Forest Service Handbook
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Forest Service Handbook 2409.12a – Timber Volume Estimator Handbook
Chapter 40 - Validation and Calibration

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Approved by: Jack Ward Thomas, Chief

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Responsible Staff:

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Digest: Following is an explanation of the changes throughout the directive by section.

2409.12a: Establishes new Timber Volume Estimator Handbook that provides Service-wide standards and instructions for preparation of equations or tables used to estimate the timber content of trees.

Table of Contents

This Chapter contains direction to determine how well the proposed equation predicts the variable of interest, usually either bole diameter or volume, and if a sufficient degree of accuracy has been achieved.

41 - Basics of Validation and Calibration

Use validation to determine the utility of a proposed estimator for a general population of trees (target population) to which the equation is applied. Use calibration to adjust a volume estimator for a specific or local target population that has been shown to vary from the general target population. Consult the intended users of an equation to determine the degree of accuracy the equation must achieve, and specify it before beginning the validation or testing phase of equation development.

41.1 - Species

Develop a profile or volume equation for a single species. However, recognize that a single-species equation sometimes must be used for another species or for a species group. Evaluate and group similar species prior to the data gathering process. specify a species or group so that the equation user neither needs to determine the range of species for which the equation applies nor to validate the results.

41.2 - Diameter Breast Height and Height

Ensure that the ranges of diameter breast height (dbh) and total height of the sample span the ranges of dbh and total height of the target population. If trees in the target population are either smaller or larger than those making up the estimation data set, determine the accuracy of the extrapolation.

Divide the trees into diameter classes and evaluate the equation across the range of tree sizes in the target population. Make the class sizes as small or large as needed to determine whether the equation works for both small trees and large trees. Determine the range of diameters for which the equation is to be used and divide it into four to six diameter groups. For example, if candidate trees range from 6 to 36 inches dbh, they may be divided into five groups as follows: 6-12 inches, 13-18 inches, 19-24 inches, 25-30 inches, and 31-36 inches. Use enough classes to detect estimation bias or inaccuracies that are attributable to tree dbh.

Divide the trees into total height classes as was done with the dbh classes and determine if the equation works for both the shortest and tallest trees in the population. Use four to six height classes, spanning the entire range of population heights.

41.3 - Volume

Use accuracy of tree volume prediction as the criterion to judge a candidate equation. Determine the prediction variable of interest which may be volume of the total tree or any merchantable portion of the tree such as individual logs, the total sawlog volume, or tree volume to the pulpwood top.

Specify, in advance, a single prediction variable to evaluate. Avoid evaluating an equation for multiple accuracy criteria which may cause confusion. For example, an equation may give excellent results for predicting total tree volume but give slightly biased results for the butt log or for the tip of the tree. If so, use total tree volume as the most reliable volume estimate to evaluate, even though the sawlog portion of the tree may be the real variable of interest. If the total estimate is reliable, expect the sawlog volume estimate to be reliable, because a high proportion of the total tree volume occurs in the sawlog portion of the tree.

41.4 - Geographic Differences

When a species occurs across several geographic or physiographic areas, use tree form as the indicator of tree differences. If two trees of equal dbh and total height grow on two distinctly different physiographic areas, expect measurable differences due to different shape and form. Eliminate some of the differences due to location by including a measure of form in the profile or volume model.

Without an available measure of form in the estimator, develop separate volume functions based on geographic location.

42 - Validation Process

Use procedures to validate an equation that range from a visual comparison of old and new volume tables to rigorous statistical tests for determining measurable statistical differences. Consider no single test or procedure sufficient for all equation validations. Ensure that validation consists of enough statistical tests and comparisons to determine the accuracy and usefulness of the candidate equation for the target population.

42.1 - Measurements

Take measurements on each tree identical to those required to use the equation plus those necessary to validate the accuracy of the equation. For example, to validate a candidate equation for cubic foot volume to a 4-inch top diameter outside bark, measure dbh, diameter at the upper merchantability point (Du), and the height where the diameter is 4 inches inside bark (H4) for individual trees. Determine cubic foot volume of the test trees by taking additional measurements along the bole at fixed height intervals and calculate volumes for each segment using standard volume formulae. Reference and use a standard geometric formulae from a forest mensuration textbook.

