HARDWOOD STRUCTURAL LUMBER FROM LOG HEART CANTS

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ABSTRACT

Expected cost advantages of using hardwood for bridge superstructures rather than steel and concrete have not been evident. Some reasons given include the use of red oak, which is in high demand for other uses, and the fact that the hardwood dimension lumber market is not established. Another reason is that the lumber supply is coming from the high-grade outer portion of oak logs. In this study, we explored the potential for producing hardwood bridge products from log heart cants, including railroad ties and pallet cants. The report evaluates the availability of cant material from West Virginia mills and structural-grade dimension lumber from ties and cants for several species: red oak, hickory, red maple, yellow-poplar, beech, and white oak.

The National Timber Bridge Initiative has promoted hardwoods as a viable and economical alternative to concrete and steel components. Because lumber appears as a major cost component of a hardwood timber bridge superstructure, the identification and implementation of methods for reducing the cost of this material should significantly affect overall bridge costs.

As specifications for hardwood bridges have been developed and bids for their construction received, it has been evident that material costs vary greatly by species, grade, and size. This may be caused by a lack of knowledge about strength, stiffness, durability, and production costs. Interestingly, the expected cost advantage of hardwood lumber compared to concrete and steel has not been evident in the bids.

In the Appalachian region, timber bridge costs are higher than expected because of 1) the use of red oak; 2) the use of the high-grade outer potion of logs; and 3) inflated material bids.

Red oak is the lumber species group most often specified by hardwood bridge designers, and it is currently in high demand for other uses, both domestically and abroad. As reported in the *Weekly Hardwood Review,*[1] red oak is among the highest-valued hardwood species.

Relatively large structural lumber components have been specified for many bridges. At least a significant portion of each of these components is taken from the outer portion of the log, where the highest quality, appearance-graded lumber is normally obtained. This substantially increases the price of bridge components because lumber from the outer portions of logs, particularly in the case of red oak from the Appalachian region, is often marketed at prices as much as three times the price of lumber taken from the center or heart of the log.

Potential producers are unsure of product recovery and costs when cutting for structural lumber, so they protect their investments with inflated material bids.

One apparent alternative for reducing bridge costs is to utilize lumber from products currently produced from log heart cants and available at relatively inexpensive prices. Admittedly, some bridge components cannot be produced directly from cants because the width will be too small. However, multiple widths as well as lumber for trusses can become bridge components from normal-sized cants.

The purpose of this study was to explore the potential of producing hardwood bridge material from cants, including railroad switch ties and pallet cants, which are traditional products of hardwood sawmills. The study contained two components:

1. To determine the availability of cant material from hardwood sawmills, using West Virginia mills as a basis, including (but not limited to) railroad ties,

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[1] *Weekly Hardwood Review.* 1993. Hardwood Publishing Co., Inc., Charlotte, N.C. Vol. 8, No. 51.

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mine material, landscape ties, industrial blocking, and pallet cants.

2. To evaluate visually graded structural-grade lumber yield from log heart cants from six hardwood species groups (red oak, hickory, red maple, yellow-poplar, beech, and white oak). Throughout the study, red oak was considered the base of comparison because it has been specified and used almost exclusively in timber bridge construction, especially in West Virginia. The other species were selected on the basis of their presumed availability and lower market prices relative to red oak.

CANT AVAILABILITY

SPECIES AND SIZES

The availability of sizes, grades, and species of sawn material produced from log hearts was obtained by surveying, through on-site visits and telephone contacts, West Virginia sawmills that produce 3 million board feet (MMBF) or more per year.[2] These mills represent about 17 percent of the total number of mills, but account for about 67 percent of the total lumber production in West Virginia. A total of 47 of 49 sawmills that fit these criteria provided usable information.

Table 1 shows approximate cant production by species for all cant sizes surveyed; cant production amounted to nearly 60 MMBF of annual production. The larger cant volumes of red oak, white oak, and yellow-poplar reflect the more commonly sawn species. Although not reflected in cant production **(Table 1),** red oaks are the most commonly sawn species overall. This fact is not obvious because many sawmills do not produce cants from the red oaks but choose instead to saw through the heart to recover the more valuable grade lumber and to obtain flooring-grade lumber.

The survey also identified 13 separate cant sizes as being produced at West Virginia mills **(Table 2).** The most common cant size is 4 by 6 inches by 8 to 16 feet (102 by 152 mm by 2.4 to 5.0 m) and is marketed almost exclusively to the pallet industry.

