Examining the Use of Internal Defect Information for Information-Augmented Hardwood Log Breakdown

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Abstract. In present-day hardwood sawmills, log breakdown is hampered by incomplete information about log geometry and internal features. When internal log scanning becomes operational, it will remove this roadblock and provide a complete view of each log's interior. It is not currently obvious, however, how dramatically this increased level of information will improve log breakdown by the sawyer. In this study, 3 hypothetical logs were generated (grades 1-3) and sawn via computer simulation using 6 established log sawing heuristics—with and without the use of internal information. These same logs were also computer sawn by applying new heuristics that take advantage of complete, defect information. Following edging and grading operations the lumber values obtained from each log breakdown were compared. Preliminary results indicate that—in the absence of an optimal log breakdown procedure—increased information about internal log features can improve value recovery by 8.5% for grade #1 logs. Lumber values for lower grades do not change significantly, which suggests that choosing a breakdown pattern with high value recovery becomes very difficult when viewing logs with many internal defects.

Introduction

The manufacture of furniture, cabinets, flooring, millwork, and molding, along with hardwood exports, accounts for most of the high- and medium-grade hardwood lumber consumption in the U. S. (Bush and others 1992). Because the value of hardwood lumber is inversely proportional to the quantity and size of defects, each log must be sawn to minimize the defects in the resulting boards. Traditionally, the sawyer chooses a sawing strategy by visually examining the exterior of a log, dynamically adjusting the cutting face as sawing exposes the log interior. This type of sawing is "information limited" in the sense that the sawyer only has knowledge of external indicators of internal features (e.g. defects). Developing nondestructive sensing and analysis methods that can accurately detect and characterize interior defects is critical to future efficiency improvements for sawmills (Occeña 1991).

Studies have demonstrated potential value gains of 11%, 10%, 14%, and 21% (Richards and others 1980, Steele and others 1994, Tsolakides 1969, Wagner and others 1989, Wagner and others 1990), respectively, that can be achieved by sawing logs under different log orientations and using different sawing methods. A tacit assumption for eventual application of internal scanning to log sawing is that knowledge of internal

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defects will lead to choosing the best sawing position and method, and therefore will allow mills to realize these potential value gains. Log breakdown in this scenario is “fully informed”, where the sawyer has knowledge about internal feature size, type, and location. Nevertheless, without a log breakdown procedure that uses internal information to *optimize* lumber value, the ability of the sawyer to improve value recovery is not guaranteed. Sawyer synthesis of internal information for application to log breakdown has not been studied previously.

As sawyers gain experience in sawing logs, they empirically developed rules-of-thumb to help them do a good job for logs of varying grades, sizes, and shapes. Six of these log breakdown heuristics for hardwoods (Table 1) were examined by Malcolm (1961) with respect to lumber grade yields and total value yield for different grade logs. In that study, also cited in Denig (1993), a large number of logs were physically cut into lumber to obtain averages for the six heuristics across 3 log grades. Current computer software, however, allows us to generate hypothetical logs (Chen and Occeña 1996) and to simulate their breakdown by computer (GRASP, Occeña and Schmoldt 1996). By knowing where internal defects are located prior to sawing, we can examine *information-augmented* sawing heuristics, in addition to traditional *information-limited* heuristics that sawyers currently use.

As internal log scanning becomes feasible for sawmills, the first, and simplest, way to aid the sawyer will be to provide a 3D view of the log and its internal defects (Schmoldt 1996). This means, also, that we need to provide new, information-augmented heuristics, analogous to traditional information-limited ones, that the sawyer can apply alongside a 3D view to improve log breakdown. Because true, log breakdown optimization has non-polynomial complexity, new heuristics may be the best approach for real-time processing.

In the remainder of this paper we describe an initial attempt to develop information-augmented heuristics for hardwood log sawing. A preliminary version of this paper was presented at the ScanPro 1997 Conference (Occeña, Schmoldt, Thawornwong 1997). Three hypothetical hardwood logs (grades 1-3) were generated and computer sawn using GRASP with Malcolm’s 6 heuristics, with information-augmented equivalents of Malcolm’s heuristics, and several new heuristics based on internal information. A comparison of the results provides some indication of the improvement that sawyers can expect with information augmentation.

