AUTOSAW Simulations of Lumber Recovery for Small-Diameter Douglas-Fir and Ponderosa Pine From Southwestern Oregon

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Abstract

Small-diameter (5- to 10-inch diameter at breast height) Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) trees were assessed for product potential by diagramming the location, size, and type of knots visible on the wood surface (inside bark) and using the AUTOSAW sawing simulator to evaluate the resulting log descriptions. The logs were then sawn to dimension lumber, dried, and graded. More than 85 percent of the resulting Douglas-fir lumber was assigned to the "No. 2 and better" group, whereas about 50 percent of the pine was assigned to the "Standard and better" group. AUTOSAW consistently underestimated (by 10 to 15 percent) the volume recovered from the logs. A correction factor could be applied to compensate for this variance. The simulator predicted higher yields of higher grade lumber than were obtained empirically. This was anticipated given the program's inability to account for knots hidden beneath the wood surface. Alternative sawing scenarios examined by using AUTOSAW suggest that greater value could have been recovered from the small-diameter Douglas-fir if it had been cut to 1- or 5/4-inch thickness and graded as "Factory" lumber. The ponderosa pine would have been more valuable cut to 1-inch thickness and graded as "Common" rather than dimension lumber.

Keywords: Small-diameter timber, volume recovery, AUTOSAW, sawing simulation, value recovery, wood product value.

Introduction

The accumulation of small trees in forests over much of the Western United States has created conditions where uncharacteristically large and severe fires are increasingly likely. Removing these small trees from densely stocked stands can reduce the intensity of the fires that do occur. It might also lower the probability or extent of insect or disease outbreaks. In certain situations, sale of the harvested trees will offset the costs of silvicultural treatments, and the conversion of these trees into wood products also can provide jobs in rural communities where few economic opportunities exist.

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The work described here demonstrates simple methods for simulating the wood product potential of small trees (5 to 10 inches in diameter at breast height [d.b.h.]). We examine broad classes of products, such as structural and appearance-grade lumber, to answer questions about how well the existing resource is suited to the manufacture of those products. We anticipate that this type of analysis will complement analyses such as those described by Funck and Zeng (1999) that use optimization to evaluate specific manufacturing processes. The simulation methods used in this report are designed to identify the tree and stand characteristics associated with higher wood product potentials. Wang et al. (in press) use the same set of trees to evaluate the mechanical properties of the lumber recovered from small trees. Together our results and those of Wang et al. (in press) provide information useful in policy-level analyses that examine manufacturing opportunities for small-diameter trees from densely stocked stands in southwestern Oregon.

Methods

Tree Selection and Log Measurement

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) trees were selected from the Applegate Ranger District on the Rogue River National Forest. One hundred forty-four ponderosa pine trees were chosen from areas designated as "No Name" and "Squaw Ridge" by ranger district staff for use in potential timber sales. One hundred forty-six Douglas-fir were identified from Yale Twin timber sale and an area designated as "Toe Top" that was being examined for an anticipated timber sale. Trees of both species ranged from 5 to 10 inches d.b.h. Transit times for stress waves within each standing tree were measured and used in a companion study on mechanical properties (Wang et al., in press).

A subsample of six Douglas-fir and six ponderosa pine trees were selected (from the Toe Top and Squaw Ridge units) for destructive sampling. These 12 trees were given unique numbers, and their breast-height diameters were recorded to the nearest tenth of an inch. As trees were felled, their total height and height to a 4-inch top were recorded. The length, large- and small-end diameters, and bark thickness of each log also were recorded. Logs were tagged with unique numbers that identified the tree number and log position within the tree. The six Douglas-fir trees yielded 24 ten-foot logs and 1 six-foot log. The six ponderosa pine trees yielded 17 ten-foot logs.

All logs from these 12 trees were diagrammed to describe and locate knots for size, azimuth, and linear distance from the large end of the log (Barbour et al. 1999). This log diagram information was used to create a data file describing the log. The data file (.dat file) was used as input by the AUTOSAW sawing simulator (Todoroki 1990).