CANT GRADES

When mill operators were asked about their method of grading cants, most indicated that the buyer specified the acceptable species and stipulated only that the cant be "Sound Square Edge."[3] This specification is simply a common arrangement that has developed between buyers and sellers. Bridge decking (3 by 8 in. (76 by 203 mm)) and landscape timbers (5-1/2 by 5-1/2 in. (140 by 140 mm)) are also frequently specified by the buyer as being Sound Square Edge.

The National Wooden Pallet and Container Association (NWPCA) has not promulgated, nor does it recognize, a grading system for cants. The only grading specification for mine materials noted by mill managers during the survey was "sound." However, railroad ties are graded under minimum specifications administered by the Railway Tie Association.[4]

AVAILABILITY ASSESSMENT

Timber bridge lumber could be ordered directly from a sawmill by specifying that, for cost considerations, the lumber be produced from resawing cants squared on the mill headrig. Under most conditions, this will yield lumber that varies no more than l/8-inch (3 mm) from the operator's target size. For structural purposes, it is important that lumber be sound. Therefore, the buyer might consider specifying "no rot" and "no shake." The structural grading rules allow some wane, which could also be specified by the buyer. Because of a lack of understanding of structural lumber grades and uncertainty on the part of sawmill managers as to grading costs, buyers will need to arrange for structural lumber grading at their own expense.

It is important to specify lumber widths no greater than 9 inches (229 mm). Mill managers overwhelmingly indicated that a 10-inch- (254-mm-) wide board would dramatically increase cost because of the board's position in the log with regard to grade lumber recovery.

A disadvantage of specifying the least popular species is the time involved until that species is again sawn by the mill. This is particularly important for beech and hickory cants and, to a lesser extent, for red maple cants. The limited availability of such species is reflected in the fact that 1/3 of the mills surveyed do not produce beech and hickory and, for many of those that do, these species are sawn as seldom as 2 to 4 times per year.

TABLE 1. — West Virginia annual cant production by study species.

Species	Volume	Volume
	(MBF)[a]	(%)
Red oak	16,671	28
White oak	13,124	22
Yellow-poplar	18,965	32
Soft maple	5,447	9
Beech	2,267	4
Hickory	2,695	5

[a] MBF = thousand board feet. One board foot = 0.0024 m^3.

TABLE 2. — West Virginia annual cant production by cant size for all study species.

Cant size[a] (8- to 16-ft. lengths)	No. of mills producing cants	Volume	Volume
		(MBF)[b]	(%)
3 by 6.5 in.	2	116	0.2
3.5 by 8 in.	1	800	1.4
4 by 4 in.	2	119	0.2
4 by 6 in.	33	40,337	68.2
5 by 6 in.	2	2,040	3.5
5 by 7 in.	3	1,199	2.0
5.5 by 5.5 in.	3	1,890	3.2
5.5 by 6.5 in.	3	1,388	2.3
6 by 6 in.	9	3,990	6.7
6 by 8 in.	5	5,215	8.8
7 by 9 in.	7	1,535	2.6
3 in. by 8 in. by 16 or 18 ft.	3	490	0.8
4 in. by 8 in. by 16 or 18 ft.	1	50	0.1
Total		59,169	100.0

[a] 1 in. = 25.4 mm; 1 ft. = 0.3048 m.

[b] MBF = thousand board feet. One board foot = 0.0024 m^3.

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[2] One board foot = 0.0024 m^3.

[3] National Hardwood Lumber Association. 1990. Rules for measurement and inspection of hardwood and cypress. National Hardwood Lumber Assoc., Memphis, Tenn. p. 68.

[4] The Railway Tie Association. 1993. Specifications for timber crossties. The Railway Tie Assoc., St. Louis, Mo.

TABLE 3. — Study sample pieces by group and species.

Group	Beech	Hickory	Yellow-poplar	Red maple	Red oak	White oak	Sycamore	Hard maple	Group total
1	236	244	240	196	240	0	4	48	1,208
2	0	0	0	0	848	152	0	0	1,000
3	164	108	152	120	112	136	0	0	792
4	240	240	0	0	0	0	0	0	480
All	640	592	392	316	1,200	288	4	48	3,480

TABLE 4. — Drying information for beech and hickory.

