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LORCAT: A Log Recovery Analysis Tool for Hardwood Sawmill Efficiency

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Abstract

The LOg ReCovery Analysis Tool (LORCAT) was developed to enable researchers and mill personnel to examine the impact and relationships among various factors that influence hardwood mill recovery. LORCAT is a spreadsheet-based tool that was developed for use with the Microsoft Excel® or LibreOffice® spreadsheet applications. LORCAT allows users to interactively view the results from a single log or view trends by using hundreds of logs with a batch interface. The analysis tool requires users to specify the log length, U.S. Department of Agriculture, Forest Service log grade, species, small- and large-end diameters, and processing specifications, including: opening face dimensions, cant size, board thickness, green allowance, sawing variation, kerf size, and taper sawing method. Given this data, LORCAT reports the expected total number and volume of lumber and cants produced and the projected recovery by National Hardwood Lumber Association grade.

KEY WORDS: sawmill, yield, recovery, application, simulation, hardwood

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Cover Photo

Stacks of yellow-poplar (*Liriodendron tulipifera*) logs await sawing at the Northwestern Hardwoods Sawmill in Buena Vista, Virginia. USDA Forest Service photo by R. Edward Thomas.

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INTRODUCTION

Numerous factors influence product recovery and efficiency in hardwood sawmills. Some factors relate to the geometric and quality characteristics of the logs processed; others relate to processing details such as kerf size, sawing variation, or sawing strategy. Also, the geometric dimensions and the type of products sawn impact recovery yield. Examining and developing an understanding of the inter-relationships among these numerous interdependent factors is the key to maximizing yield, efficiency, and profit.

The most important factors affecting log recovery identified by Steele (1984) were:

- log diameter, length, taper, and quality,
- kerf width, and
- sawing variation, green lumber size, and kiln dry-dressed lumber size.

Lin et al. (2011) examined hardwood sawmills in West Virginia and found that lumber recovery at all mills they sampled differed significantly ($\alpha = 0.05$). Overall, Lin et al. (2011) found that log grade, species, log diameter, length, and sawmill parameters had statistically significant effects on lumber volume recovery. Further, due to variances in processing and log resource, these factors are rarely consistent from mill to mill (Steele 1984).

Given the critical importance of the interaction of all these factors on mill profitability, there have been numerous sawmill simulation tools created that help sawmill managers explore the consequences that these factors have on mill operations. One of the earliest tools developed was the Best Opening Face (BOF) program by Lewis and Hallock (1974), which was developed long before computers were commonplace in the industry. The BOF program determined the optimum placement of saw lines in a log to effect recovery of maximum yield based on log size and quality characteristics. Because potential users did not have access to their own computer, BOF was used to develop a series of publications that explored various interactions of sawing and product factors, from which users could then extrapolate results to their situation and achieve improved recovery yields and mill efficiencies.

Adams, in 1995, developed another sawmill simulation program—the Solve program (Adams 1995)—to help sawmill managers improve efficiency and solve common hardwood mill issues such as log size distribution, lumber grade yields, lumber recovery factors, overrun log costs, and break-even log costs. Solve requires users to conduct a comprehensive mill study and collect data related to various aspects of their mill's operation, including: operating costs, lumber grades, lumber thicknesses, lumber prices, and, most importantly, Forest Service log grades, log sizes, and the volumes of lumber recovered by National Hardwood Lumber Association (NHLA) grade. Solve proved quite popular in the industry and hence Palmer et al. in 2009 upgraded the program with additional functionality and with improvements on the ease of use (Palmer et al. 2009).

In 2005, Govett et al. created the spreadsheet-based sawmill analysis tool PROYIELD capable of projecting sawmill yields (Govett et al. 2005). PROYIELD was designed to develop initial estimates of sawmill yields for planning and feasibility studies as well as to explore and test what-if questions related to processing. However, PROYIELD was not designed to optimize recovery, optimize sawline placement, or make opening face decisions for maximum value recovery; PROYIELD returns summaries of expected lumber and residuals yield for specific scenarios. As such, PROYIELD requires the user to enter fewer data than does the Solve program (Palmer et al. 2009), but PROYIELD nonetheless is a complex tool for which the authors recommend a training course prior to its use (Govett et al. 2005).