Methods

Log Simulation

Using a log and knot defect generator (Chen and Occeña), three hypothetical logs corresponding to the three hardwood log grades (Rast et al. 1973) were generated as specimens for the simulated sawing experiments. These logs were generated in the same way that a three-dimensional (3D) CT reconstruction of a log is done, that is, slice upon slice following the natural contour of a log cross-section and of the whole log profile. Post-processing data reduction procedures were required to keep the number of points in a slice and the number of slices computationally manageable. The slices were then reconstructed into a solid log model. The resulting logs are shown in Figure 1 after scaling according to the Forest Service log grading rules. The assigned log grades were verified by an experienced, third-party log scaler. Initially, the grade #2 log scaled as grade #3; however, by removing one knot we were able to obtain a legitimate grade #2 log. Nevertheless, this grade #2 log may be a marginal grade #2.

Knot defects were generated in a similar manner, slice by slice followed by a reconstruction into solid knot models. The solid models were then placed in the log based on the natural occurrence of knots, around the core and outwards in a random radial pattern following the upwards direction of the tree growth. Only knot-type defects were included in this study. The surface appearance of knots on each log can be seen in Figure 1. Complete knot defects are shown with the logs in Figure 2, representing the “glass log” view that CT internal imaging would provide.

Unlike Malcolm's study which required the physical sawing of a large number of log specimens, the computer simulation performed in GRASP (Occeña and Schmoldt 1996) allowed the repeated sawing of the same logs but with varying breakdown patterns. This enabled the direct comparison of yields from different breakdown patterns applied to the same log specimen. In this initial study, we only considered one log sample for each log grade for illustration purposes. An extended study involving a bigger sample will be required to arrive at results having an established level of statistical significance.

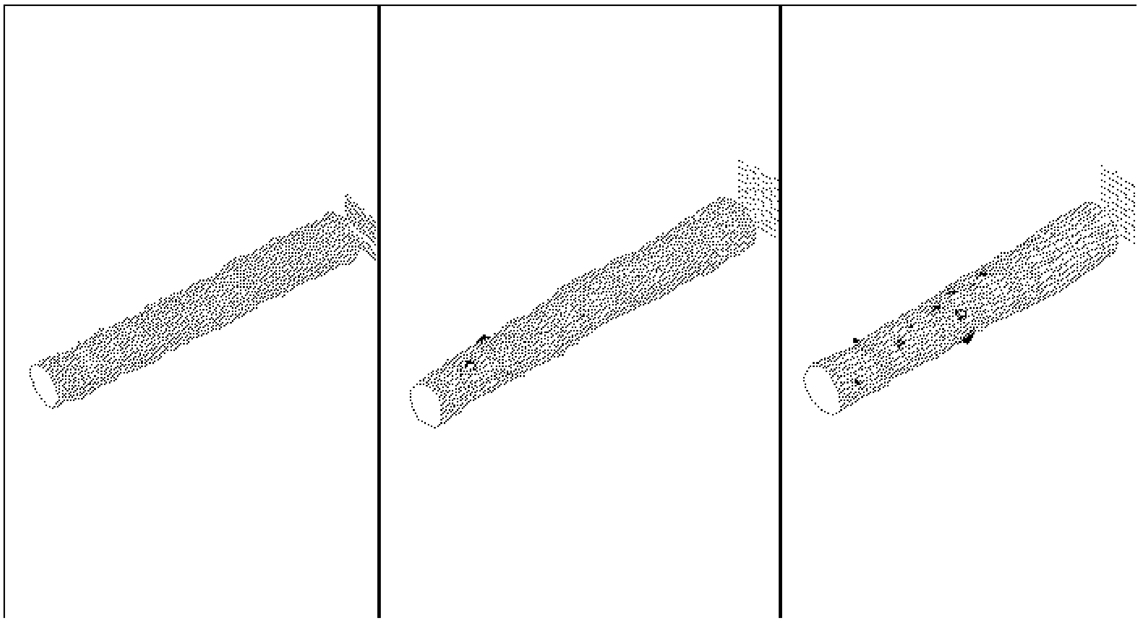

Figure 1. Log Specimens (L to R: grade 1 log, grade 2 log, grade 3 log).