Group	Species	MC[a] In	MC[a] Out	No. of days in schedule	Average daily MC reduction
		(%)	(%)		(%)
1	Beech	22.1	10.8	14	0.81
	Hickory	25.2	12.6	14	0.97
4	Beech	31.4	12.9	27	0.69
	Hickory	41.0	11.8	25	1.17

[a] MC = moisture content.

DISCUSSION

The results of the survey of hardwood sawmills in West Virginia indicate reasonable availability of cant material for bridge applications. The range of sizes available indicates a number of opportunities to obtain lumber of various dimensions, up to 9 inches (229 mm) wide, without incurring a price premium. Buyers of cant material should recognize that each mill is different in terms of physical capabilities, access to raw material, and management philosophy with regard to grade recovery, production costs, prices, and markets. A pertinent example with regard to markets is the recent strong demand in the flooring and dimension part industries for cant material from pallet producers and tie manufacturers in a market that is also experiencing strong demand for lower grade appearance lumber. Although cant prices remain competitive relative to those of the upper grades of appearance lumber, supply may be somewhat restricted because of the level of competition in the marketplace.

STRUCTURAL LUMBER YIELDS FROM LOG HEART CANTS

This component of the project involved a yield study of cant material currently utilized to supply the hardwood bridge program. The material was expanded to include a total of six species. A mill that currently fabricates timber bridges in West Virginia under the National Timber Bridge Initiative was contracted to furnish red and white oak lumber already in-stream for grading purposes only and lumber sawn from red oak and five alternative species for further processing and grading. The latter was resawn from graded switch ties on a gang-rip saw to nominal 2- by 7-inch dimensions (standard 38 by 165 mm; hereafter called 2 by 7). In addition, a second mill in West Virginia provided mill-run cants (6 by 8 in. (152 by 203 mm)) that were processed on a bull-edger to nominal 2- by 6-inch lumber and graded on-site. (Note: standard 38- by 140-mm lumber; hereafter called 2 by 6).

METHODS

The yield study was designed to determine the structural grade yield from 7- by 9-inch (178- by 229-mm) freshly sawn, graded switch ties and from 6- by 8-inch (152- by 203-mm) freshly sawn, mill-run (ungraded) pallet cants. All ties were end-coated to reduce defects from drying. The ties were ripped into 7-inch- (178-mm-) wide dimension lumber and nominal 2-inch (51 mm) thickness (actual green thickness was 1.75 in. (44.5 mm)). Allowing for kerf and sawing variation, four boards were produced from each tie.

The mill-run pallet cants were sawn from logs available at the mill log yard. The cants were not end-coated because they were processed immediately through the bull edger. Four boards were produced from each cant.

All lumber was graded by one of two agencies certified to grade structural hardwood lumber (i.e., the Northeastern Lumber Manufacturer's Assoc. or Timber Products Inspection). Grade was based on the standard grades for joists and planks: Select Structural (SS), No. 1, No. 2, and No. 3. All grade lumber, including Below Grade, was tallied to compare and determine the relative yields among species and cant types.

GREEN LUMBER

Four different groups of green lumber were used in this study. **Table 3** gives the sample breakdown by group and species.

Group 1 consisted of 1,208 pieces sawn from 302 7- by-9 switch ties.[4] The intention was to obtain 240 pieces each of beech, hickory, yellow-poplar, red maple, and red oak.

Group 2 contained 1,000 pieces of 2 by 7 lumber sawn from two hundred fifty 7-by-9 red and white oak switch ties. The data were obtained during the sawing of the switch ties into timber bridge components at the bridge fabricator's plant in West Virginia.

Group 3 consisted of 792 pieces of 2 by 6 lumber of 6 species (beech, hickory, yellow-poplar, red maple, red oak, and white oak) sawn from 198 mill-run cants at a local hardwood sawmill.

Group 4 contained 480 pieces of 2 by 7 beech and hickory lumber sawn from 120 graded switch ties. This material was purchased from the bridge fabricator to augment the group 1 sample for subsequent mechanical testing.

The lumber from all four groups was identified by tie or cant and board number as it was sawn. All lumber was structurally graded by the same grader within 7 days after sawing. The green yield data were used to compare the groups for the effects of cant source and species on yield.

DRY LUMBER

The green lumber from groups 2 and 3 was not processed beyond the green stage. The lumber from groups 1 and 4 was dried and regraded using three different procedures. All beech and hickory boards were dried to about 12 percent moisture content (MC) in four charges in a small dehumidification kiln using a relatively gentle schedule. The group 1 beech and hickory were stored under roof on stickers for about 10 months before kiln-drying. The group 4 beech and hickory were sawn and dead-stacked shortly before kiln-drying. Drying information for these two groups of beech and hickory is given in **Table 4.** After drying, all boards were regraded (unsurfaced) by the same grader who graded the green lumber.