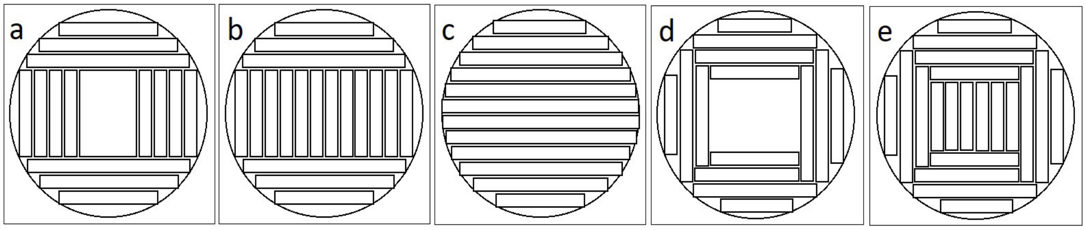


Figure 1.—1a. Sawing to a specified cant size; 1b. Sawing to specified cant size then completing sawing with a gang-resaw; 1c. live sawing; 1d. grade sawing to specified cant size; 1e. grade sawing to specified cant size then completing sawing with a gang-resaw

Building on the strengths of Solve (Palmer et al. 2009) and PROYIELD (Govett et al. 2005), and acknowledging the strengths' complexity as a potential barrier in practice, the creators of the LOg ReCovery Analysis Tool (LORCAT, described below) designed the tool to be straightforward to use with easily understood results.

METHODS

LORCAT is a geometrically based sawing simulator that models logs as truncated cones. The use of truncated cones is a common method of geometrically modeling logs for research (Kubojima et al. 2018) and measurement and is the basis for Smalian's log volume formula (USDA Forest Service 2006). However, there exists no option for the modeling and sawing of elliptical logs, as full-length elliptical hardwood logs are not commonly encountered (Thomas et al. 2017).

LORCAT was designed to simulate the sawing of logs using one of five common sawing methods. The first method simulates sawing logs to a cant with a specified size (for example, 6 inches x 4 inches; Fig. 1a). For cant size and all other sawing parameters, the user can change them to suit their operation or analysis needs. The second method simulates by using a gang-resaw to saw the billet or cant produced from sawing the first two faces into lumber (Fig. 1b). The third method simulates the European method of live or flitch sawing where the log is sawn through-and-through (Fig. 1c). The fourth and fifth sawing options emulate grade sawing where the log is rotated and lumber is sawn from the best face. The grade sawing methods can saw to a cant (Fig. 1d) or simulate a gang-resaw to saw the cant into lumber (Fig. 1e). Users can select the method and all sawing parameters to suit their operation or their analysis needs.

For all five sawing methods, there is the option of either split-taper or full-taper sawing (Malcolm 1961). In split-taper sawing, the taper of the log is split between opposite faces and the log is sawn parallel to its central axis (Hallock et al. 1978). This sawing method has the potential to produce shorter boards if the amount of taper is large enough. Full-taper sawing saws the log with all the taper put to one face of the log, which is done by sawing parallel to one of the outside faces of the log (Hallock et al. 1978). Thus, the grain will be parallel to the board surface in the resulting boards, making lumber sawn stronger in general than split-taper sawn lumber.

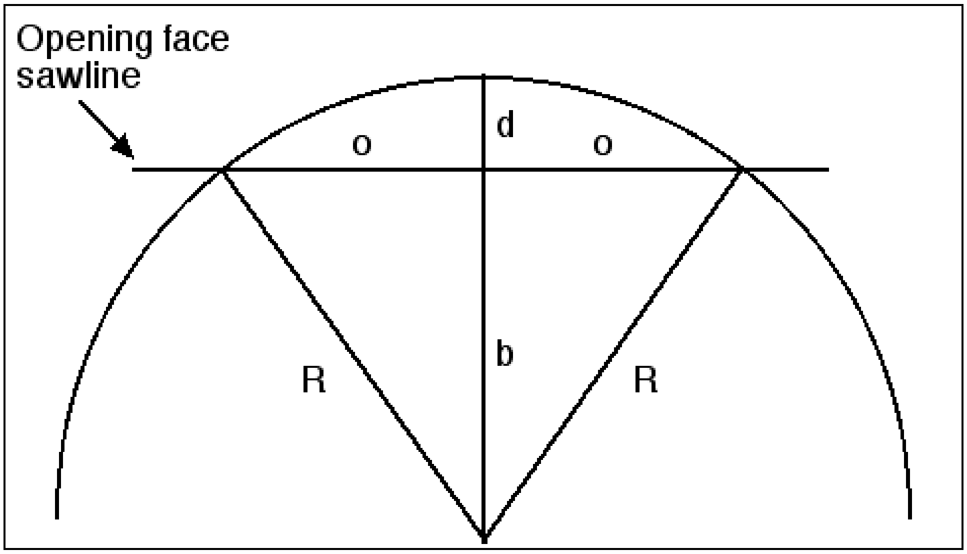


Figure 2.—Variables (R, b, d, o) used to determine the opening face sawing depth.

