Green lumber grade yields from black cherry and red maple factory grade logs sawed at band and circular mills

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Multivariate regression models were developed to predict green board-foot yields (1 board ft. = 2.360 dm^3) for the standard factory lumber grades processed from black cherry (*Prunus serotina* Ehrh.) and red maple (*Acer rubrum* L.) factory grade logs sawed at band and circular sawmills. The models use log measurements of grade, scaling diameter, length, and proportion of scaling defect. They can be used in computer programs related to sawmill simulations, economic modeling, or log-yard inventory systems.

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Des modèles de régression multivariés ont été développés pour prédire le rendement en pied-planche vert (1 pied-planche = 2.360 dm^3) selon les classes standards de bois de menuiserie préparé en usine à partir de billes de Cerisier tardif (*Prunus serotina* Ehrh.) et d'Érable rouge (*Acer rubrum* L.) de différentes classes sciées dans des scieries à scie circulaire et à ruban. Les modèles utilisent les mesures de classement des billes, le diamètre au mesurage, la longueur et la proportion de défauts notés au mesurage. Ils peuvent être utilisés dans les progiciels de simulation de sciage, de modélisation économique et dans les systèmes d'inventaire de parc à grumes.

[Traduit par la revue]

Introduction

The value a of a log should be based on an estimate of the amount and quality of the end products that may be produced from that log. The USDA Forest Service has developed standard factory log grades for eastern hardwoods as indicators of quality (Rast *et al.* 1973). Estimates of lumber grade yields can be obtained for these log grades and scaling diameter classes by using percentage tables also developed by the Forest Service for 18 hardwood species (Hanks *et al.* 1980). These tables work well when used with an estimate of total board-foot (1 board ft. = 2.360 dm^3) volume of the log obtained with a standard log rule. However, these tables are difficult to incorporate into a computer program for sawmill simulation or economic analysis.

Some of the data used in the development of the percentage tables has been analyzed using multivariate regression to develop equations that are useful to programmers. Previous equations have been calculated for northern red oak (*Quercus rubra* L.) (Yaussy and Brisbin 1983), white oak (*Q. alba* L.), black oak (*Q. velutina* Lam.), and chestnut oak (*Q. prinus*, L.) (Yaussy 1986), sugar maple (*Acer saccharum* Marsh.) and basswood (*Tilia americana* L.) (Yaussy 1987), and yellow birch (*Betula alleghaniensis* Britt.) (Howard and Yaussy 1986). Univariate least-squares equations also exist for five Great Lake States species (Wilson *et al.* 1982).

Data

The black cherry logs for this study were sawed at three circular and two band mills located in New York, Pennsylvania, and West Virginia. Four circular and two band mills located in Maine, Michigan, Pennsylvania, West Virginia, and Vermont were used for the red maple. The logs were scaled and then graded using Forest Service log grades. The green lumber was separated into the grades recognized by the National Hardwood Lumber Association (NHLA) (Table 1). Data for 820 black cherry and 590 red maple logs were collected. Approximately half of these logs (401 and 287, respectively) were randomly set aside as an independent data set to be used in validating the models. Summary statistics for the model development and the model validation data sets are presented in Tables 2 and 3.

Methods

Bruce (1970) developed a theoretical model to predict lumber recovery based on cubic volume of the scaling cylinder, surface area, length, and defect ratio.

$$[1] \quad Y = b_0D^2L + b_1DL + b_2L + b_3D^2LP$$

where

Y = total lumber volume recovery from a log
D = scaling diameter
L = log length
P = proportion of the log considered defective
b_j = coefficients determined by regression

He then weighted this equation by D^2L to obtain homogenous variances. In the present study, this model was expanded to predict the volumes within individual lumber grades.

Figures 1 and 2 show the means of the development data set. These graphs imply that there is a substantial difference in lumber grade volumes due to differing log grades. Mill type also accounts for some volume differences, but to a lesser extent. Since these two factors are not continuous variables, dummy variables were included in [1] to account for differences due to log grades and mill types (Draper and Smith 1981).

TABLE 1. NHLA lumber grades for black cherry and red maple

Black cherry	Red maple
First and seconds (FAS)	FAS
Selects (SEL)	FAS one face (F1F)
1 common (1C)	SEL
2 common (2C)	1C
3A common (3A)	2A common (2A)
3B common (3B)	2B common (2B)
	3A
	3B

TABLE 2. Board-foot yields for NHLA lumber grades for black cherry logs and descriptive statistics