TABLE 5. — Summary of chi-square tests: mill run cants compared to graded switch ties.

		NeLMA grade frequencies					
Species	Cant type	SS	No. 1	No. 2	No. 3	Below grade	Total chi-square[a]
Beech	**Mill run**	14	3	23	67	57	34.163
	% of row	8.5	1.8	14.0	40.9	34.8	
	(cell chi-square)	(0.224)	(2.220)	(10.264)	(0.647)	(12.053)	
	Graded switch tie	48	24	150	170	84	
	% of row	10.1	5.0	31.5	35.7	17.6	
	(cell chi-square)	(0.077)	(0.765)	(3.536)	(0.223)	(4.153)	
Hickory	**Mill run**	25	2	17	27	37	102.538
	% of row	23.1	1.9	15.7	25.0	34.3	
	(cell chi-square)	(0.080)	(5.387)	(14.239)	(2.111)	(62.015)	
	Graded switch tie	120	47	209	85	23	
	% of row	24.8	9.7	43.2	17.6	4.8	
	(cell chi-square)	(0.018)	(1.202)	(3.177)	(0.471)	(13.838)	
Yellow-poplar	**Mill run**	15	8	49	39	41	120.399
	% of row	9.9	5.3	32.2	25.7	27.0	
	(cell chi-square)	(19.982)	(10.359)	(0.944)	(10.642)	(31.787)	
	Graded switch tie	101	53	61	21	4	
	% of row	42.1	22.1	25.4	8.8	1.7	
	(cell chi-square)	(12.655)	(6.561)	(0.598)	(6.740)	(20.132)	
Red maple	**Mill run**	4	5	18	33	60	64.289
	% of row	3.3	4.2	15.0	27.5	50.0	
	(cell chi-square)	(6.495)	(1.110)	(5.045)	(0.477)	(26.749)	
	Graded switch tie	31	16	62	65	22	
	% of row	15.8	8.2	31.6	33.2	11.2	
	(cell chi-square)	(3.976)	(0.679)	(3.089)	(0.292)	(16.377)	
Red oak	**Mill run**	6	6	36	48	16	11.586
	% of row	5.4	5.4	32.1	42.9	14.3	
	(cell chi-square)	(0.087)	(0.288)	(4.533)	(3.234)	(2.363)	
	Graded switch tie	51	74	513	349	101	
	% of row	4.7	6.8	47.2	32.1	9.3	
	(cell chi-square)	(0.009)	(0.030)	(0.467)	(0.333)	(0.243)	
White oak	**Mill run**	18	6	34	52	26	11.066
	% of row	13.2	4.4	25.0	38.2	19.1	
	(cell chi-square)	(0.375)	(0.056)	(3.043)	(2.366)	(0.000)	
	Graded switch tie	15	8	63	37	29	
	% of row	9.9	5.3	41.4	24.3	19.1	
	(cell chi-square)	(0.335)	(0.051)	(2.722)	(2.117)	(0.000)	
All species	**Mill run**	82	30	177	266	237	252.929
	% of row	10.4	3.8	22.4	33.6	29.9	
	(cell chi-square)	(5.548)	(13.543)	(40.470)	(6.155)	(129.650)	
	Graded switch tie	385	225	1072	738	268	
	% of row	14.3	8.4	39.9	27.46	10.0	
	(cell chi-square)	(1.635)	(3.990)	(11.924)	(1.814)	(38.201)	

[a] Chi-square value > 9.49 implies independent distributions at a practical level. Each pair of rows summarizes an independent test; chi-squares do not total downward.

The remaining four species of lumber in group 1 (red oak, yellow-poplar, red maple, and hard maple) were stored under roof on stickers for 12.5 months and were air-dry (below 19% MC) at the time of regrading. The green and dry grade distributions were compared to determine the effect of drying on yield.

STATISTICAL METHODS

Because the data (for both the green and dry lumber by grade) were collected in the form of frequency counts, row by column (*r* ö *c*) contingency tables were used to present the data. In these tables **(Tables 5** to **8),** $r = 2$ and $c = 5$. The rows represent either two species or mill-run compared to graded switch-tie cants, or green compared to dry lumber. The columns correspond to the five grades: SS, No. 1, No. 2, No. 3, and Below Grade. Each lumber piece in a sample was assigned to the appropriate cell of a table. We wanted to test the hypothesis that the probability of being in a given grade did not vary from row to row. A chi-squared analysis was performed.