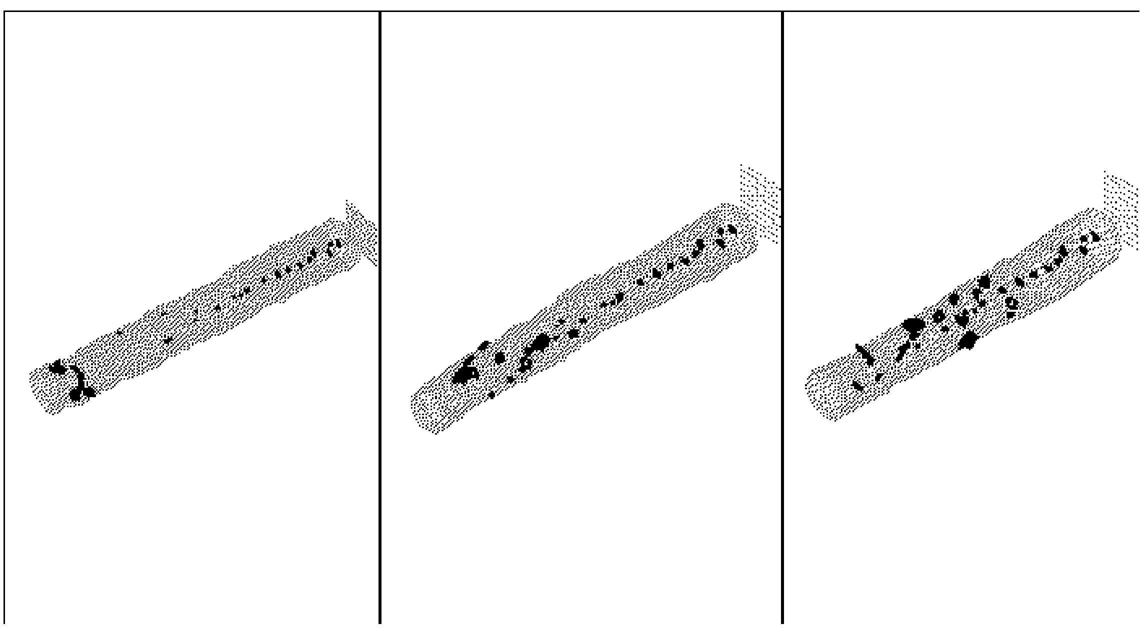

Figure 2. CT information-augmented view of the same logs as in Figure 1.

Sawing Heuristics

The sawing heuristics examined (Table 1) in the simulated sawing experiments included the original six heuristics tested by Malcolm (1961) with no internal defect information (limited), followed by equivalents of Malcolm's heuristics with internal defect information augmentation, and also exploratory heuristics which attempted to capitalize on the available internal defect information. The six heuristics by Malcolm assume no prior knowledge of internal defects other than those externally visible on the log faces, and combine three factors (defect positioning, taper setting, choice of opening face). Defect positioning places visible defects either on the center of log faces or on the edges of log faces. Taper setting uses either full taper, half taper, or no taper setting of the log relative to the sawline. Opening face chooses either the best face or the worst face for the opening cut.

Table 1. Malcolm's sawing heuristics were modified for internal information and four additional heuristics were added.

