so combining defect and recovery is not a serious deviation from the original approach.

Two methods were used to model recovery. The first method used a non-linear model which was solved using all possible combinations regression techniques. The second method used a linear model and stepwise regression techniques.

After gross volume and recovery were predicted, their product was multiplied by a final coefficient to predict lumber volume in cubic feet. Board foot/cubic foot ratios are provided to convert the lumber volume in rough green cubic feet to surfaced dry board feet.

Lumber value was modeled using two approaches. The first approach used the logistic function to predict the percentage volume in each of three lumber grades. This method was useful in only three data groups (Burney/white, Burney/Red, and all data). The second approach predicted an indexed value which was calculated from the relative prices of the three lumber grades. This approach worked for all the data sets.

Accuracy and bias were calculated for each general and specific prediction of lumber volume and lumber value. The mill/species specific equations were more accurate and less biased than the general equations.

RECOMMENDATIONS

The equations described in this paper should be used by public agencies and private industry to predict the volume and value of standing young-growth true fir for appraisals.

The mill/species specific recovery and value equations should only be used by the original study mills or mills with the same equipment used in the same order. Any use of the equations outside of the specific geographic areas and data limits (i.e. D from six to thirty inches and H from 67 to 110 feet) may not produce accurate results.

Bibliography

Allen, G. M.; Adams, D. L.; and Prausa, C. R. Preliminary volume tables for small trees in northern Idaho. Station Note, Forestry, Wildlife, and Range Experiment Station, University of Idaho, No. 21. 1974.

Aho, P. E. Defect estimation for grand fir in the Blue Mountains of Oregon and Washington. USDA For. Serv. Res. Pap. PNW-175. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1974.

Aho, P. E.; Simonski, P. Defect estimation for white fir in the Fremont National Forest. USDA For. Serv. Res. Pap. PNW-196. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1975.

Aho, P. E.; Roth, L. F. Defect estimation for white fir in the Rogue River National Forest. USDA For. Serv. Res. Pap. PNW-240. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1976.

Barger, R. L.; Ffolliott, P. F. Evaluating product potential in standing timber. USDA For. Serv. Res. Pap. RM-57. Fort Collins, CO: Rocky Mountain For. and Range Exp. Stn. 1970.

Baskerville, G. L. 1972. Use of logarithmic regression in the estimation of plant biomass. Canadian Journal of Forest Research 2,49-53.

Bruce, D.; DeMars, D J. Volume equations for second-growth Douglas-fir. USDA For. Serv. Res. Pap. PNW-239. Portland, OR: Pac Northwest For. and Range Exp. Stn.; 1974.

Buse', A. Goodness of fit in generalized least squares estimation. American Statistician 27:106-108; 1973.

Cunia, T. Weighted least squares method and construction of volume tables. Forest Science. 10(2): 180-191; 1964.

Fahey, T. D. Grading second-growth Douglas-fir by basic tree measurements. J. of Forestry. 78(4):204-206: 1980.

Fahey, T. D.; Woodfin, R. O., Jr. The cubic are coming: predicting product recovery from cubic volume. J. of Forestry 74(11):739-743; 1976.

Furnival, G. M. An index for comparing equations used in constructing volume tables. Forest Science 7(4):337-341; 1961.

Gallant, A. R. Nonlinear regression. The American Statistician 29(2):73-81; 1975.

Grosenbaugh, L. 1967. Rex--Fortran - 4 system. USDA For. Serv. Res. Pap. PSW-44. Berkeley, CA: Pac Southwest For. and Range Exp. Stn.; 1967.

Hann,D.W. and B.B.Bare. 1978. Comprehensive tree volume equations for major species of New Mexico and Arizona, I. Results and Methodology. USDA For. Serv. Res. Pap. INT-209. Ogden UT: Intermountain For. and Range Exp. Stn.; 1978.

Husch, B. Forest mensuration and statistics. New York: The Ronald Press Co.; 1963.

Jackson, G. H., J.W. Henley, and W.L. Jackson. Log diagraming guide for western softwoods. USDA For. Serv. Portland, OR: Pac Northwest For. and Range Exp. Stn.; 1967.