The test statistic for this procedure is defined as follows:[5]

$$T = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

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[5] Conover. W.J. 1980. Practical Nonparametric Statistics. John Wiley & Sons, New York. 493 pp.

TABLE 6. — Summary of chi-square tests; red oak compared to alternative species groups 1, 2, and 4 (graded switch ties).

Species	Row title	NeLMA grade frequencies					Total chi-square[a]
		SS	No. 1	No. 2	No. 3	Below grade	
Red oak	Frequency	51	74	513	349	101	56.877
	% of row	4.7	6.8	47.2	32.1	9.3	
	(cell chi-square)	(4.637)	(0.498)	(5.814)	(0.402)	(5.961)	
Beech	Frequency	48	24	150	170	84	
	% of row	10.1	5.0	31.5	35.7	17.6	
	(cell chi-square)	(10.598)	(1.138)	(13.289)	(0.918)	(13.623)	
Red oak	Frequency	51	74	513	349	101	163.602
	% of row	4.7	6.8	47.2	32.1	9.3	
	(cell chi-square)	(38.328)	(1.134)	(0.354)	(7.871)	(2.684)	
Hickory	Frequency	120	47	209	85	23	
	% of row	24.8	9.7	43.2	17.6	4.8	
	(cell chi-square)	(86.159)	(2.549)	(0.795)	(17.693)	(6.034)	
Red oak	Frequency	51	74	513	349	101	362.573
	% of row	4.7	6.8	47.2	32.1	9.3	
	(cell chi-square)	(43.417)	(8.678)	(3.884)	(6.940)	(2.607)	
Yellow-poplar	Frequency	101	53	61	21	4	
	% of row	42.1	22.1	25.4	8.8	1.7	
	(cell chi-square)	(196.822)	(39.339)	(17.605)	(31.463)	(11.819)	
Red oak	Frequency	51	74	513	349	101	42.293
	% of row	4.7	6.8	47.2	32.1	9.3	
	(cell chi-square)	(4.917)	(0.067)	(1.363)	(0.009)	(0.100)	
Red maple	Frequency	31	16	62	65	22	
	% of row	15.8	8.2	31.6	33.2	11.2	
	(cell chi-square)	(27.292)	(0.372)	(7.568)	(0.051)	(0.554)	
Red oak	Frequency	51	74	513	349	101	99.066
	% of row	4.7	6.8	47.2	32.1	9.3	
	(cell chi-square)	(3.839)	(0.001)	(0.292)	(0.051)	(0.003)	
Hard maple	Frequency	19	3	10	11	5	
	% of row	39.6	6.25	20.8	22.9	10.4	
	(cell chi-square)	(87.010)	(0.020)	(6.624)	(1.166)	(0.061)	
Red oak	Frequency	51	74	513	349	101	22.908
	% of row	4.7	6.8	47.2	32.1	9.3	
	(cell chi-square)	(0.824)	(0.059)	(0.114)	(0.314)	(1.496)	
White oak	Frequency	15	8	63	37	29	
	% of row	9.9	5.3	41.4	24.3	19.1	
	(cell chi-square)	(5.901)	(0.419)	(0.819)	(2.249)	(10.711)	

[a] Chi-square value > 9.49 implies independent distributions at a practical level. Each pair of rows summarizes an independent test; chi-squares do not total downward.

where:

T = test statistic, where rejection of the null hypothesis takes place when T exceeds the 95th percentile of a chi-square random variable with $(r - 1)(c - 1)$ degrees of freedom.

O_{ij} = number of observations (boards) that fall into the ith row and jth column of the $r \times c$ contingency table

E_{ij} = expected number of observations in the ith row and jth column of the $r \times c$ contingency table, and is calculated as $(R_iC_j)/N$, where R_i is the total number of observations in row i, C_j is the total number of observations in column j, and N is the total number of observations in the sample

RESULTS

EFFECT OF CANT SOURCE

Part 1 of the analysis was designed to compare the structural yield distributions of green lumber sawn from graded switch ties to the distributions of green lumber sawn from mill-run cants. Distribution frequencies were found by sorting the mill-run cants (group 3) from the rest of the sample using the SAS Proc Sort procedure[6] and generating a frequency table of species versus green NeLMA (Northeastern Lumber Manufacturers Assoc.) grades for each group.[7] Chi-square tests were run under the same procedure to test whether the combined structural grade distributions of groups 1, 2, and 4 (switch-tie lumber) for each species were the same as the distributions for group 3 (mill-run cant lumber) structural grades.