	Information-Limited Heuristics
Heuristic 1	Random defect position, random opening face, no taper set (the control case)
Heuristic 2	Defects on center of faces, best face sawn first, half taper set
Heuristic 3	Defects on center of faces, best face sawn first, full taper set
Heuristic 4	Defects on edge of faces, worst face sawn first, no taper set
Heuristic 5	Defects on edge of faces, best face sawn first, half taper set
Heuristic 6	Defects on edge of faces, best face sawn first, full taper set
	Information-Augmented Heuristics
Alternative 1	Defects on center of faces, best quadrant sawn first, full taper set
Alternative 2	Defects on center of faces, best quadrant sawn first, half taper set
Alternative 3	Defects on edge of faces, best quadrant sawn first, half taper set
Alternative 4	Defects on edge of faces, best quadrant sawn first, full taper set
Alternative 5	Defects on edge of faces, best quadrant sawn first, no taper set
Alternative 6	Glass Log 1
Alternative 7	Glass Log 2
Alternative 8	Pattern Directed Inference Model (PDIM)
Alternative 9	Reverse PDIM

The information-augmented heuristics include variations of the same three factors, but substitute opening quadrant selection in place of opening face selection. When an internal view of the log is available, a quadrant orientation supercedes face orientation. We also examined four exploratory approaches that consider defect clustering patterns (Occeña 1992), as well as the internal defect distributions along the length of the log. The Pattern Directed Information Model (PDIM) treats defects as an aggregated cluster with a dominant axis, whereas the Glass Log sawing is a more ad hoc approach guided only by an objective to contain the defects in the fewest number of lumber boards. The information-augmented heuristics involve a 3D visualization of the log and its internal defects, dealing with volumes instead of two-dimensional (2D) areas. Thus, there is a natural shift in reference for information-augmented sawing from sawing faces to sawing quadrants.

Sawing Simulation

The simulated sawing was conducted interactively using the GRASP sawing simulator (Occeña and Schmoldt 1996). For the first six heuristics (information-limited), the hidden line removal algorithm was activated to show only the surfaces that would normally be visible to the sawyer. Like physical sawing where the log is rotated or turned about its longitudinal axis, the simulated sawing in this study rotated the log representation about its longitudinal axis. However, it was also possible to reposition the sawline relative to the log representation, while still giving the same geometrical results as would be obtained from physical sawing. Kerf was not generated in the current simulation, although it can be accommodated in future studies by offsetting the sawline an extra amount (0.125 inches) to account for kerf In a bandsaw headrig. For the information-augmented heuristics, no hidden line removal was performed to simulate a glass log image of the log and its internal knot defects.

Edging and Grading

The resulting flitches were then edged severely to remove all wane. This was consistently applied to all edging operations. The green lumber was then graded and priced using a price estimator program called HLPEP (Vara and Occeña, 1996) that takes the geometric data directly from GRASP and generates a report summarizing the lumber grade and price per lumber piece as well as for the entire log breakdown pattern. In a few exceptions of defect-ridden boards from lower grade logs, ripping of boards was required for successful grading and pricing.

Results

After performing all 45 simulations—for each of the 15 heuristics and for the log in each of the 3 grades—the dollar values presented in Table 2 were obtained. Averages for the 5 information-limited heuristics are \$133.52, \$41.69, and \$44.05 for grades #1, #2, and #3, respectively. Averages for the 5 information-augmented heuristics are \$144.80, \$40.32, and \$41.84 for grades #1, #2, and #3, respectively. The difference in log averages for grade #1 (8.45%) is statistically significant (p = 025); differences for grades #2 and #3 are not significant.

When we examine more closely why this value difference occurs for the grade #1 log, we find (Table 3) that the distribution of lumber grades differs. The average number of #1Common boards differs significantly between the information-limited and information-augmented heuristics. That is, the increase in value is due, not to an increase in volume, but to a shift to higher value board grades. This result is consistent with those of other researches that have compared value increases for different sawing patterns and log orientations.

Because this preliminary study is limited to one log in each grade and each heuristic, there are few other variables that can be analyzed statistically. We did, however, examine the impact of taper setting by combining the data for both the information-limited and information-augmented heuristics. Averages for the different taper settings (Table 4) demonstrate a significant difference between no taper and half taper and between no taper and full taper—only for log grade #2.