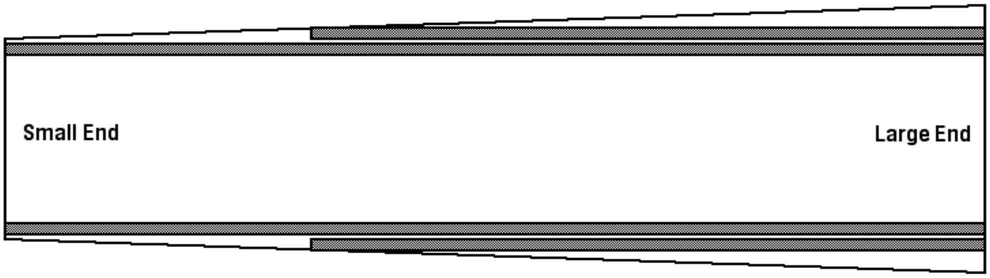


Figure 3.—Split-taper short board fitting solution into wider tapered area at large log end.

The geometric log modeling that LORCAT uses to simulate the sawing processes does not incorporate log defects. Hence, in the absence of log defect information, the selection of an opening face is arbitrary, as all faces are equal. The first step in opening up a log is to determine the depth of the saw cut on the opening face. Figure 2 shows the different variables involved in this calculation and their relationships to each other. In figure 2, R is the radius and is half of the small-end diameter (SED), o is ½ of the opening face width, b is the distance from the cut to the geometric center of the log, and d is the depth of the opening face cut measured from the small end. The value of d is calculated using the Pythagorean theorem.

Mathematically, the processes of simulating full-taper and half-taper sawing are very similar. For full-taper sawing, a saw line along the length of the log is calculated that is parallel to the log surface. For half-taper sawing, a saw line is calculated that is parallel to the geometric center of the log. An additional consideration with half-taper sawing is that, given a minimal opening face length that is shorter than the log length, it may be possible to fit a board into the available tapered area at the large end of the log (Fig. 3). This added short board sawn out of the tapered region at the large end of the log could actually be recovered from two, three, or four faces of the log as it is turned on the carriage.