Lumber Processing and Testing

Once field measurements and diagramming were complete, the logs were bundled on pallets and shipped to Michigan Technological University (MTU) in Houghton, Michigan. At MTU the logs were tested by using three methods of nondestructive evaluation (NDE): stress wave timing (longitudinal), transverse vibration, and static bending (Wang et al., in press). After NDE data were collected, logs were sawn into 2 by 4 and 2 by 6 dimension lumber on a portable horizontal band sawmill. As logs were sawn, the position of the azimuth reference line on the log end was recorded, and the position of each piece of lumber sawn from each log was drawn on a diagram sheet showing an end view of the sawn log. The piece number (e.g., 22A, 22B, 22C for the first, second, and third piece removed from log 22) was written on each piece of lumber (fig. 1).
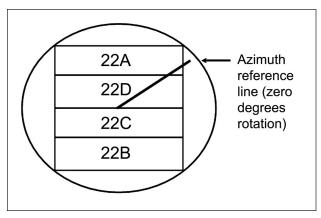
Figure 1—Typical sawing pattern, log orientation, and piece numbering. Piece numbers are not sequential because the log was rotated 180 degrees after the first piece of lumber was removed.

After sawing, each piece of lumber was measured to obtain green thickness and width. The pieces were then tested for stress wave timing (longitudinal), transverse vibration, and static bending (Wang et al., in press). Lumber was stacked with stickers between each course and allowed to air dry until it reached a moisture content of approximately 15 percent. When dry, the lumber was planed to industry standard thickness and width (1.5 inches thick by 3.5 or 5.5 inches wide) for surfaced dry lumber. The dry lumber was then tested in the same three ways as when green (transverse, longitudinal, and static bending) (Wang et al., in press).

After planing was complete, a lumber grading inspector from the Northeastern Lumber Manufacturers' Association examined each piece and awarded it two or three grades based on rules established by the American Lumber Standards Committee (2000). Two by four lumber was graded by using "light framing" and "structural light framing" rules for visually graded lumber plus the "visual quality" rule for machine stress-rated lumber. Two by six lumber was graded by using the "joist and plank" rule for visually graded lumber plus the "visual quality" rule for machine stress-rated lumber. The reason each piece was not placed in the next higher grade also was recorded along with the assigned grades. This information was used in understanding the differences between the empirical grades and the grades assigned by AUTOSAW.

Sawing Simulation

Log diagram data were entered into the AUTOSAW sawing simulator. Sawing diagrams were used to duplicate sawing patterns for each log as nearly as possible (e.g., fig. 1). The cubic recovery percentage (CRP: cubic feet of lumber per cubic foot of log) and outturn of dimension lumber by grade for simulated sawing and empirical sawing were compared. The yields of appearance grades of lumber also were simulated for this set of logs to demonstrate how sawing simulation might be used in evaluating the wood product potential of a resource.

Results and Discussion

Lumber Recovery

Empirical results—Volume recovery percentages measured for the portable sawmill (empirical results) and those estimated by AUTOSAW (simulated results) are reported in table 1. Results are reported for rough green lumber tally and for surfaced dry lumber tally. There is typically a curvilinear relation between CRP and log small-end diameter (SED) with the model form of 1/SED or 1/SED^2 (Ayer-Sachet and Fahey

Table 1—Average cubic recovery percentage (cubic feet of lumber per cubic foot of log) for all logs from six trees each of Douglas-fir and ponderosa pine

Type	Rough green			Surfaced dry	
	N	*Mean*	*SD*	*Mean*	*SD*
Douglas-fir:					
Empirical	25	62	13.1	50	10.9
Simulated	24	48	10.4	37	8.1
Difference		14		13	
Ponderosa pine:					
Empirical	16	51	15.6	41	12.5
Simulated	14	38	9.4	30	7.4
Difference		13		11	

Note: The table compares results for the Wood Mizer® portable sawmill [a] (empirical) and the AUTOSAW sawing simulator (simulated). N = number, SD = standard deviation.

1988, Fahey 1983, Parry et al. 1996, Willits and Fahey 1988), but in this case regressions for rough green CRP on diameter were nonsignificant for both Douglas-fir (p = 0.24) and ponderosa pine (p = 0.53). This was probably because of the small sample size and narrow log SED range (3.5 to 9 inches in Douglas-fir and 3.0 to 8 inches in ponderosa pine). Accordingly, only mean CRPs and their standard deviations are reported in table 1. As expected, the CRP for rough green lumber was about 25 percent higher than the CRP for surfaced dry lumber. The empirical results are also in line with those expected from other wood product recovery studies for small-diameter logs (Lowell and Green 2001).