Table 2. Dollar values obtained by the sawing simulation for each sawing heuristic and each log grade. Averages for information-limited and information-augmented heuristics are included.

Sawing Pattern	Grade #1	Grade #2	Grade #3
Random, No Taper, No Face	131.32	31.75	35.60
Defect on Center, Half Taper, Best Face	138.44	44.00	41.99
Defect on Center, Full Taper, Best Face	133.01	40.63	38.06
Defect on Edge, No Taper, Poor Face	125.36	31.55	44.34
Defect on Edge, Half Taper, Best Face	131.25	47.64	53.92
Defect on Edge, Full Taper, Best Face	139.56	44.62	41.95
Average for above 5 heuristics	133.52	41.69	44.05
Glass Log 1	144.08	43.16	51.06
Glass Log 2	129.40	35.52	39.40
Original PDIM	154.35	43.16	42.12
Reverse PDIM	128.28	38.50	54.88
Defect on Center, Half Taper, Best Quadrant	141.06	34.93	40.98
Defect on Center, Full Taper, Best Quadrant	143.12	45.20	38.44
Defect on Edge, No Taper, Best Quadrant	150.13	35.91	46.75
Defect on Edge, Half Taper, Best Quadrant	150.06	42.20	39.92
Defect on Edge, Full Taper, Best Quadrant	139.64	43.38	43.09
Average for above 5 heuristics	144.80	40.32	41.84

Table 3. The average number of boards in each lumber grade for log grade #1 differs between information-limited and information-augmented heuristics.

Board Grade	Information Limited	Information Augmented
FAS	2.0	4.4
Selects	2.6	4.8
#1 C	9.2	5.4
#2 C	1.0	0.6
#3 C	0.2	0.0
BG	0.0	0.2

Table 4. Lumber values for different taper settings were combined for information-limited and information-augmented heuristics for log grade #2. Averages for each setting appear in the last row.

No Taper	Half Taper	Full Taper
31.75	44.00	40.63
35.91	47.64	44.62
31.55	34.93	45.20
	42.20	43.38
33.07	42.19	43.46

Conclusions

The inability of information-augmented heuristics to improve on lumber value over information-limited heuristics for the lower-grade logs seems puzzling at first glance. However, lower-grade logs contain an abundance of defects, so visually finding a better opening face/quadrant is difficult. Consequently, information-augmented heuristics show no value improvement for those grades. On the other hand, when a log contains fewer defects (i.e., grade #1), it is relatively easy to find a face/quadrant that relegates the defects onto fewer boards, and thereby creates a greater number of higher grade boards (Table 3) for a greater total value. Because the level of internal information doesn't seem to impact value returns for grades #2 and #3, other factors become important, e.g., taper setting, which we see in Table 4 for log grade #2.

If this trend proves correct—i.e. little impact by internal information to improve value for grade #2 and #3 logs—as we simulate the breakdown of other logs in each of the grades, then we need to do one of 2 things in order to use internal defect information effectively as part of grade sawing in mill operations. One, we could develop new heuristics that better utilize internal information for sawing lower grade logs, while still doing well with grade #1 logs. Or two, we could use simulation to cut each log in a number of orientations and then select the one that provides the highest value (i.e. a limited empirical search). The former solution is computationally simpler, and could be easily implemented on-line; the latter may require significant off-line computation.

The ranges of values (Table 2) for the different grade logs have nearly the same magnitude, approximately $20. However, because of the lower value of grades #2 and #3 in general, this $20 magnitude becomes a 50% range. Consequently, greater percentage value gains can potentially be recovered for lower quality logs if internal defect information can be used wisely.

The highest dollar value for log grade #1 was obtained by the PDIM heuristic. However, it also performed quite poorly for the other grades. This heuristic was originally designed to make relatively intelligent sawing decisions based on defect hull shape, so it could be easily fooled by an extensively defected log. Nevertheless, we view PDIM as a starting point for the development of better, information-augmented heuristics.

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