	Development data set				Validation data set			
	Min	Max	Mean	SE	Min	Max	Mean	SE
	Band mill, grade 1, 29 logs				Band mill, grade 1, 21 logs			
FAS	0	152	64.931	7.853	0	122	47.857	7.108
SEL	6	143	51.345	6.617	4	91	41.190	5.009
1C	0	86	24.759	3.576	0	89	29.429	5.605
2C	6	70	23.034	2.848	0	69	20.048	3.635
3A	0	28	14.690	1.268	0	32	10.190	2.035
3B	0	28	4.724	1.609	0	18	4.810	1.251
Diam. (in.)	13	22	17.172	0.474	13	22	16.476	0.600
Length (ft.)	10.2	16.6	13.597	0.403	10.3	16.5	13.048	0.514
Defect	0.000	0.188	0.035	0.010	0.000	0.323	0.062	0.020
	Band mill, grade 2, 49 logs				Band mill, grade 2, 49 logs			
FAS	0	48	8.592	1.796	0	24	6.082	1.028
SEL	0	55	18.735	2.137	0	44	14.980	1.750
1C	0	86	22.592	2.766	0	113	27.429	3.379
2C	0	65	20.510	2.169	0	56	22.551	2.020
3A	0	32	13.306	0.948	0	28	12.408	1.001
3B	0	24	2.612	0.816	0	21	2.286	0.762
Diam. (in.)	10	20	13.449	0.314	10	20	13.694	0.312
Length (ft.)	8.2	16.6	11.600	0.409	8.2	16.6	11.273	0.439
Defect	0.000	0.286	0.034	0.010	0.000	0.333	0.030	0.009
	Band mill, grade 3, 58 logs				Band mill, grade 3, 63 logs			
FAS	0	6	0.621	0.208	0	13	0.429	0.257
SEL	0	24	2.828	0.590	0	24	2.175	0.651
1C	0	49	8.190	1.271	0	79	11.540	1.914
2C	0	51	18.086	1.518	0	62	19.714	1.756
3A	0	29	13.828	0.938	0	40	12.857	0.935
3B	0	34	3.638	0.935	0	28	2.651	0.713
Diam. (in.)	8	16	10.810	0.242	8	18	11.048	0.269
Length (ft.)	8.2	16.5	10.400	0.300	8.2	16.3	10.290	0.298
Defect	0.000	0.250	0.033	0.009	0.000	0.333	0.057	0.012
	Circular mill, grade 1, 73 logs				Circular mill, grade 1, 53 logs			
FAS	0	168	60.055	4.894	7	207	57.302	5.614
SEL	0	79	32.767	2.392	6	62	26.170	2.094
1C	0	118	22.904	2.522	0	80	27.132	2.764
2C	0	57	19.726	1.557	0	63	18.660	1.856
3A	0	27	9.068	1.010	0	40	8.094	1.183
3B	0	35	4.616	0.882	0	32	6.321	1.199
Diam. (in.)	13	25	16.753	0.300	13	25	16.491	0.399
Length (ft.)	10.2	16.3	12.723	0.233	10.2	16.4	12.770	0.284
Defect	0.000	0.206	0.023	0.005	0.000	0.294	0.040	0.009

TABLE 2 (*concluded*)

	Development data set				Validation data set			
	Min	Max	Mean	SE	Min	Max	Mean	SE
	Circular mill, grade 2, 112 logs				Circular mill, grade 2, 98 logs			
FAS	0	95	10.438	1.570	0	55	7.316	1.052
SEL	0	69	16.571	1.507	0	72	15.133	1.324
1C	0	110	28.607	2.393	0	122	29.296	2.401
2C	0	70	18.929	1.222	0	109	20.918	1.517
3A	0	42	10.759	0.933	0	40	8.847	0.847
3B	0	65	6.232	1.033	0	38	6.959	0.931
Diam. (in.)	10	23	14.071	0.258	10	25	13.816	0.263
Length (ft.)	8.2	16.8	11.775	0.220	8.2	16.3	12.009	0.229
Defect	0.000	0.286	0.050	0.006	0.000	0.289	0.047	0.007
	Circular mill, grade 3, 101 logs				Circular mill, grade 3, 117 logs			
FAS	0	58	1.545	0.635	0	69	2.239	0.756
SEL	0	47	2.762	0.614	0	33	2.470	0.471
1C	0	59	10.950	1.256	0	113	15.256	2.033
2C	0	51	18.347	1.106	0	56	17.744	1.153
3A	0	38	10.297	0.845	0	42	10.932	0.842
3B	0	41	5.733	0.912	0	45	4.581	0.704
Diam. (in.)	8	18	11.188	0.221	8	22	11.453	0.269
Length (ft.)	8.0	16.5	11.035	0.247	8.0	16.4	10.914	0.247
Defect	0.000	0.385	0.062	0.009	0.000	0.400	0.074	0.010