Consider each segment of the tree to be a truncated geometric solid. Calculate volumes in the bottom 10 percent of the tree using the formula for a truncated neiloid. Calculate volumes in the top 10 percent of the tree using the formula for a truncated cone. Calculate volumes in the middle portion of the bole using the formula for a truncated paraboloid. Calculate the volume of each bole segment. Sum the segments to obtain the measured tree volume from stump to a 4 inch diameter inside bark (V4).

42.2 - Statistical Tests

Within each group, calculate the statistics needed to help evaluate the accuracy and precision of the equation. Use all available statistics since no single statistic is adequate. See section 42.3 for an example application. In addition to statistics, plot the individual residual values against the variables used in the equation (section 42.29).

Calculate the following statistics for each group:

1. Sample mean, YBAR.

2. Mean bias, BBAR.

3. Percent bias, PBIAS.

4. Coefficient of determination; R-Squared or Fit Index (FI).

5. Standard error of estimate, SE.

6. Coefficient of Variation, CV.

7. 95% Chi Square Error Limit, CSEL.

42.21 - Variable Descriptions

The following variables are used throughout the remaining sections of this chapter:

1. N - The number of trees or observations in the group.

2. VCAP - The predicted volume of an individual tree.

3. VOSS - The observed or measured volume for a tree.

4. RESID - The residual for a tree prediction; RESID = VCAP - VOSS.

5. TSS - Total SUM Of Squares for the observed volumes; TSS = sum(VOBS*VOBS), summed over the N values.

6. RSS - Residual sum of squares for the group; RSS = sum(RESID*RESID), summed over the N values.

42.22 - Sample Mean

Calculate the sample mean as the average measured tree volume for the group. Use it to give an indication of the relative size of the measured trees and to predict other statistics.

$$YBAR = \frac{\sum^{N} VOBS}{N}$$

42.23 - Mean Dias

Calculate the mean bias as the average of the difference between measured volume and calculated volume for all trees in the group. The individual tree differences are the prediction residuals. Use these residuals to calculate most evaluation statistics. Expect that the more precise and accurate the equation, the smaller the individual residual, the smaller the sum of the residuals, and the smaller the mean bias. If the equation could predict each volume exactly, the value of the mean bias would be zero. Thus, a smaller mean bias provides greater confidence that the equation is producing accurate results.

$$BBAR = \frac{\sum^{N} RESID}{N}$$

42.24 - Percent Bias

Express percent bias as the ratio of mean bias to sample mean in percent. Use this as a measure of how far the average prediction misses the average "true" or measured value. This statistic should be "small," with small being as close to zero as possible and no larger than can be tolerated. Consider values smaller than 10 percent to be acceptable.

$$PBIAS = 100(BBAR/YBAR)$$

42.25 - Coefficient of Determination (R-Squared or Pseudo R-Squared)

Use R-Squared as a measure of how well the equation predicts individual volumes. The magnitude of R-Squared lies between 0.0 and 1.0. If the equation exactly predicts the volume of every tree, then each residual is zero, the RSS is zero, and R-Squared = 1.0. The R-Squared should be as close to 1.0 as possible.

Use pseudo R-Squared or Fit Index (FI) in place of R-Squared when an equation is fit using techniques that produce statistically biased predictions. interpret Fit Index the same as R-Squared and it should have magnitude between 0.0 and 1.0. However, recognize that if the equation fit is extremely poor, FI may sometimes be negative, since FI is computed using raw, not mean-corrected, squares.

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R-Squared = [(TSS-RSS)/TSS]
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42.26 - Standard Error of Estimate

Use the standard error of the estimate as a measure of the variation of the observed volumes not accounted for by the equation. This statistic should be "small" relative to YBAR.

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SE = [RSS/(N-p)]**0.5,
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where:

p is the number of coefficients in the taper equation.

42.27 - Coefficient of Variation

Use the coefficient of variation as the measure of the relative size of the standard error to the group mean. If the value is 0.0, then no prediction residuals exist and the equation exactly predicts every volume. This value should be as close to 0.0 as possible. Consider a value of 10 percent or less to be acceptable.

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CV = 100(SE/YBAR)
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42.28 - Chi Square Error Limit (CSEL)

Consider this statistic to be a modification of Freese's Chi Square statistic (Freese, Frank. 1960). This may be a more meaningful accuracy statistic than Freese's. For example, if CSEL = 4.8 percent, expect 95 percent of the deviations to be within +- 4.8 percent of their estimated values.