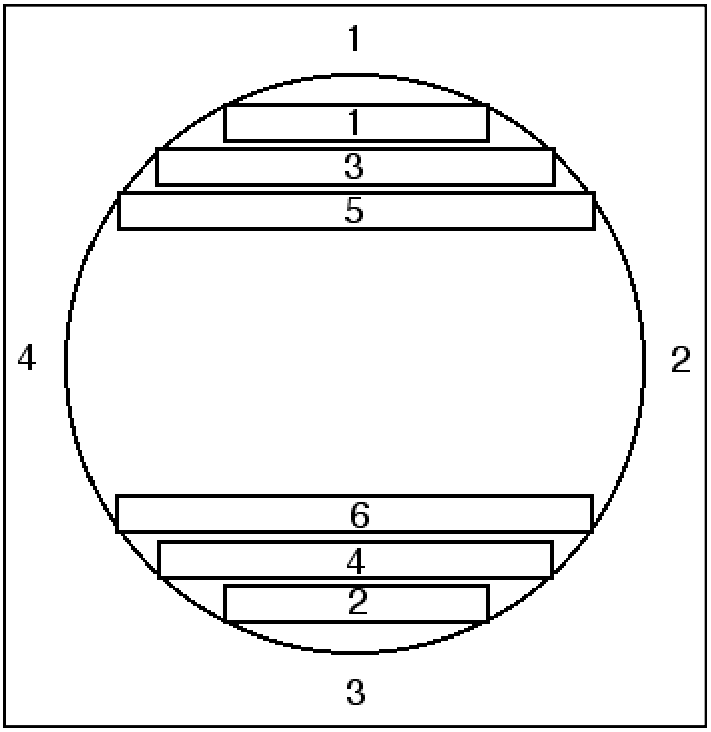
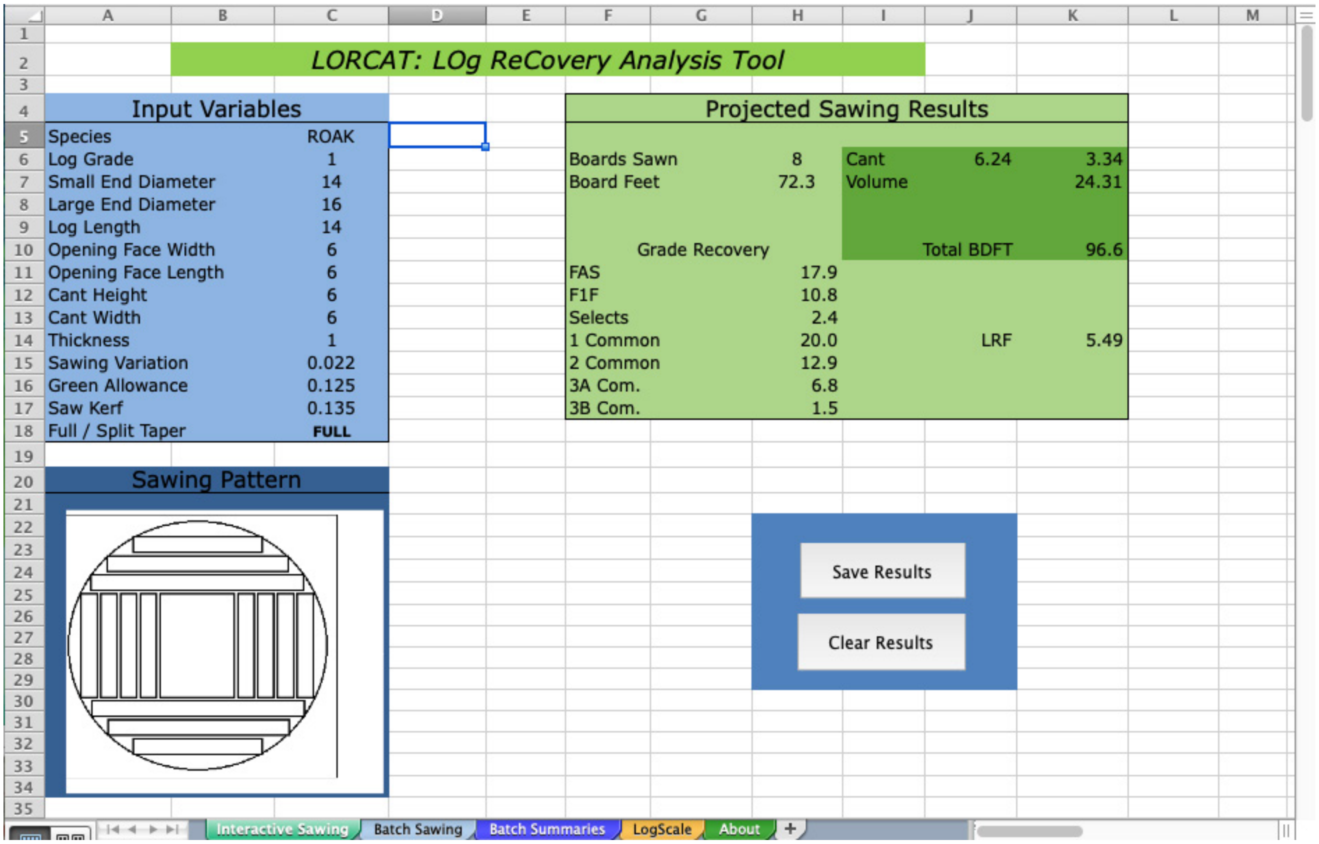


Figure 4.—LORCAT board sawing order and number log faces.

The total lumber thickness of each board sawn is the sum of the target lumber thickness, the green allowance for drying shrinkage, and the within-board sawing variation (Young et al. 2007). The within-board sawing variation allows LORCAT to model inaccuracies in the sawing process encountered in sawmills. Thus, given the position of the outer surface of a board, the next cutting position is the current position minus the total lumber thickness and kerf thickness. In this way, the sawing depths of the remaining boards are calculated.