TABLE 3. Board-foot yields for red maple logs and descriptive statistics

	Development data set				Validation data set			
	Min	Max	Mean	SE	Min	Max	Mean	SE
	Band mill, grade 1, 30 logs				Band mill, grade 1, 17 logs			
FAS	0	239	56.100	10.288	9	125	61.118	8.603
F1F	0	64	23.367	2.930	0	50	17.059	3.804
SEL	0	42	7.867	1.827	0	14	8.294	1.084
1C	0	93	29.200	3.525	0	39	15.412	2.923
2A	11	55	27.500	2.491	0	50	21.353	3.004
2B	0	34	10.400	1.873	0	34	12.765	3.188
3A	0	44	6.000	1.862	0	35	3.235	2.112
3B	0	18	1.567	0.819	0	18	1.353	1.081
Diam. (in.)	13	20	16.433	0.373	13	18	15.059	0.406
Length (ft.)	10.3	16.6	14.623	0.385	12.2	16.5	15.082	0.381
Defect	0.000	0.222	0.042	0.010	0.000	0.052	0.011	0.005
	Band mill, grade 2, 71 logs				Band mill, grade 2, 69 logs			
FAS	0	69	6.915	1.443	0	69	8.870	1.755
F1F	0	56	11.620	1.617	0	61	10.754	1.654
SEL	0	21	5.056	0.644	0	23	4.043	0.709
1C	0	78	20.211	1.889	0	60	21.739	1.927
2A	0	81	26.563	2.037	0	132	25.681	2.688
2B	0	102	12.577	2.005	0	60	14.261	1.302
3A	0	28	4.070	0.772	0	34	4.812	0.885
3B	0	18	1.775	0.445	0	40	3.101	0.790
Diam. (in.)	10	18	13.254	0.218	11	20	13.261	0.261
Length (ft.)	8.2	16.6	12.938	0.296	8.2	16.5	12.771	0.325
Defect	0.000	0.280	0.056	0.009	0.000	0.306	0.049	0.008

TABLE 3 (*concluded*)

	Development data set				Validation data set			
	Min	Max	Mean	SE	Min	Max	Mean	SE
	Band mill, grade 3, 134 logs				Band mill, grade 3, 129 logs			
FAS	0	44	0.925	0.397	0	18	0.442	0.211
F1F	0	28	1.537	0.336	0	19	1.070	0.280
SEL	0	15	1.149	0.231	0	13	1.023	0.219
1C	0	88	7.246	0.993	0	44	6.031	0.729
2A	0	81	16.545	1.267	0	104	16.047	1.339
2B	0	85	20.015	1.334	0	58	20.287	1.137
3A	0	28	3.007	0.441	0	39	3.783	0.542
3B	0	51	1.448	0.464	0	35	1.581	0.381
Diam. (in.)	8	18	10.627	0.167	8	17	10.667	0.172
Length (ft.)	8.2	16.8	11.790	0.240	8.1	16.7	11.607	0.249
Defect	0.000	0.333	0.044	0.006	0.000	0.333	0.042	0.006
	Circular mill, grade 1, 16 logs				Circular mill, grade 1, 6 logs			
FAS	0	65	31.500	4.140	6	95	27.167	14.455
F1F	0	97	31.000	6.012	0	40	18.833	6.019
SEL	0	27	6.688	2.075	4	19	8.500	2.172
1C	2	58	25.438	4.531	9	71	31.667	9.925
2A	8	72	22.438	3.965	9	35	18.667	3.921
2B	0	24	4.125	2.061	0	12	3.500	2.247
3A	0	42	11.500	3.402	0	12	6.500	1.688
3B	0	11	1.938	0.924	0	9	2.333	1.563
Diam. (in.)	13	20	15.875	0.576	13	21	15.667	1.430
Length (ft.)	10.2	16.3	13.419	0.518	10.3	16.3	12.617	0.804
Defect	0.000	0.064	0.018	0.006	0.000	0.148	0.049	0.023
	Circular mill, grade 2, 22 logs				Circular mill, grade 2, 22 logs			
FAS	0	143	11.000	6.573	0	8	1.591	0.598
F1F	0	64	10.909	2.860	0	24	5.409	1.663
SEL	0	12	5.045	0.771	0	9	1.955	0.626
1C	0	70	16.818	3.398	0	43	13.000	3.131
2A	4	47	17.818	2.441	5	58	17.773	2.830
2B	0	25	6.273	1.683	0	26	6.545	1.815
3A	0	24	5.909	1.713	0	22	5.455	1.296
3B	0	31	5.455	1.981	0	26	8.455	1.881
Diam. (in.)	0	19	12.955	0.499	10	18	13.000	0.492
Length (ft.)	8.3	16.3	14.109	0.511	8.3	14.3	12.118	0.392
Defect	0.000	0.364	0.050	0.019	0.000	0.368	0.115	0.027
	Circular mill, grade 3, 32 logs				Circular mill, grade 3, 42 logs			
FAS	0	12	0.500	0.391	0	0	0.000	0.000
F1F	0	32	1.750	1.077	0	0	0.000	0.000
SEL	0	11	1.156	0.514	0	13	0.571	0.341
1C	0	21	3.938	0.981	0	59	3.595	1.478
2A	0	31	7.625	1.420	0	23	5.786	1.120
2B	0	46	8.281	1.933	0	84	9.333	2.086
3A	0	23	8.188	1.205	0	27	7.048	1.133
3B	0	42	10.125	1.611	0	35	9.738	1.340
Diam. (in.)	8	15	10.750	0.336	8	18	10.095	0.310
Length (ft.)	8.3	16.3	12.425	0.380	8.3	16.3	12.110	0.372
Defect	0.000	0.422	0.072	0.021	0.000	0.345	0.035	0.012