The grade frequencies and results of the chi-square tests between the green NeLMA grade distributions of lumber from both sources is shown by species in

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[6] SAS Procedures Guide. 1988. SAS Institute, Inc., Cary, N.C.

[7] Northeastern Lumber Manufacturers Association. 1986. Standard grading rules for Northeastern lumber. Northeastern Lumber Manufacturers Assoc., Cumberland Center, Maine.

Table 5. For all species, the grade distributions were found to be different for lumber sawn from mill-run cants and graded switch ties. Generally, the mill-run cants produced lower grades and a much higher percentage of Below Grade lumber. (Note the very high chi-square value in the All Species, Mill-Run, Below Grade cell.) The two species that deviated from this trend were red oak and white oak. For both species, the major difference was that graded switch ties contained a greater proportion of No. 2 pieces and fewer No. 3 pieces than did the mill-run cants. Red maple and beech distributions were particularly poor for the mill-run cants—more than 75 percent of the lumber was graded No. 3 or Below Grade. Although hickory and yellow-poplar mill-run distributions contained higher percentages of the better grades, they still compared less favorably to the grade distributions from the switch ties.

More than 42 percent of the yellow-poplar switch-tie lumber was graded SS. This may be an artificially high figure caused by lack of randomness in sample procurement. Because switch ties are not normally sawn from yellow-poplar, the yellow-poplar ties used were bought specifically for this study and may not be representative of a normal mix of ties found in the supplier's yard. It is therefore likely that the grade of yellow-poplar ties sawn in the future would not be as high as that of the sample used here.

Effect of species

Part 2 of the analysis was designed to determine if the green structural grade distributions were species independent. Because red oak was to serve as a baseline for evaluating the efficacy of utilizing alternative species, the chi-square tests were performed pairwise, using red oak as the base comparison.

Two specific analyses were of interest. The first analysis combined all data for graded switch ties (i.e., groups 1, 2, and 4) to make pairwise species comparisons of all species with red oak **(Table 6).** The contingency table results indicated that all the alternative species in group 1 had different distributions than red oak. The beech and white oak distributions had more spread than did the red oak distribution. Both beech and white oak showed percentages of SS and Below Grade that were higher than expected and percentages that were lower than expected in the middle of the distribution. Hickory, red maple, and yellow-poplar showed more shifts toward higher grades compared to red oak. Because of the relatively small sample of hard maple boards, the results should not be considered especially reliable for this species. The low percentages in the No. 3 grade and high percentages in the SS cells for both hickory and yellow-poplar were important when compared to red oak. The red maple distribution showed more SS frequency than expected, accounting for the majority of the observed difference with red oak.

The second analysis consisted of pair-

TABLE 7. — Summary of chi-square tests; red oak compared to alternative species group 3 (mill-run cants).

		NeLMA grade frequencies					
Species	Row title	SS	No. 1	No. 2	No. 3	Below grade	Total chi-square[a]
Red oak	Frequency	6	6	36	48	16	24.296
	% of row	5.4	5.4	32.1	42.9	14.3	
	(cell chi-square)	(0.552)	(1.509)	(6.073)	(0.038)	(6.265)	
Beech	Frequency	14	3	23	67	57	
	% of row	8.5	1.8	14.0	40.9	34.8	
	(cell chi-square)	(0.377)	(1.031)	(4.147)	(0.026)	(4.279)	
Red oak	Frequency	6	6	36	48	16	34.596
	% of row	5.4	5.4	32.1	42.9	14.3	
	(cell chi-square)	(6.063)	(0.912)	(3.014)	(2.524)	(4.470)	
Hickory	Frequency	25	2	17	27	37	
	% of row	23.2	1.9	15.7	25.0	34.3	
	(cell chi-square)	(6.287)	(0.946)	(3.126)	(2.618)	(4.635)	
Red oak	Frequency	6	6	36	48	16	12.248
	% of row	5.4	5.4	32.1	42.9	14.3	
	(cell chi-square)	(0.950)	(0.001)	(0.000)	(3.333)	(2.768)	
Yellow-poplar	Frequency	15	8	49	39	41	
	% of row	9.9	5.3	32.2	25.7	27.0	
	(cell chi-square)	(0.700)	(0.000)	(0.000)	(2.456)	(2.040)	
Red oak	Frequency	6	6	36	48	16	34.508
	% of row	5.4	5.4	32.1	42.9	14.3	
	(cell chi-square)	(0.285)	(0.090)	(3.783)	(2.024)	(11.667)	
Red maple	Frequency	4	5	18	33	60	
	% of row	3.3	4.2	15.0	27.5	50.0	
	(cell chi-square)	(0.266)	(0.084)	(3.531)	(1.889)	(10.889)	
Red oak	Frequency	6	6	36	48	16	6.335
	% of row	5.4	5.4	32.1	42.9	14.3	
	(cell chi-square)	(2.160)	(0.062)	(0.609)	(0.178)	(0.464)	
White oak	Frequency	18	6	34	52	26	
	% of row	13.2	4.4	25.0	38.2	19.1	
	(cell chi-square)	(1.779)	(0.051)	(0.501)	(0.147)	(0.382)	

