Effect of Sawing Variation on Hardwood Lumber Recovery—Part I: Volume

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Abstract

Sawing variation (SV), the degree of deviation from a specified target lumber size, is an unavoidable component of the sawing process. SV is influenced by several factors such as machine, material, set works, feed works, and cutting parameters. To account for these factors resulting in deviations from the desired target size, the target thickness of the lumber cut must be increased such that only a minimal number of boards is less than target thickness. Thus, the greater the amount of SV, the larger the target thickness must be such that a minimal quantity of undersized lumber is produced. Hence, with larger amounts of SV come greater waste and decreased opportunities for optimizing lumber recovery. However, the decrease in material loss due to a reduction in SV may not necessarily translate into a statistically significant increase in lumber product recovery by volume. This study explored the effect of varying degrees of SV on lumber recovery by volume for a range of hardwood log diameters using the US Forest Service's LOg ReCovery Analysis Tool sawmill simulation software. A minimal average recovery improvement of 3 percent due to reduced SV was observed across all kerf thicknesses, equating to a production value improvement of \$336,000 for an 8 million board feet mill. Results indicate that the recovery gains realized by volume depend upon the log diameters sawn, the lumber target thickness, and the change (reduction) in SV.

Sawing variation refers to the degree of deviation from a specified target lumber thickness incurred during the sawing process (Brown 2000). Two measurements of sawing variation exist: (1) within-board and (2) between-board variation. The two together combine to report (3) total sawing variation, commonly referred to simply as sawing variation (SV). SV is an unavoidable component of the sawing process; however, excessive SV is a symptom of an out-of-control process (Vuorilehto 2001). SV can be attributed to two factors: set works and feed works. Set works refers to issues such as wear in the machinery, dulling of blades, improper setup or alignment, issues with automatic controls, or software issues. Likewise, feed works refers to issues such as worn-out or out-of-alignment guides, feed rollers, or holding systems (Vuorilehto 2001).

Excessive SV affects lumber volume recovery because the larger the SV, the thicker the target lumber size cut must be to avoid producing lumber that is scant or undersized. Although the thicker target lumber size compensates for the SV in the boards that otherwise would be undersized, it wastes usable lumber when processed by surfacing to final thickness in oversized boards (Young et al. 2007). Depending on the capacity of the sawmill and the degree of SV, the oversizing of lumber can cost the mill as much as \$250,000 per year (Brown 1997), \$466,000 adjusted for inflation (InflationTool 2022). To minimize the negative economic impact of SV in the form of scant and oversized lumber, Brown's equation (Brown 2000) for target thickness is used to calculate the required rough-dimension target lumber thickness on the basis of the desired final lumber thickness, shrinkage allowance, planer allowance, and SV (Eq. 1).

$$T = ([F + P] \times [1 + \mathrm{SA}]) + (Z \times \mathrm{SV}) \tag{1}$$

where T is target thickness, F is final size, P is planer allowance, SA is shrinkage allowance, and Z is standard normal variation. The values of Z are statistically determined and based on the characteristics of a normal distribution.

In a study of 50 hardwood band mills, Steele et al. (1992) found a mean total SV of 0.047 inches. Thus, to produce 1-inch-thick dried, rough lumber given a shrinkage allowance of 0.125 inches and SV of 0.047 inches, given a Z value of 1.97 corresponding to allowing a maximum of 2.5 percent undersize boards, a common industrial practice (Brown 2000), would require a 1.218-inch target thickness (Eq. 1). Unfortunately, Steele et al. (1992) published their numbers

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as a graph and not as numerical values, but estimates show that decreasing the SV from the mean value of 0.047 inches to 0.030 inches, the smallest SV observed, would reduce the target thickness to 1.184 inches, a difference of 0.034 inches. Although a target thickness difference of 0.034 inches per board sawn does not appear to be much, consider a log with a small-end diameter (SED) of 18 inches. If a minimum of 6 boards is sawn from each face, there will be a total of 12 boards sawn from the two opposite faces. Thus, a total of 0.408 inches (12 × 0.034) of the SED will be conserved because of the reduction of SV, possibly enough, combined with the leftover material, to derive additional volume and possibly another board from the log. As log diameters increase or thinner boards are produced, more cuts will be made, and even more material is saved.