The expanded model is

$$[2] \quad Y_i/(D^2L) = b_{i0} + b_{i1}/D + b_{i2}/D^2 + b_{i3}P + b_{i4}G_1 + b_{i5}(G_1/D) + b_{i6}(G_1/D^2) + b_{i7}PG_1 + b_{i8}G_2 + b_{i9}(G_2/D) + b_{i10}(G_2/D^2) + b_{i11}PG_2 + b_{i12}M + b_{i13}(M/D) + b_{i14}(M/D^2) + b_{i15}PM + b_{i16}G_1M + b_{i17}G_1(M/D) + b_{i18}G_1(M/D^2) + b_{i19}PG_1M + b_{i20}G_2M + b_{i21}G_2(M/D) + b_{i22}G_2(M/D^2) + b_{i23}PG_2M$$

where

Y_i = green board-foot volume for the ith lumber grade, i = first and seconds, ..., 3B common

b_{ij} = regression coefficient for the jth variable and the ith lumber grade, $j = 0, \ldots, 23$

G_k = 1 if log is grade k, 0 otherwise, $k = 1, 2$

M = 1 if log is sawed at circular mill, 0 for band mill

Multivariate multiple regression analysis was considered the appropriate method of developing prediction equations for this data. Ordinary least-squares regression could be used

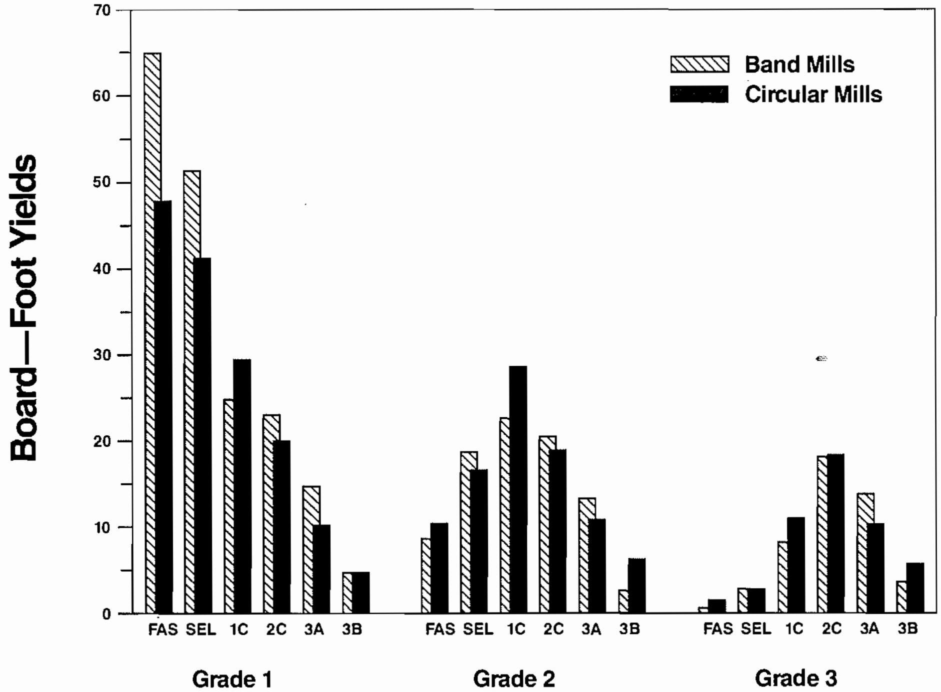

FIG. 1. Comparison of mean lumber grade yields by log grade for black cherry sawed at band and circular mills.