[a] Chi-square value > 9.49 implies independent distributions at a practical level. Each pair of rows summarizes an independent test; chi-squares do not total downward.

TABLE 8. — Summary of chi-square tests: green NeLMA grades compared to dry NeLMA grades. Groups 1 and 4 combined.

		NeLMA grade frequencies					
Species	Condition	SS	No. 1	No. 2	No. 3	Below grade	Total chi-square[a]
Beech	**Green**	48	24	150	170	84	21.459
	(cell chi-square)	(0.107)	(2.318)	(1.067)	(0.298)	(6.871)	
	Dry	43	11	124	154	138	
	(cell chi-square)	(0.108)	(2.347)	(1.081)	(0.302)	(6.959)	
Hickory	**Green**	120	47	209	85	23	24.161
	(cell chi-square)	(2.656)	(0.252)	(0.755)	(3.283)	(5.085)	
	Dry	86	40	183	121	50	
	(cell chi-square)	(2.678)	(0.254)	(0.761)	(3.311)	(5.127)	
Yellow-poplar	**Green**	101	53	61	21	4	14.120
	(cell chi-square)	(1.127)	(0.478)	(0.001)	(4.446)	(6.527)	
	Dry	80	43	61	45	9	
	(cell chi-square)	(1.137)	(0.482)	(0.001)	(4.483)	(6.473)	
Red maple	**Green**	31	16	62	65	22	56.883
	(cell chi-square)	(7.843)	(6.178)	(0.439)	(11.256)	(2.726)	
	Dry	71	43	52	21	9	
	(cell chi-square)	(7.843)	(6.178)	(0.439)	(11.256)	(2.726)	
Red oak	**Green**	21	35	99	72	13	16.392
	(cell chi-square)	(5.374)	(0.256)	(0.020)	(2.512)	(0.000)	
	Dry	48	29	101	47	13	
	(cell chi-square)	(5.419)	(0.258)	(0.020)	(2.533)	(0.000)	
Hard maple	**Green**	19	3	10	11	5	8.583
	(cell chi-square)	(0.000)	(1.500)	(0.333)	(1.125)	(1.333)	
	Dry	19	9	14	5	1	
	(cell chi-square)	(0.000)	(1.500)	(0.333)	(1.125)	(1.333)	
All species	**Green**	340	178	595	424	151	17.027
	(cell chi-square)	(0.085)	(0.000)	(1.249)	(0.464)	(6.679)	
	Dry	348	176	537	393	220	
	(cell chi-square)	(0.086)	(0.000)	(1.259)	(0.468)	(6.735)	

[a] Chi-square value > 9.49 implies independent distributions at a practical level. Each pair of rows summarizes an independent test; chi-squares do not total downward.

wise comparisons (red oak compared to beech, hickory, yellow-poplar, red maple, and white oak) of the yields from ungraded, mill-run cants (group 3). The chi-square test results in **Table 7** show that yellow-poplar and white oak were practically distributed like red oak, whereas beech and red maple had low No. 2 and high Below Grade percentages when compared to red oak. The distribution of group 3 hickory, with high SS and Below Grade percentages, was spread more uniformly than that of red oak. Finally, yellow-poplar exhibited low No. 3 yield, high Below Grade yield, and almost twice the SS yield as that of red oak.