Sawmill personnel are often unaware of the implications of minimizing SV in their operation. Ideally, they would know what amount of reduction in SV is necessary to see a meaningful improvement in recovery for a given SED. This paper researches the impact of total SV on raw lumber recovery by volume using the LOg ReCovery Analysis Tool (LORCAT; Thomas et al. 2021) using a range of realistic scenarios. A key part of this analysis is determining what degree of SV reduction leads to a statistically significant improvement in lumber recovery for a range of common bandsaw blade thicknesses.

Methods

Using the LORCAT sawmill analysis tool (Thomas et al. 2021), a series of processing simulations was designed and executed to research the impact of varying amounts of SV on lumber volume recovery (board feet). There is an ongoing validation effort for the LORCAT analysis tool. A sample of eight logs was processed in a sawmill and the recovery information was recorded. Logs of the same quality were then sawn using LORCAT and the output was recorded. The absolute cumulative difference was 23.39 board feet and the average absolute difference was 3.34 board feet for those eight logs. The maximum absolute difference for one log was 4.93 board feet, whereas the minimum absolute difference was 0.97 board feet. At the time of this writing, a larger 19-log sample is being processed for further validation of LORCAT.

The log data used in this study and processed by LORCAT are described by four key elements: (1) SED, (2) large-end diameter (LED), (3) length, and (4) grade. Length (all logs processed for this study were 12 ft) and grade (all logs processed were US Forest Service factory log Grade 2) were kept constant throughout this study to avoid masking results, conferring a benefit of simulation over real-world studies. In simulation, the same log can be used for any number of iterations, whereas in real-world mill studies the same logs can only be processed once, thereby masking the results no matter if the replacement logs are of the same grade and diameter. As log diameter is of critical importance to the outcomes of this study, we used mill study data collected from 34 mills and consisting of 2,030 red oak (*Quercus rubra)* logs by Wiedenbeck (2004), who found that the SED processed in mills surveyed ranged from 8 to 27 inches.

Using the Wiedenbeck (2004) LED and SED data, the authors calculated the mean and standard deviation of taper per foot of log length for each 1-inch SED class. This allowed for the creation of a random normal distribution of log taper for each 1-inch SED class. The taper distribution data combined with a set of log SEDs ranging from 8.0 to 27.9-inches (e.g., 20 1-inch SED classes) in 0.10-inch increments permitted the generation of a log data bank that represented actual log diameters and taper amounts found in the 34 mills studied (Wiedenbeck 2004). The LED of each log was then calculated as LED = SED + taper × log length (12 ft). This resulted in a data set of evenly distributed log diameters with SEDs from 8 to 27.9 inches that reflects the diameter and taper distribution found by Wiedenbeck (2004). Within each 0.10-inch SED increment, 10 logs were created to match the normal distribution of taper for that SED class. Thus, a total of 100 logs was generated for each 1-inch SED class for a total sample size of 2,000 logs (100 logs per 1-in. SED class × 20 1-in. SED classes). The goal was to create a data set of log sizes and shapes that accurately represents real-world logs as opposed to a random sample that could result in unrealistic results. For example, logs with large amounts of taper will produce shorter boards that are sawn from the tapered regions. Only if the taper contained in our database is representative of the real world will the results from our study be representative (Thomas et al. 2021). Hence, the sample created reflects the taper found in the 34 hardwood sawmill log yards studied by Wiedenbeck (2004). However, the evenly distributed log sizes (from 8 to 27.9 in.) of the sample are a theoretical construct to avoid masking the findings of this study.

LORCAT was set up to completely saw each log into 4/4 lumber only, with no cants, using the sawing pattern shown in Figure 1. This method of sawing emulates the practice of grade sawing where the log is rotated during sawing such that boards are sawn from the best face of the log. Sawing continues until a cant of the desired size is produced, which is then gang-sawn into boards. For the smaller-diameter logs with a SED less than 12 inches, a minimum opening face size of 5 inches by 8 feet, and a cant height of 5 inches was used. For logs with a SED of 12 inches or more, a minimum opening face of 6 inches by 8 feet and a cant height of 6