Simulated results—Simulation consistently projected lower CRPs than were found in the empirical study (table 1). We believe this happens because of the way the simulation algorithm deals with wane. AUTOSAW consistently edges lumber to lower levels of wane than were found for the corresponding pieces actually sawn from the logs. In terms of lumber tally, it appears that AUTOSAW is fairly consistent in underestimating volume recovery. It would be a relatively simple matter to increase simulated volume recovery estimates by some uniform amount, say 10 to 15 percent (table 1) to obtain a reasonably close correspondence with empirical results.

Grade Yield

Empirical results—The yield of higher structural lumber grades from Douglas-fir was much better than from ponderosa pine (table 2). More than 85 percent of the Douglas-fir lumber was graded as "No. 2 and better," whereas only about 50 percent of the ponderosa pine lumber was assigned to the "Standard and better" grade group. Warp was an important reason why this lumber was not more highly graded (table 3). Warp has not previously been identified as a problem in lumber sawn from small-diameter Douglas-fir from densely stocked stands, but it has been recognized as a problem in this type of ponderosa pine (Blake and Voorhies 1980, Simpson and Green 2001).

[a]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 2—Volume in board feet and percentage of yield by grade for empirical sawing results (Wood Mizer® outturn) of dimension lumber from all logs in six Douglas-fir and six ponderosa pine trees

Grade	Douglas-fir		Grade	Ponderosa pine	
	Board feet	*Percent*		*Board feet*	*Percent*
Select Structural	148	39.6			
No. 1	0	0.0	Construction	30	9.2
No. 2	174	46.5	Standard	140	42.9
No. 3	45	12.0	Utility	76	23.3
Economy	7	1.9	Economy	80	24.5
Total	374	100	Total	326	100

Table 3—Percentage of lumber tally (volume) degraded at least one grade for warp

Grade	Douglas-fir	Ponderosa pine
	Percent	
No. 1 or Construction	0	0
No. 2 or Standard	44.5	35.0
No. 3 or Utility	25.0	22.3
Economy	0	87.5

Note: Entries in the table indicate the percentage of volume in that grade that could have been graded at least one grade higher if warp were not a factor.

Comparison of empirical and simulated lumber grade yields—The AUTOSAW sawing simulator accounts for wane, knot size, knot location, and knot condition (live or dead), and pith where appropriate, but it does not currently account for warp or other defects such as rot or stain. We therefore adjusted the empirical lumber grade results to remove the in uence of warp in order to compare them with simulated results from AUTOSAW. We increased the grade of the lumber recovered in the empirical sawing study according to the results for warp given in table 3 to re ect what would be expected without warp (table 4). This was done under the assumption that most of the grade-reducing warp in this lumber was of a type that could be controlled by improved drying techniques (Koch 1974). Even with this adjustment the grade-for-grade correspondence between the empirical results and the simulated results is rather poor. For both species, AUTOSAW produced more lumber in the higher grades than was recovered by actually sawing logs. This is not particularly surprising even when warp is eliminated because AUTOSAW does not account for the full range of potential defects.

When the results were further summarized into grade groups (table 5), the comparisons were much better. The comparison of empirical results to the simulated results for No. 2 and better for Douglas-fir is quite good. Even though AUTOSAW projects about 5 percent more volume in the higher grade group than was actually recovered, this result is adequate for many purposes. The result for ponderosa pine is better when grades are grouped, but the correspondence is still not as good as for Douglas-fir. Even with aggregated data, AUTOSAW overestimates the higher quality component

Table 4—Comparison of empirical lumber grade yield (corrected to remove warp) and lumber grade yields simulated with AUTOSAW

Species and grade	Volume, empirical no warp		Volume, AUTOSAW		Difference
	Board feet	Percent	Board feet	- - - Percent - - - -	
Douglas-fir:					
Select Structural	148	39.6	257	80.8	41.2
No. 1	123	32.9	33	10.4	-22.5
No. 2	72	19.3	18	5.7	-13.6
No. 3	24	6.4	10	3.1	-3.3
Economy	7	1.9	0	0.0	-1.9
Total	374	100.0	318	100.0	
Ponderosa pine:					
Construction	79	24.2	135	79.9	55.6
Standard	108	33.1	14	8.3	-24.8
Utility	129	39.6	10	5.9	-33.7
Economy	10	3.1	10	5.9	2.8
Total	326	100.0	169	100.0	0.0

Note: Difference is the simulated grade yield percentage minus the empirical grade yield percentage.