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CSEL = 100{Z*Z[sum[(RESID/VCAP)*(RESID/VCAP)]/CHISQ]**0.5}
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where:

Z = 1.96, the value of the standard normal deviate at the 95% probability level,

CHISQ = 0.853 + v + 1.645(2v-1)**0.5,

v = degrees of freedom for the Chi Square statistic; v = N-1.

42.29 - Plotting of Residuals

Plot the residuals (observed predicted) against the variable used in the estimation process, as well as other variables such as crown class, location, and elevation. Make special note of plotting the predicted merchantable height verses the actual merchantable height.

Expect no correlation between the values of the input variables and the residuals. The plotted residuals should form a horizontal band spanning the range of the equation variable. If the predicted volumes are plotted against the measured volumes, the plotted data should generally show a straight line trend at a 45-degree angle with most of the points clustered near the line.

42.3 - Example - Short Leaf Pine In Alabama

A form class profile equation was developed for shortleaf pine in Alabama. It was conditioned so the plotted taper line would pass through the points (4.5,D), (17.3,Du), and (H4,4.0); that is, when the measured height on the bole is 4.5 feet, the equation will equal the measured dbh, at the Girard Form Class height of 17.3 feet, the equation equals the measured outside bark form diameter (Du), and at the height of the merchantable bole to a 4-inch top (H4), the outside bark bole diameter is 4 inches.

To validate this equation, evaluate the equation for a sample of trees representative of short leaf pine in Alabama where the equation is expected to be applied. Establish the minimum and maximum size trees for which the equation is to be valid. Measure representative trees to establish a data set for validation testing.

In this example, a representative sample of shortleaf pine trees were selected and measured in conjunction with existing logging operations. In addition to the measures of dbh, Du, and H4, required for equation use, bole diameter outside bark and bark thickness were measured at 5-foot intervals on the bole starting with a 1-foot stump. Volume of each tree was computed using formulae for geometric solids. The computed statistics (section 42.2) are presented in exhibit 01.

The equation was compared for three diameter groups, three height groups, and for all groups combined. The mean volume of all trees in the first diameter group (6-10 inch class) was 17.60

cubic feet. The mean bias shows the equation slightly underestimated tree volume by an average of -0.483 cubic feet or a percent bias of -2.745. The fit index is 0.933, which was reasonably close to 1.0, indicating that individual predictions were close to the measured volumes. The standard error of 1.04 compared to the mean of 17.60 gave a good coefficient of variation of 5.912 percent. The chi square error limit showed that 95 percent of the predictions are within 6.58 percent of their true value for that diameter group.

A scan of the rest of exhibit 01 showed all FI's larger than 0.90, coefficients of variation near 5 percent, and chi square error limits ranging from 6.2 to 8.2 percent. The tallest height group showed slight differences from those just described. These statistics were acceptable and were caused by the relatively few number of trees represented in that group.

The evaluation across all groups showed a mean bias of -1.001 compared to a mean of 39.91, indicating a slight underestimation of volume by -2.509 percent. The FI of 0.988 compared very well to the possible 1.0. The overall chi square error limit showed that 95 percent of the volume predictions were within 8.147 percent of their measured values.

Based on these statistics, the equation was found to be useful for volume prediction with little or no adjustment. If adjustment is needed, use calibration procedures in section 43.

42.3 - Exhibit 01

Example Table of Statistics for Validation of Form Class Taper Equation in Alabama Shortleaf Pine.

	Diameter Class Group (inches)			
Statistic	6 - 10	11 - 15	16 - 20	21 - 25
Mean volume, cuft	17.60	34.39	65.22	*
Mean bias, cuft	-0.483	-0.793	-1.794	*
Percent bias	-2.745	-2.306	-2.751	*
Fit index	0.933	0.969	0.932	*
Standard error, cuft	1.040	1.903	3.340	*
Coef. of variation	5.912	5.533	5.121	*
Chi sq. error Limit (%)	6.580	8.210	7.140	*