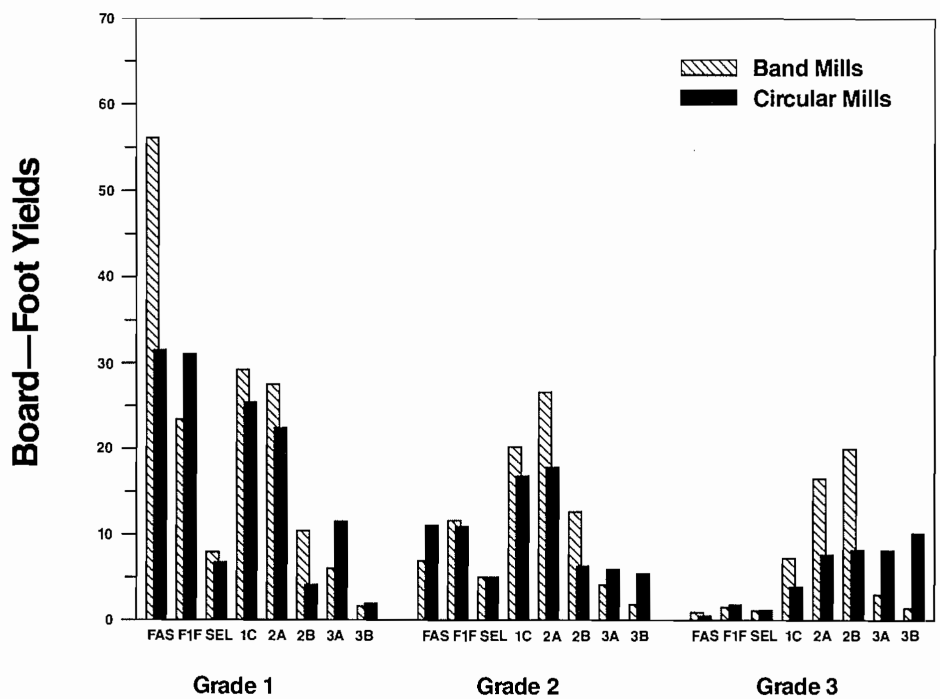

FIG. 2. Comparison of mean lumber grade yields by log grade for red maple sawed at band and circular mills.

if the lumber grade volumes were considered independent of each other. However, this assumption does not hold since the volumes must sum to the total volume of the log. Multivariate analysis utilizes the interdependency of the lumber grade volumes to test for significance of the independent variables (Kramer 1972).

The Wilks' criterion (L) was used to identify nonsignificant variables. This test considers the effect an independent variable has on all lumber grade yields simultaneously. After elimination of all nonsignificant ($p = 0.05$) variables in [2], the models were

Black cherry:

$$[3] \quad Y_i/(D^2L) = b_{i0} + b_{i1}/D + b_{i2}/D^2 + b_{i13}P + b_{i4}G_1 + b_{i5}(G_1/D) + b_{i9}(G_2/D) + b_{i13}(M/D) + b_{i19}PG_1M$$

Red maple:

$$[4] \quad Y_i/(D^2L) = b_{i0} + b_{i1}/D + b_{i12}/D^2 + b_{i3}P + b_{i4}G_1 + b_{i5}(G_1/D) + b_{i9}(G_2/D) + b_{i13}(M/D) + b_{i16}G_1M + b_{i17}G_1(M/D) + b_{i20}G_2M$$

TABLE 4. Matrix of coefficients for the lumber grade yield models

Lumber grade (i)	Independent variables (j)											
	D^2L	DL	L	D^2LP	D^2LG_1	DLG_1	DLG_2	DLM	D^2LG_1M	DLG_1M	D^2LPG_1M	D^2LG_2M
						Black cherry						
FAS	0.0183	−0.3475	1.6502	−0.0043	0.0161	−0.0507	0.0232	0.0011	—	—	−0.0323	—
SEL	−0.0152	−0.2543	1.2542	−0.0089	−0.0034	0.1527	0.0608	−0.0109	—	—	−0.0064	—
1C	0.0240	−0.1714	−0.1169	−0.0062	−0.0166	0.1648	0.0104	0.0038	—	—	0.0120	—
2C	−0.0115	0.5434	−2.7482	−0.0050	0.0046	−0.1563	−0.0464	−0.0128	—	—	−0.0008	—
3A	0.0042	−0.0403	1.2404	−0.0024	−0.0006	−0.0244	−0.0184	−0.0340	—	—	0.0040	—
3B	−0.0006	0.0659	−0.3442	−0.0020	0.0007	−0.0343	−0.0084	0.0159	—	—	0.0063	—
						Red maple						
FAS	0.0160	−0.3016	1.4579	−0.0090	0.0282	−0.2591	0.0262	−0.0030	−0.0330	0.4361	—	−0.0006
F1F	0.0057	−0.0657	0.1738	−0.0064	−0.0054	0.1424	0.0453	−0.0028	0.0143	−0.1806	—	−0.0010
SEL	−0.0021	0.0677	−0.3663	−0.0019	−0.0013	0.0455	0.0168	−0.0008	0.0054	−0.0851	—	−0.0003
1C	0.0288	−0.3919	1.3904	−0.0062	−0.0152	0.1925	0.0308	−0.0140	0.0128	−0.1591	—	−0.0015
2A	−0.0122	0.5885	−3.4373	−0.0109	−0.0050	0.0194	0.0022	−0.0605	0.0131	0.1541	—	0.0015
2B	−0.0060	0.2838	−0.4553	−0.0188	0.0033	−0.1539	−0.0788	−0.1031	0.0027	0.0318	—	0.0059
3A	0.0016	0.0008	0.0762	0.0076	0.0004	−0.0212	−0.0077	0.0261	−0.0006	0.0093	—	−0.0015
3B	−0.0004	0.0130	0.0097	0.0044	0.0004	−0.0099	0.0022	0.0673	−0.0015	−0.0394	—	−0.0030