The sawing process begins on face 1 (Fig. 4) of the log. Once the opening face solution is determined, the same solution is duplicated on the opposite log face, face 3. Note that the kerf for the opening cut is made such that the cut is toward the slab and the volume loss from the kerf does not affect recovery volume. Sawing then proceeds by alternating sawing between face 1 and face 3. In the absence of internal defect information, as in this simulation, this provides a reasonable approximation of a sawmill rotating the log and sawing from the best face. Figure 4 shows a sawing solution after three boards have been sawn from faces 1 and 3. Note that the sawing order of the boards in figure 4. If a cant height is not specified, then the log will be live sawn (Fig. 1c), with boards sawn until the distance between the innermost boards is less than a board thickness. If a cant height is specified, boards are alternatively sawn from faces 1 and 3 until sawing one more board would result in a cant height less than the specified dimension. Note that in most cases, this approach will result in slightly oversize cants, with the oversize always less than the total thickness of a board.

When a cant height is specified, the sawing method used will be either the method shown in figure 1a or figure 1b, depending on whether or not a cant width is also specified. When sawing begins on the 2nd and 4th faces, the procedures used are the same as those used to determine the opening face sawing depth and the width of the next boards sawn on the 1st and 3rd faces. However, sawing on the 2nd and 4th faces must also consider the position of the boards sawn from the 1st and 3rd faces. Specifically, the maximum board width will be the height of the cant or billet that results from sawing faces 1 and 3.



LORCAT: LOg ReCovery Analysis Tool

Input Variables

Species	ROAK
Log Grade	1
Small End Diameter	14
Large End Diameter	16
Log Length	14
Opening Face Width	6
Opening Face Length	6
Cant Height	6
Cant Width	6
Thickness	1
Sawing Variation	0.022
Green Allowance	0.125
Saw Kerf	0.135
Full / Split Taper	FULL

Projected Sawing Results

Boards Sawn	8	Cant	6.24	3.34
Board Feet	72.3	Volume		24.31
Grade Recovery		Total BDFT		96.6
FAS	17.9			
F1F	10.8			
Selects	2.4			
1 Common	20.0	LRF		5.49
2 Common	12.9			
3A Com.	6.8			
3B Com.	1.5			

Sawing Pattern

Figure 5.—LORCAT: Log Recovery and Analysis Tool main window.

LORCAT simulates the sawing of logs by using generic geometric models of logs. As such, these models currently do include logs with crook or sweep. To simulate the processing of these and logs with large defects, determine the scaling deduction (percent) for that log using the Forest Service Log Grading Rules (Rast et al. 1973) and apply it to the recovery results.

RESULTS

LORCAT simulates the sawing of logs represented by geometrically truncated cones employing user-specified sawing parameters. First, LORCAT determines the opening face sawing depth for the minimal-sized board face specified by the user for all four faces of a log. After the opening face calculations are performed, it proceeds to saw the log. After sawing, LORCAT uses the Forest Service hardwood lumber yield tables (Hanks et al. 1980, Hanks 1973) to estimate the lumber recovery by NHLA grade. LORCAT, a spreadsheet-based analysis tool, requires minimal data input from the user to make it as easy to use as possible. The main user interface of LORCAT is shown in figure 1.

The LORCAT main window (Fig. 5) asks users for the relevant input data in the upper left box labeled “Input Variables.” Comments and drop down boxes are present in this section to guide in data entry. LORCAT tries to calculate results every time an entry is made into the “Input Variables” box, but only after all the relevant information is entered will the results be shown in the “Projected Sawing Results” box to the right. Until then, results are shown as zero (Boards Sawn, Board Feet, Cant, Volume, and Total BDFT [total board feet]) or as “Not Available” for Grade Recovery.

Table 1.—LORCAT analysis and scale results for a sample of 200, 12-ft-long logs having an average small-end diameter of 16 inches and variable amounts of taper

Source	Kerf	Lumber recovery factor	Recovery	Doyle overrun	Int 1/4-inch overrun
	(inches)		*(bf)*	*(percent)*	*(percent)*
LORCAT	0.125	6.845	28,887	33.7	10.8
LORCAT	0.111	6.946	29,311	35.7	12.4
LORCAT	0.096	7.047	29,737	37.6	14.1
LORCAT	0.084	7.136	30,113	39.4	15.5
Doyle Scale	--	--	26,070	--	20.7
Int 1/4-inch Scale	--	--	21,605	-17.1	--

Demonstration

To demonstrate the abilities of the LORCAT analysis tool, we constructed a sample of 200, 12-foot-long logs. Using the R statistical program (R Core Team 2020), we created a normal distribution of SEDs with a mean of 16 inches and a standard deviation of 3 inches. To determine the large-end diameters (LEDs), we first created a natural distribution of log taper amounts with a mean of 3 inches and a standard deviation of 1. Adding the taper and SED distributions together yielded a naturally distributed large-end diameter sample. Using Smalian's equation (USDA Forest Service 2006), we calculated the volume of the log sample to be 4,220 ft^3. The International ¼-inch scale (USDA Forest Service 2006) volume was 26,070 board feet (bf) and the Doyle scale (Cassens 2011) volume was 21,605 bf.