		Bole Height to 4-inch Top dob (feet)		
Statistic	< 25	26 - 50	51 - 75	76+
Mean volume, cuft	*	20.27	40.63	75.99
Mean bias, cuft	*	-0.475	-1.169	0.448
Percent bias	*	-2.342	-2.877	0.590
Fit index	*	0.979	0.984	0.909
Standard error, cuft	*	1.019	2.059	8.906
Coef. of variation	*	5.024	5.0691	1.721
Chi sq. error limit (%)	*	6.240	7.720	10.900

Statistic	Across All Groups
Mean volume, cuft	39.91
Mean bias, cuft	-1.001
Percent bias	-2.509
Fit index	0.998
Standard error, cuft	2.182
Coef. of variation	5.467
Chi sq. error limit	8.147

* Too few observations to compute this statistic.

43 - Calibration

This procedure is the final step in the validation process and may be used to develop a correction factor which becomes part of the final estimation process. Use calibration to eliminate the bias found between the estimator and the local condition; however, do not use it to create a new or modified volume estimator for use elsewhere.

43.1 - When to Calibrate

Determine the need to adjust a volume equation to local conditions subjectively, depending on the importance of its use. Recognize that obtaining an accuracy better than 2.5 percent is unlikely and that accuracy of 10 percent or more is inaccurate and should be reevaluated (FSH 2409,12, sec. 22.23).

To determine if a profile/volume equation needs refinement, estimate cubic volume using the model on the target population. Calculate the actual volume of the target population by means of a local sample of limited size measured in great detail. Since the need for calibration is a subjective Judgment, it may not be necessary to calibrate to every local condition but simply to realize the strengths and weaknesses of the estimates. However, when predicted volumes versus actual volumes have a difference of 10 percent or more, consider using a different model, developing a new model, or calibrating the current model. If it is decided to calibrate, prepare a graphical solution of predicted over actual volume along with the validation statistic.

43.2 - How to Calibrate

Use information readily available from the validation statistics to in indicate bias. Use graphical presentation of the predicted volume over the actual volume to further support the general trend of the bias across the range of the target population.

Expand on the statistics and graphical solutions by using two common techniques.

1. Adjust the intercept of the profile equation (often referred to as a percentage adjustment), if it has one. This procedure may be acceptable if the bias is relatively constant over the range of the local volume estimates and a single coefficient would be adequate to correct for the volume difference (bias).

2. Adjust each diameter class by an appropriate correction factor. Develop a functional relationship of volume difference over diameter, and use this method if the volume difference Ls correlated to the changes in diameter

43.3 - Field Procedures

Regions may supplement this section with procedures for calibration of equations in local use.

44 - Conclusion and Documentation

Document validation and calibration projects in a consistent format using an outline similar to that displayed in exhibit 01. Include a statistical summary similar to that shown in section 42.3 exhibit 01. Include graphical comparisons, if any are made, and a concise narrative explanation of the validation/calibration project results. Distribute informational copies to the affected National Forests and the national data base coordinator (sec. 04.13). If calibration of volume estimators is expected to be necessary, provide direction for field application a regional supplement to section 43.3.

44 - Exhibit 01

Validation/Calibration Project Report Outline

I. Introduction: A brief introduction to the project, including a general description, objectives, purpose, and the need for the project. If a project plan was prepared, include it by reference, and enclose a copy.

II. Equations Being Tested: List the equations being tested and their geographic limitations (Region-wide, forest by forest, and so forth).

III. Results.

A. Data Summary.

1. Data items gathered.

2. Range and averages of data by species and equation.

a. DBH.

b. Height.

c. Predicted Volume/Tree.

d. Actual Volume/Tree.

e. Other Pertinent Data Items.

B. Data Analysis: Predicted versus Actual Values - summary of comparisons by equation.

C. Statistical Variation and Tolerance Limits: Are predicted versus actual variations acceptable? Describe tolerance limits.

D. Limits of Validation Results.

1. Region-wide.

2. Forest by forest.

IV. Need for Calibration: Does the data analysis indicate a need for calibration? If so, are more data needed, or will validation data be used? If calibration is necessary, include the following:

A. Calculation of ratio or coefficient adjustment.

B. Limits of calibration: Forest by forest or Region-wide.

C. Regional direction: Include Regional direction on use of calibration (section 43.3).

V. Data Storage: Explain where data are stored, how to access data and the electronic and hardcopy format.