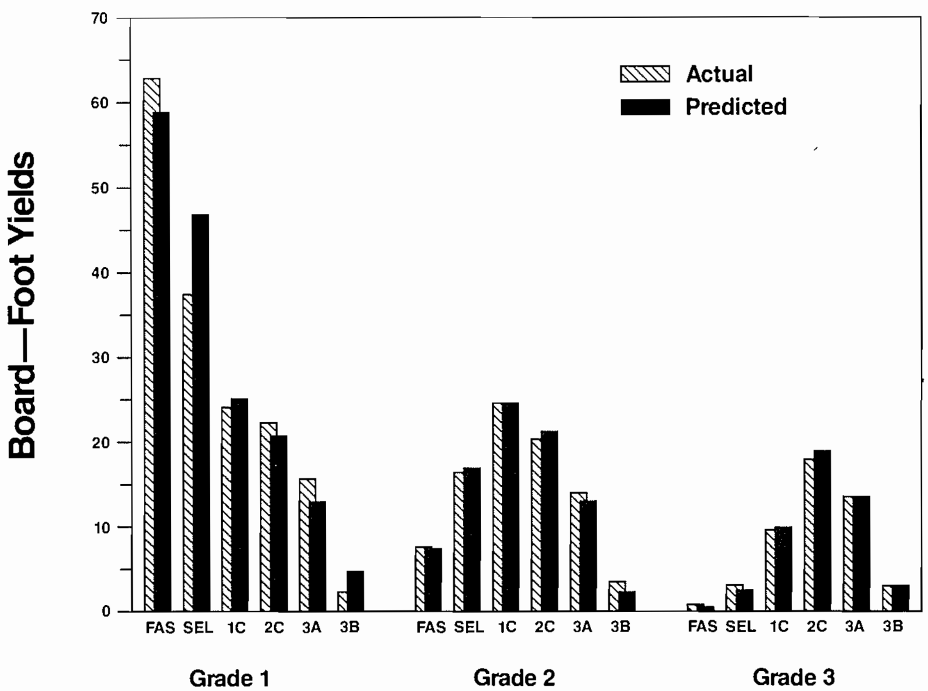

FIG. 3. Predicted and actual mean lumber volumes per log by log grade for black cherry sawed at band mills.

Validation

The method used for validating these models involves the calculation of coefficients for models [3] and [4] using the validation data set (Seegrist 1975). These coefficients are then compared with the coefficients from the model development data set. If there is no significant difference between the two sets of coefficients, the models have been validated. The validation tests of these models resulted in L's of 0.84 and 0.95 for red maple and black cherry, respectively. Since these values are larger than the 0.05-level critical values, 0.75 and 0.88, respectively, the hypothesis that there was no difference between the coefficients from the model development sets and the validation sets was not rejected; therefore, the models were statistically validated. Rejection of L is the reverse of most statistics, such as Student's t in which values larger than the critical value reject the null hypothesis.

Results

The regressions were rerun using the data of both the model development and validation data sets. All coefficients were significant at the 0.05 level.

Just as the statistic for testing significance of independent variables is different between multivariate and univariate regression, the statistic indicating the fit of the models is expanded. The Wilks statistic for the overall multivariate model is equivalent to $1 - R^2$ in the univariate case. Therefore, $1 - L$ represents the proportion of the variability around the mean of the data sets explained by the models.

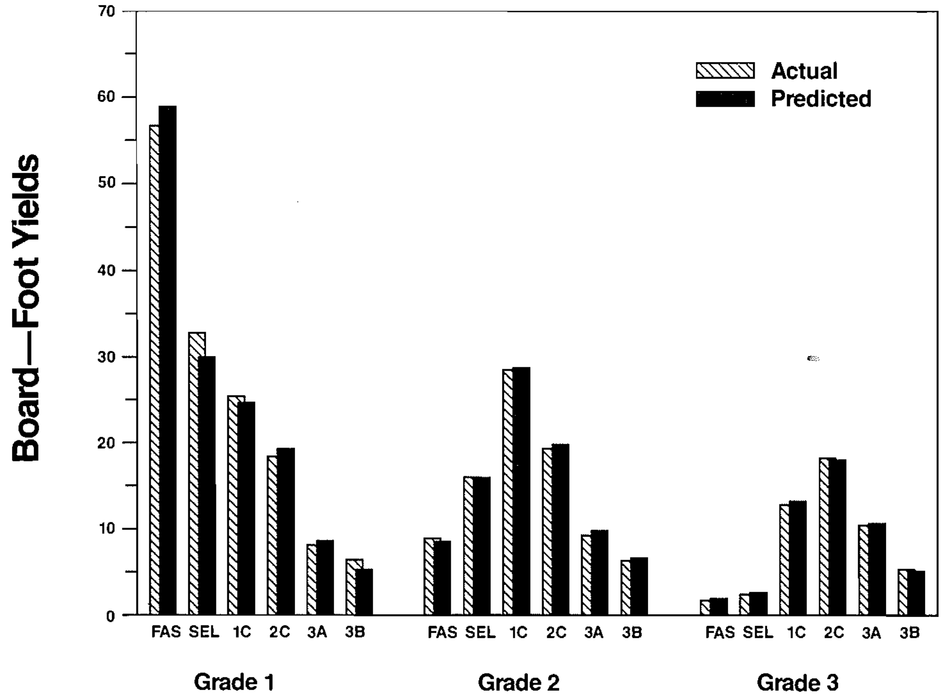

FIG. 4. Predicted and actual mean lumber volumes per log by log grade for black cherry sawed at circular mills.