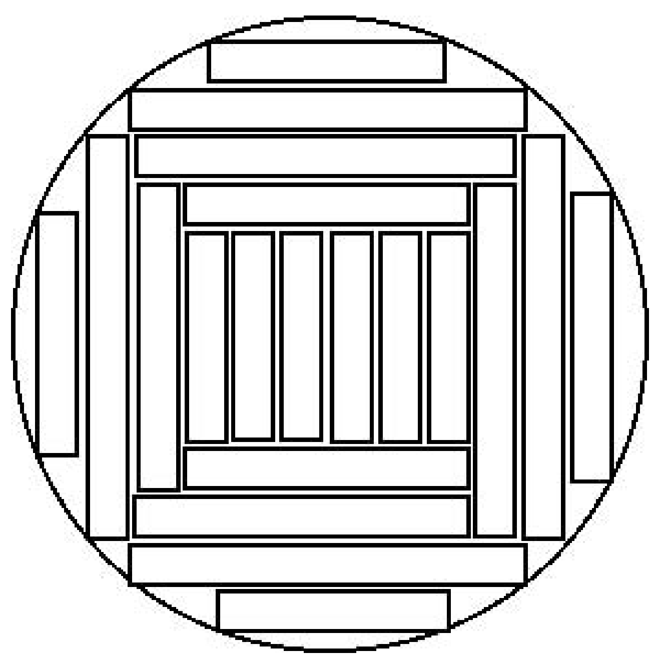

Figure 1.—General sawing pattern design used for all logs.

inches were used. The cants were then gang-sawn into boards. This was done to reduce yield loss on small-diameter logs as a smaller opening face specification pushes the outer board surface closer to the log surface, resulting in a thinner slab cut and consequently generating less residue.

For the analysis of total SV, we examined SVs ranging from 0.020 to 0.070 inches in 0.05-inch increments. We determined that this range of SV was representative of the variation that is encountered in hardwood sawmills (Steele et al. 1992, Brown 2000, Young et al. 2000). For each SV, the target lumber thickness was then calculated using Brown's equation (Eq. 1, Brown 2000). In Brown's equation, the planer allowance amount was set to 0 because our final target was 1-inch-thick dried, rough-dimension lumber. A shrinkage allowance of 0.125 inches was used for all target thickness calculations. Last, Z, the standard normal variation variable in Equation 1, was assigned a value of 1.97; this corresponds to permitting 2.5 percent of all boards to be undersized (Brown 2000).

Using SVs ranging from 0.020 inches (min.) to 0.070 inches (max.) in 0.05-inch increments resulted in a total of 11 target thicknesses (Table 1) used for the necessary simulation runs with LORCAT (Thomas et al. 2021). Hence, the difference between the smallest and largest target thickness is 0.0985 inches. The simulation also examined three different kerf thicknesses, 0.095, 0.125, and 0.162 inches, in combination with the 11 SVs. These three kerf thicknesses are common in the industry, with 0.095 inches being commonly used in portable band mills (Panko 2020), whereas Lin et al. (2011) found that 0.125 inches was the mean head rig kerf size for band mills in a study of five mills in the Appalachian region; Steele et al. (1992) found in a study of 50 hardwood mills the mean head rig kerf to be 0.162.

For each SV and kerf size combination, LORCAT performed 2,000 log-sawing simulations. Thus, a total of 66,000 log-sawing simulations (2,000 logs $\times$ 3 kerf sizes $\times$ 11 SVs = 66,000) was performed for the analysis. Using LORCAT (Thomas et al. 2021), the total lumber recovery volume and the number of boards produced by SED class and kerf thickness were derived. LORCAT is a geometric-based sawing simulator that models logs as truncated cones defined by length, LED, and SED. As such, the log definitions that are processed do not contain any defect information (Thomas et al. 2021). However, LORCAT uses the US Forest Service log grades and grade yield tables to account for the effect of log grade (defects) on recovery. Hence, LORCAT allows users to obtain recovery estimates of lumber quality and value. Yet, as this study is focused only on recovered volume or on recovered boards, log and lumber grades and values are omitted from consideration. Further, as the results of this study are based on simulated lumber production, an examination of board surface roughness, a component of in-mill SV analyses, could not be performed.

Table 1.—Sawing variation amounts and resulting target thickness.