Lane, P. H.; Plank, M. E.; Henley, J. W. A new and easier way to estimate the quality of inland Douglas-fir sawtimber. USDA For. Serv. Res. Pap. PNW-101. Portland, OR: Pac Northwest For. and Range Exp. Stn.; 1970.

MacLean, C. D.; Berger, J. M. Softwood tree volume equations for major California species. USDA For. Serv. Res. Pap. PNW-266. Portland, OR: Pac Northwest For. and Range Exp. Stn.; 1976.

Marden, R. M. A new approach to tree grading for northern hardwoods. Forest Products Journal. 15(5):179-184; 1965.

Mitchell, B. R.; Hann, D. W. Brex: a computer program for applying ridge regression techniques to multiple linear regression. USDA For. Serv. Gen. Tech. Report INT-51. Ogden UT: Intermountain For. and Range Exp. Stn.; 1979.

Nie,N.H., C.H. Hull, J G Jenkins, and others. Statistical package for the social sciences. 2d edition, McGraw-Hill Book Co., 1975.

Plank, M. E.; Snellgrove; T. A. An equation for estimating the value and volume of western larch trees. USDA For. Serv. Res. Pap. PNW-266. Portland, OR: Pac Northwest For. and Range Exp. Stn.; 1978.

Plank, M. E.; Johnson, F. A. An empirical log rule for Douglas-fir in western Oregon and western Washington. J. of Forestry 73(5):288-293; 1975.

Pong, W. Y.; Jackson, G. H. Diagraming surface characteristics of true fir logs. USDA For. Serv. Portland, OR: Pac Northwest For. and Range Exp. Stn.; 1972.

Snellgrove, T. A.; Plank, M. E.; Lane, P. H. An improved system for estimating the value of western white pine. USDA For. Serv. Res. Pap. PNW-166. Portland, OR: Pac Northwest For. and Range Exp. Stn.; 1973.

Strub,M. Estimation of multiproduct yield and grade from tree and stand characteristics. In Forest Inventory Workshop Proceedings. 1980.

USDA Forest Service. 1977. Forest Statistics of the US, 1977. 133p.

USDA Forest Service. 1973. Increasing your lumber recovery. Sawmill Improvement Program p35.

Wensel,L.C. 1977. Volume tables for young growth conifers in the northern regions of California. Division of Agricultural Sciences, University of California. Bulletin 1883. 43pp.

Wise, H. F., and R. H. May. 1958. Lumber grade recovery from old-growth white fir on the Sequoia National Forest, California. USDA For. Serv. Res. Pap. PSW-**. Berkeley, CA: Pac Southwest For. and Range Exp. Stn.; 1958.

A P P E N D I C E S

Appendix I. Diagram Sheets

GENERAL:

State Calif
County Shasta
Location T 32N R 3E
Section 13
Project 31-01
Area No. 2
Species [illegible]
Ownership FS

TREE STEM DATA:

Tree No. 153
d.b.h. 16.7
Form class: 16 ft.
32 ft.

Log grades:

Total height 99.8
Est. Merch. Ht.
Meas. Merch. Ht.
Utilized Ht. 79.8
Ht. clear bole
Ht. first dead limb 54
Size first dead limb 1½
Ht. first live limb 50
Size first live limb 1½
Lean - amount
Lean - direction
Stump height .8
Tree age 90

CROWN DATA:

Ht. to start of crown
Crown length
Crown density
Crown class

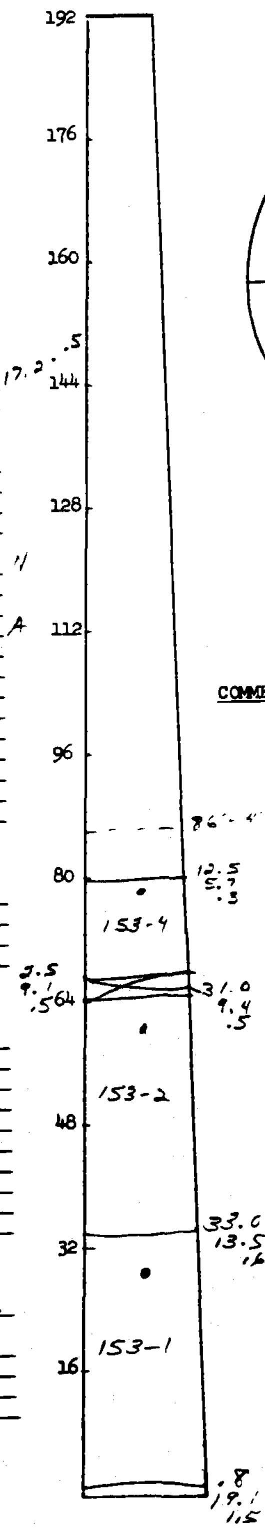
STAND DATA:

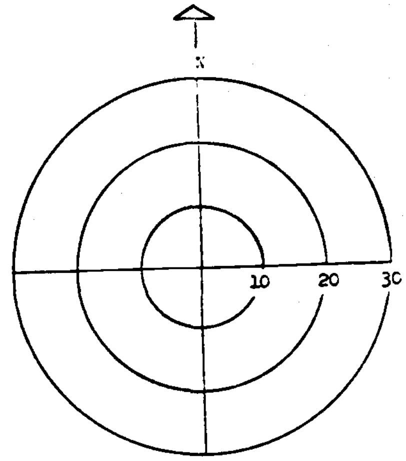
Stand age
Local type
Basal area
Site index
Soil type

Elevation
Aspect
Slope %
Slope position

DEFECT INDICATORS:

Ht.	Type	% Vol. ded.





Legend
Orientation Line Location
Tree Crown Outline
- - - - Adjacent Crown Outline

COMMENTS:

33.8
31.0
64.8
2.5
12.5
79.8
20
99.8

DFLGP No. 2
1964

LEGEND TO CODE 8 FOOT LENGTHS:

- A Indicates clear face, 4 feet long.
- B Overgrown knot, dead knot or live knot size.
- C Number of knots by type and size.
- D Percentage of log surface visible.

LOG GRADE:	LENGTH:
LONG ____	____
SAWN ____	____
____	____

CIRCLE ONE:
LOG
LONG BUTT
BREAK
CULL LOG

TREE NO. 151

LOG NO. ____

PROJECT 3601

℄ ___

	4	8	12	16	20	24	28	32	36	40
	$\bar{x}=3/4$									
	$\bar{x}=1/2$									
	$\bar{x}=1/2$ Indicators only									
	$\bar{x}=1/2$	3/4								

0–4	4–8	8–12	12–16	16–20	20–24	24–28	28–32	32–36	36–40
B	1/2-3/4	B 1/2-3/4		B	1/2-1	B 1/2-1	1/2-1	B 1/2-1	3/4-1
C 4,0,0	1/2	C 3/4	1,1-3-1,0	C 4,1-1,0	3/4	C 3/4	3/4	C 3/4	1
D 1/2,0,0	2	D 2	1/2,1/2-3/4-1,0	D 1/2,3/4-1,0	2	D 2	2	D 2	2
50%			50%	50%					

COMMENTS:

LONG LOG: GROSS ____ NET ____ SCALE DIAM ____ LOG $/M ____ TOTAL VALUE ____

SAWN LOG: 1____ 2____ 1____ 2____ 1____ 2____ 1____ 2____ 1____ 2____

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

TREE-LOG DIAGRAM Rev. 6/70. PNW

Appendix II. Mill equipment.

Martell

One nine-foot double cut with a 54-inch carriage, a nine-foot single cut with a 72-inch carriage, two edgers, one line bar resaw, one trimmer, and a 24 tray automatic sorter. Mill production averaged 150 MBF a shift and the mill runs two shifts a day.

Medford

One single cut seven-foot bandsaw, a four by 66-inch single edger, a 32-foot gang trimmer, a twin band vertical line-bar resaw and a single band resaw on the green chain. Mill production averaged 90 MBF a shift.

Burney

One quad band headsaw, one debarker, one single band resaw, two double arbor edgers, one trimmer, an automatic pocket drop sorter, and a lumber stacking and stickering machine. Mill production averages approximately 150 MBF a shift and the mill runs two shifts a day.

Grangeville

One nine-foot single cut band headsaw, on 16-inch chip-n-saw, two debarkers, one twin band resaw, one gang bull edger, two single edgers, one trimmer, and a drop sorter. Mill production averaged approximately 150 MBF of lumber per shift, and the mill runs two shifts a day.