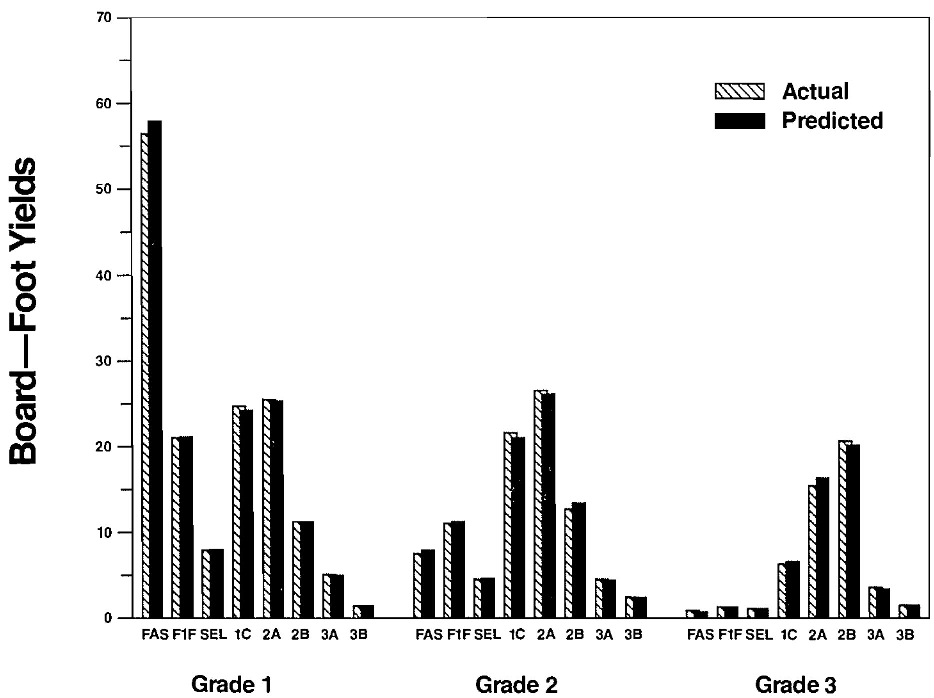

FIG. 5. Predicted and actual mean lumber volumes per log by log grade for red maple sawed at band mills.

These fit statistics were 0.88 for black cherry and 0.87 for red maple.

For prediction, [3] and [4] would be transformed by multiplying both sides of the equations by D^2L resulting in

Black cherry:

$$Y_i = b_{i0}D^2L + b_{i1}DL + b_{i2}L + b_{i3}D^2LP + b_{i4}D^2LG_1 + b_{i5}DLG_1 + b_{i9}DLG_2 + b_{i13}DLM + b_{i19}D^2LPG_1M$$

Red maple:

$$Y_i = b_{i0}D^2L + b_{i1}DL + b_{i2}L + b_{i3}D^2LP + b_{i4}D^2LG_1 + b_{i5}DLG_1 + b_{i9}DLG_2 + b_{i13}DLM + b_{i16}D^2LG_1M + b_{i17}DLG_1M + b_{i20}D^2LG_2M$$

The coefficients are presented in Table 4. Figures 3 through 6 show the predicted and actual mean lumber volumes per

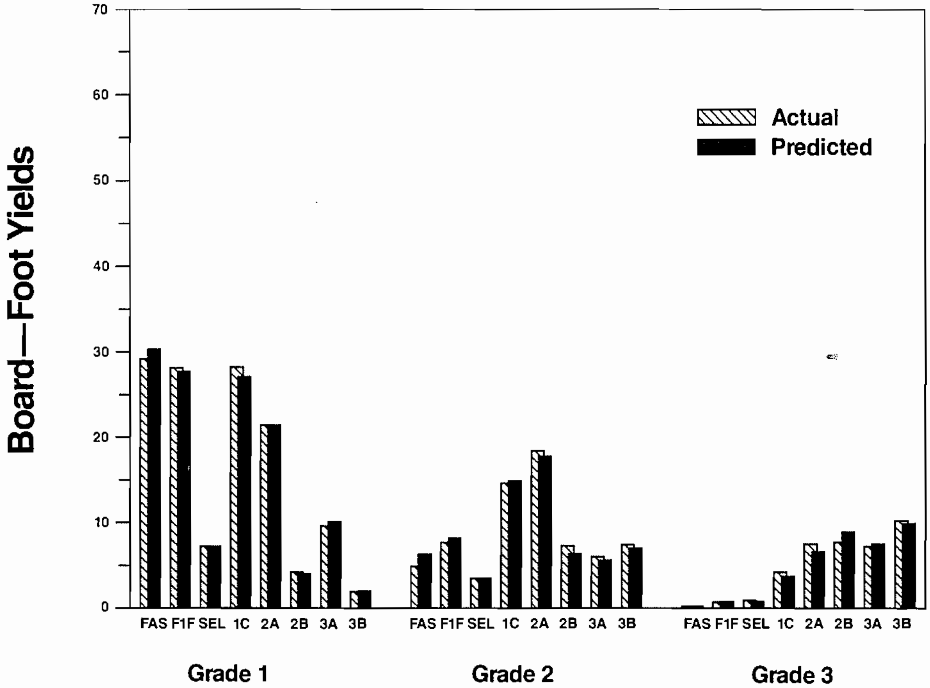

FIG. 6. Predicted and actual mean lumber volumes per log by log grade for red maple sawed at circular mills.