Table 5—Results grouped to compare lumber grade groups that are typically marketed for each species

Grade	Douglas-fir		Ponderosa pine	
	Empirical	AUTOSAW	Empirical	AUTOSAW
	Percentage of yield			
No. 2 and better	92	97		
Standard and better			57	88
No. 3 and Economy	8	3	43	12
Total	100	100	100	100

for ponderosa pine by about 30 percent. The results, however, are useful for comparing the relative quality of the two species and also for understanding the quality concerns generally associated with small-diameter ponderosa pine.

Simulation of different products—Sawing simulation makes it possible to use log characteristics such as stem size and shape, and knot size and location that were collected for each log during the empirical study to consider different sawing patterns or different sets of products. We simulated two additional sets of products by using the same logs that were sawn in the empirical recovery study. Results for simulated sawing of Common lumber (nominal 1-inch thick lumber) are presented in table 6, and results for Select and Factory lumber (Clear and Shop lumber) are presented in table 7. The results presented in table 7 are estimates of the American Lumber Standards grades that are roughly equivalent to the New Zealand clear grades used by AUTOSAW. Composite prices for 2001 for the various lumber grades reported in

Table 6—Simulated yield of Common lumber

Grade	Douglas-fir	Ponderosa pine
	Percentage of yield	
No. 1 Common	74.6	64.2
No. 2 Common	14.1	23.6
No. 3 Common	3.1	3.4
No. 4 Common	8.2	8.8
No. 5 Common	0	0
Total	100.0	100.0

Table 7—Simulated yield of Select (Clear lumber) and Factory lumber (Shop grades)

Grade	Douglas-fir	Ponderosa pine
	Percentage of yield	
D Select and better	52.8	0.0
No. 1 and 2 Shop	11.7	2.1
No. 3 and better Common	10.5	37.7
Utility and Economy	25.0	60.3
Total	100.0	100.1

tables 4, 5, 6, and 7 (table 8 in WWPA 2002) were used to estimate the gross product value for each sawing option. Results from this analysis are illustrated for Douglas-fir in figure 2 and for ponderosa pine in figure 3.

The results shown in these figures suggest that whereas warp decreased gross product value for both species, it was more important in pine than in Douglas-fir. Alternative sawing strategies might substantially increase the gross dollar value per thousand board feet of the small-diameter resource. This is consistent with empirical results reported by Lowell and Green (2001). The most striking difference is the higher gross product value estimated for the Factory lumber option for Douglas-fir. This sawing strategy increased gross product value by about one-third. Under this option, about half of the lumber tally was graded as "Clear" or "Clear one face," roughly equivalent to "D and better Select," and about 12 percent of the lumber was graded as "No. 1 or 2 Shop." Both of these grade groups have rather high prices (table 8). These results, however, might overestimate the volume in these groups (especially the Clear group) because we only measured knots that were visible on the surface of the logs and did not have a way to estimate the number of knots that had been overgrown. By using this technique, we reported several knot-free Douglas-fir logs. It is highly unlikely that this was actually the case, and methods are needed to adjust grades downward to account for overgrown knots. With the methods used here, all the lumber from these logs would be graded as Clear, and it is certain that this would not be the outcome in an empirical study. Even so, the price advantage associated with sawing appearance lumber from these logs is probably large. If, for example, all the lumber graded as Clear were actually downgraded to No. 1 or No. 2 Shop it would still enjoy a price premium of $100 to $177 per thousand board feet as compared to Select Structural (the highest value dimension lumber grade) (see table 8).
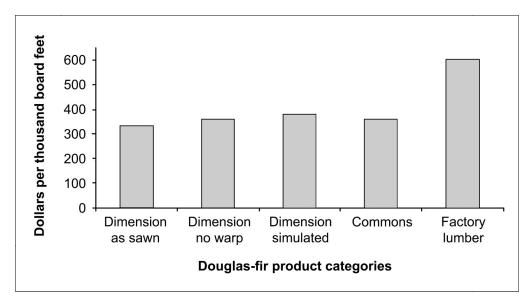
Figure 2—Gross value for processing options for Douglas-fir trees. The dimension as sawn category is the empirical result, dimension no warp is the empirical result corrected for warp, dimension simulated is the AUTOSAW result simulating empirical sawing, Commons is 1-inch (4/4) lumber graded only by using Common lumber grading rules, and Factory lumber is 1-inch lumber graded for Clear, Shop, and Common lumber grades.
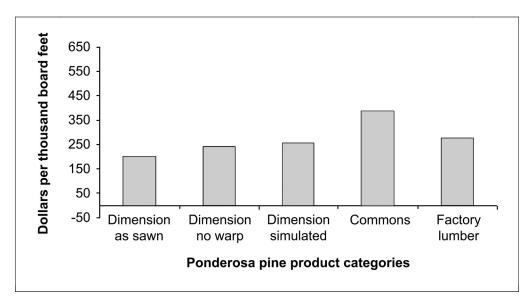