EFFECT OF DRYING

The chi-square analysis between NeLMA grades for the same lumber when green and dry in groups 1 and 4 combined is summarized in **Table 8.** A practical difference was found in the green NeLMA grade distribution for the All Species category compared to the dry NeLMA grade distribution; the major shift was an increased frequency of Below Grade boards in the dry category. Some drying degrade is expected and considered normal.

When considered by species, hard maple maintained its grade distribution when dried. Conversely, beech, hickory, red maple, yellow-poplar, and red oak grade distributions changed when the lumber was dried. The beech distribution decreased slightly in all the grades and increased substantially in the Below Grade category. The hickory distribution dropped in the top three grades and increased in the No. 3 and Below Grade categories. In both cases, the Below Grade increases exerted the greatest influence on the chi-square values, pushing them beyond the range of acceptance. Yellow-poplar yields decreased in the SS and No. 1 grades, with substantial increase in No. 3 grade. Unexpectedly, the red maple and red oak distributions appeared to improve as a result of drying. No obvious reason for this was evident, since only one grader was used. Other studies that included grade before and after drying had similar results.

A question arises as to whether the beech and hickory drying degrade was species dependent or a result of kiln-drying. Because monitoring drying degrade was not a goal of our study, there was no air-dried control for these two species and the information for answering that question was not directly available. However, a comparison of group 1 and group 4 boards indicated a possible influence resulting from drying. A contingency table analysis was performed on the following four combinations:

1. Green grade yield of group 1 compared to group 4 beech. Results indicated that these distributions had a non-practical difference (chi-square test statistic = 3.21< 9.49).

2. Green grade yield of group 1 compared to group 4 hickory. Results indicated that these distributions had a practi-

TABLE 9. — Percentage yield of No. 2 and Better green structural lumber by species and cant source.

Species	Graded switch-ties	Mill-run cants
	(%)	
Yellow-poplar	89.6	47.4
Hickory	77.7	40.7
Red oak	58.7	42.9
White oak	56.6	42.6
Red maple	55.6	22.5
Beech	46.6	24.3
All species	62.6	36.6

cal difference (chi-square test statistic = 31.38 >9.49).

3. Dry grade yield of group 1 compared to group 4 beech. The distributions in this case had a practical difference (chi-square test statistic = 23.54> 9.49).

4. Dry grade yield of group 1 compared to group 4 hickory. The distributions had a non-practical difference (chi-square test statistic = 7.79 < 9.49).

The fact that moving from the green condition to the dry condition caused practical differences in the grade yield distributions for both species (albeit different changes) indicates a possible influence resulting from the way in which the two groups of lumber were dried. while not conclusive, this result does point to the need for close consideration of the drying aspect.

DISCUSSION

The results indicate that there is a positive potential for producing structural grade lumber for the species studied. However, several factors will come into play. The source of the cant (graded switch ties or mill-run cants) was found to have a pronounced effect on the structural lumber yield for all species. The structural lumber grade distributions were generally shifted more toward the lower grades for lumber sawn from mill-run cants compared to lumber sawn from graded switch ties. Species was found to affect yield, when compared to red oak, in all cases. Beech, red maple, and white oak were found to have lower or more uniformly spread grade distributions than that of red oak. Yellow-poplar, hickory, and hard maple (with a limited sample) grade yields were shifted more toward the higher grades than was red oak.

Drying had varied effects on yield distributions, depending on the species. Beech and hickory lumber generally declined in grade when dried on a gentle schedule in a dehumidification kiln. Hard maple lumber maintained its grade distribution when air-dried, wherein red maple and red oak distributions improved when air-dried. Air-dried yellow-poplar exhibited a decline in grade over the green yields.

From a commercial standpoint, structural lumber is often marketed as No. 2 and Better. Therefore, for a mill manager who is considering the production of visually graded structural lumber, the yield percentage in No. 2 and Better is probably the critical measure for determining the viability of the opportunity **(Table 9).** Yellow-poplar and hickory yields from the switch ties are the highest.

The results strongly indicate that success In producing structural lumber from cant material will require some sort of grading scheme, possibly like the grading specifications for railroad ties. In addition, from a sawmiller's point of view, the decision to cut structural lumber will involve examining the economic tradeoff between selling cants outright, cutting them into appearance-graded lumber, or cutting them into nominal 2- inch-thick (standard 38-mm-thick) material, sorting out the No. 2 and Better structural lumber, and marketing the remainder as appearance-graded lumber.