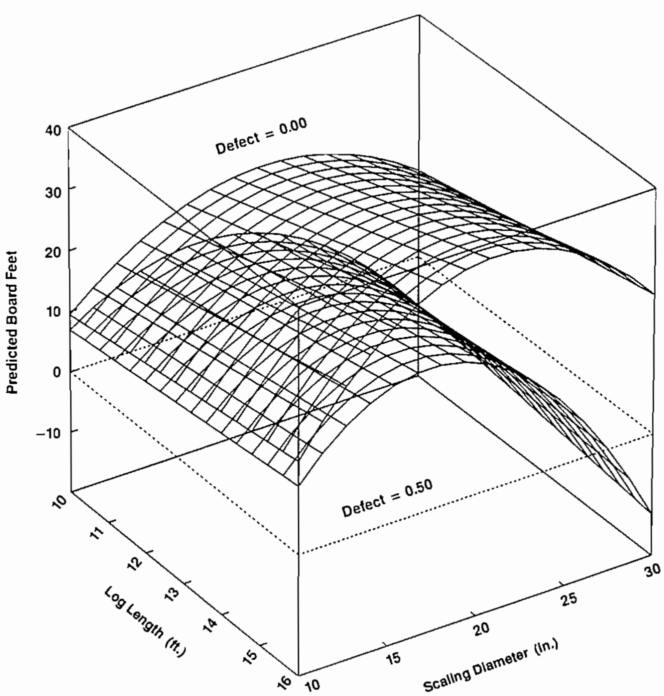

FIG. 7. Surface predicted by the equation for black cherry 2C lumber produced from grade 2 logs sawed at circular mills.

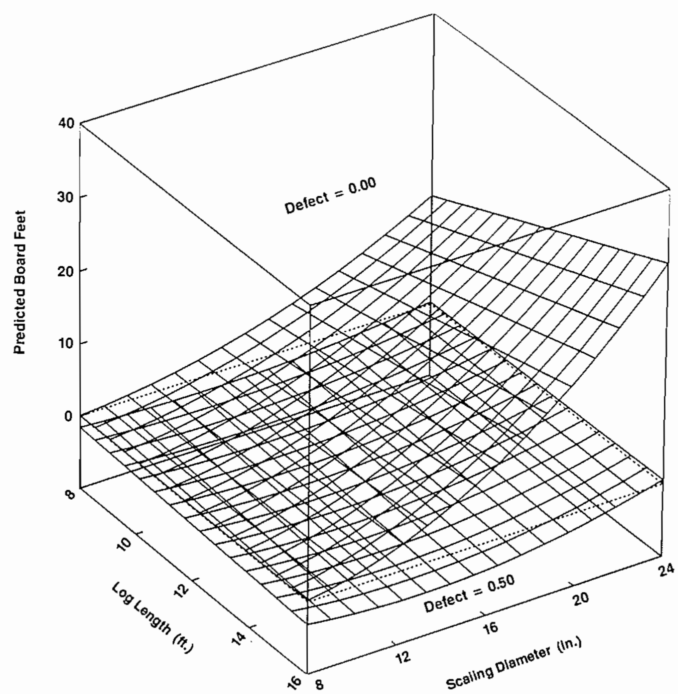

FIG. 8. Surface predicted by the equation for red maple F1F lumber produced from grade 3 logs sawed at band mills.

log for each mill type and log grade for both species for all logs.

Figures 7 and 8 are graphs of the surfaces produced by the models for two lumber grades. These illustrate that for a few lumber grades, negative volumes can be predicted if the values used in the equations are at or beyond the extremes of the collected data. In Fig. 7, scaling diameters greater than 27 in. (1 in. = 25.4 mm) in conjunction with 0.5 proportion of defect, predict negative 2 common volumes for grade 2 black cherry logs sawed at circular mills. Table 2 indicates that in the data for this study there were no black cherry logs with a scaling diameter greater than 25 in. and no defect greater than 0.4. Likewise, Fig. 8 shows that small negative volumes are predicted for high-grade lumber produced from grade 3 red maple logs with heavy defect. These negative volumes are relatively small compared with the overall lumber volume of the log.

The band mill models presented in this paper, along with models presented in the author's previous papers, are incorporated into a computer program called STUMP, a system of timber utilization and mill processing.

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