Kerf is the amount of wood removed by the blade during sawing that ends up as sawdust. Using LORCAT, we examined the consequences of three common kerf sizes used in typical band mills. Lin et al. (2011) found that mean kerf size of sawmills they examined in West Virginia was 0.125 inch. Three common blade thicknesses for portable mills are 0.042, 0.045, and 0.055 inch, which produce 0.084, 0.096, and 0.111-inch kerfs, respectively. Steele et al. (1992) found that the mean within-board sawing variation for band saw mills was 0.022 inch. Using these kerf thicknesses and sawing variations, we constructed four LORCAT simulations to examine recovery differences among the kerf sizes. The volume recovery results for the 200 logs were statistically analyzed for each kerf simulation.

The LORCAT simulations used a minimum opening face (minimum size of first board removed from a log face) of 6 inches wide and 6 feet long. If the taper was 1 inch or greater, half-taper or split-taper sawing was used. The sawing process simulated sawing the logs to produce a 6-inch billet that was sawn into 6-inch wide boards. This sawing process used the sawing pattern template shown in figure 1b. The target thickness was 1 inch plus a green thickness allowance of 0.125 inch plus sawing variation.

To provide a basis for the comparison, we report and compare LORCAT's results to the Doyle and International ¼-inch scale volumes. Table 1 lists total recovery for the analyses of different kerf sizes, as well as those calculated for the Doyle and International ¼-inch log scales. In addition, overrun for each is calculated against the Doyle and International log scales.

Although the diameters of the log sample were normally distributed, estimated lumber recovery was not normally distributed for any of the mill simulations or log scales using the Shapiro test for normality (Shapiro and Wilk 1965) with a significance level of 0.05. This required nonparametric methods to compare the recovery results from the simulations for the larger and smaller kerf scenarios. Using Gastwirth et al.'s (2019) test for symmetry ($\alpha = 0.05$), we determined that the lumber distributions for each mill configuration were symmetric about the median. This allowed us to perform two sample Wilcoxon rank sum tests (Hollander and Wolfe 1999) to determine if the distributions of lumber recovery are the same.

The simulations examined the impact on recovery of reducing kerf size from 0.125 inch to 0.084 inch in 3 increments corresponding to common kerf sizes (Table 1). The 0.125-inch kerf simulation resulted in a recovery of 28,887 bf. The next smallest kerf, 0.111 inch, produced 29,311 bf, a percentage improvement of 1.47 percent (424 bf) over the larger 0.125 kerf. Similarly, the 0.096-inch kerf produced 29,737 bf, a percentage improvement of 1.45 percent (425 bf) over the 0.111 kerf. The thinnest kerf thickness examined (0.084 inch) produced 30,113 bf and an additional 1.26 percent improvement. Overall, the thinnest kerf resulted in 1,224 more bf, a percent improvement of 4.24 percent. Recovery differences among all the kerf sizes were tested using the Wilcoxon rank sum tests and were found to be significant ($\alpha = 0.05$). All mill simulation lumber recovery distributions were significantly different ($\alpha = 0.05$) from the International ¼ and Doyle scale volumes.

CONCLUSIONS

The ability to easily examine potential interactions among log characteristics, processing configurations, products, and yield allows sawmill managers to determine effective and efficient strategies and to examine alternative approaches that maximize recovery. LORCAT's yield predictions are sensitive to small kerf and variability changes, allowing the detection of seemingly small changes in a mill's operation. In the processing samples, a 0.012-inch difference kerf resulted in a significant difference in recovery. The ability to repeat simulations using the same log data sample eliminates sample variation that often confounds traditional mill studies by masking true recovery differences.

LORCAT simulates the sawing of logs by using generic geometric models of logs. As such, these models currently do include logs with crook or sweep. To simulate the processing of these and logs with large defects, the user can determine the scaling deduction (percent) for that log using the Forest Service Log Grading Rules (Rast et al. 1973) and apply it to the recovery results.

LORCAT's spreadsheet interfaces allow simulations to be run quickly and with ease. Log data consisting of diameters, length, log grade, and species, along with mill processing parameters, can be pasted into the Batch Processing worksheet, and results copied and analyzed allowing for simulation comparisons among a large number of processing parameters.

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