Figure 3—Gross value for processing options for ponderosa pine trees. The dimension as sawn category is the empirical result, dimension no warp is the empirical result corrected for warp, dimension simulated is the AUTOSAW result simulating empirical sawing, Commons is 1-inch (4/4) lumber graded only by using Common lumber grading rules, and Factory lumber is 1-inch lumber graded for Clear, Shop, and Common lumber grades.

Table 8—Western Wood Products Association yearly composite prices per thousand board feet of surfaced dry lumber for 2001

Grade	Douglas-fir	Ponderosa pine
	Dollars per thousand board feet (2001 average)	
Dimension lumber:		
Select Structural	389.72	*
No. 1	386.35	*
No. 2	329.91	*
Standard and better	356.63	264.46
No. 2 and better	329.91	259.10
No. 3 or Utility	203.03	213.65
Economy	115.49	143.98
Common lumber:		
No. 2 and better Common	*	414.66
No. 3 and better Common	366.85	*
No. 3 Common	*	244.40
No. 4 Common	298.17	157.02
No. 5 Common	110.57	96.51
Selects and Factory lumber:		
4/4 by 4-inch D Select and better	872.12	755.59
4/4 No. 1 Shop	569.02	445.32
4/4 No. 2 Shop	480.40	303.00
4/4 Shop Outs	*	171.62

* = Price not available or grade not produced in this species.
Source: WWPA 2002.

Using methods such as those used by Funck and Zeng (1999), where logs were actually dissected and the internal knots and other defects mapped, will eliminate this problem. The disadvantage is that the dissection method does not provide an empirical lumber sample with which to validate simulation results. X-raying the logs would provide an alternative that would allow both validation through empirical sawing of lumber and mapping of internal defects, but CAT scanning equipment was not available for this study.

Our analysis does suggest, however, that small-diameter Douglas-fir can yield dimension lumber that is about as valuable as might be expected from the traditional resource. It also suggests that some improvement in value might be expected if Factory-grade lumber were sawn. In other words, there might be some advantage to sawing either 1- or 5/4-inch lumber over sawing 2-inch dimension from logs of this type.

The results for ponderosa pine are somewhat different. The gross product value for dimension lumber from this sample was fairly low (fig. 3), about $200 per thousand board feet when warp was included and about $250 per thousand board feet when it was not. This compares to about $290 for the framing lumber composite price[3] for late

[3]The Random Lengths framing lumber composite price is a benchmark for framing lumber prices for the Western United States.

2001 (Random Lengths 2001). When 1-inch lumber was sawn, there was a substantial increase in value if the lumber was graded as "Common" rather than dimension lumber, but only a slight increase over the dimension result if the lumber was graded as "Factory lumber." This happened because the logs all contained surface knots, so AUTOSAW did not simulate recovery of very high value Select (Clear) lumber (table 8). Consequently, the outcome for ponderosa pine might actually better represent reality than the result we report for Douglas-fir Factory lumber.

The conclusion that, for both species, Common or Factory lumber could provide a higher value alternative to dimension lumber is worth exploring with additional empirical work. In fact, this has already been done for ponderosa pine from the Flagstaff, Arizona, area (Lowell and Green 2001) and the results agree quite well with the simulated result reported.

Conclusions

The AUTOSAW sawing simulator consistently underestimated the lumber tally by about 10 to 15 percent. This difference between simulated and empirical results could easily be adjusted for during analyses. For both Douglas-fir and ponderosa pine, the lumber grade yield results suggest that one-to-one correspondence between empirical and simulated results is not possible when diagramming of surface knots is used without evaluation of internal defects. Simulation of alternative sawing patterns suggested that production of Common and Factory lumber, as opposed to dimension lumber, could result in higher value recoveries, but additional empirical studies will be needed to confirm this result.

Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters
Cubic feet	.0283	Cubic meters

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