Sawing variation (in.)	Target thickness (in.)
0.020	1.16440
0.025	1.17425
0.030	1.18410
0.035	1.19395
0.040	1.20380
0.045	1.21365
0.050	1.22350
0.055	1.23335
0.060	1.24320
0.065	1.25305
0.070	1.26290

Using the R statistical program (R Core Team 2020) we compared the variances of the volume recovery (board feet) for the kerf thicknesses and SED classes described above. Using Levene's test (Brown and Forsythe 1974, Fox and Weisberg 2019), variances among the SED classes were found not to be equal. Thus, a nonparametric approach was required to analyze the differences among the SED classes. To determine which SVs resulted in significantly different recovery or board count within each SED class, respectively, the aligned rank transform (ART) statistical test (Wobbrock et al. 2011) was used in conjunction with R (R Core Team 2020). ART allows for the analyses of multifactor designs, whereas traditional nonparametric tests permit the analysis of only one single factor. In this approach, the data are first rank-transformed, and then a factorial analysis of variance is performed. Post hoc pairwise comparisons were conducted using ART-C (Elkin et al. 2021, Kay et al. 2021), which showed the instances where the differences in volume recovered between any SVs within a SED class were significant. A 0.05 level of significance was used for all comparisons in this study. No statistical comparisons between kerf thicknesses were performed, as kerf thickness was not the focus of this study (Thomas and Buehlmann 2022).

The factorial approach used by this analysis compared each resulting SV (from 0.020 to 0.070 in. in 0.05-in. increments) and log SED class (8.0 to 27 in. SED in 1-in. increments) with every other SV (for example, comparing the 0.020-in. with the 0.035-in. SV) and with every SED class (for example, comparing the 8.0-in. SED class with the 9.0-in. SED class). Thus, many of the comparisons are meaningless since a significant difference in recovery or the number of boards sawn should be expected when comparing, for example, a 10-inch SED log with a 27-inch SED log, regardless of SV. Thus, we limited the comparisons to those within 1-inch SED classes (e.g., for 10-in. SED logs, all logs between 10.0 and 10.9 in. SED, in 0.10-in. increments, with 10 logs for each increment, for a total of 100 logs). Overall, these comparisons allow one to determine if a reduction in SV will result in a statistically significant and meaningful difference in total recovery produced within each 1-inch SED class. This paper shows total recovery in volume, as lumber is bought and sold by volume. However, the impact of reducing SV in terms of boards produced is part of a forthcoming second paper (Thomas and Buehlmann 2023).

Results and Discussion

Sawmills, to account for SV inherent in their process, cut their lumber to thicknesses larger than the drying and the planer allowance would demand (Eq. 1, Brown 2000), thereby wasting some yield to assure thickness compliance. Sawmills, therefore, strive to reduce SV, but this requires investment and time, leading to additional costs that need to be carefully weighed with the benefits. Using the US Forest Service's LORCAT sawmill simulation tool (Thomas et al. 2021), this study researched the recovery gains due to a reduction in SV for volume; a second paper will show the relationship for boards (Thomas and Buehlmann 2023).

Impact on volume recovery

The ART statistical test (Wobbrock et al. 2011) established that both SED and SV had a significant effect on volume recovery within the three kerf thicknesses examined. A contrast test of main effects (Wobbrock et al. 2011) across all diameters (e.g., SED classes) showed the points at which differences in volume produced among the different amounts of SV were significant at the 5 percent significance level.

A sawmill, looking to judge if a reduction in SV is worthwhile and how big a reduction of SV is needed to have a significant impact on lumber volume recovery, can use findings from this study and answer questions like ''If total SV is currently 0.050 inches, then how much reduction in SV is necessary to realize a statistically significant improvement in recovery for an 18-inch SED log?'' Figure 2 answers this question for a kerf thickness of 0.125 inches and the 18-inch SED log group. The bars in Figure 2 denote volume recoveries that are not statistically significantly different ($\alpha = 0.05$) among the SV recoveries covered by that bar or any overlapping bar. Figure 2 reveals that the volume recoveries with 0.050-inch SV, indicated by the solid vertical line, are part of three-variation groupings (e.g., bars): the grouping from 0.035 to 0.050 (gray bar), from 0.040 to 0.055 (blue bar), and from 0.045 to 0.065 inches (orange bar). Thus, within the range of these three bars (total

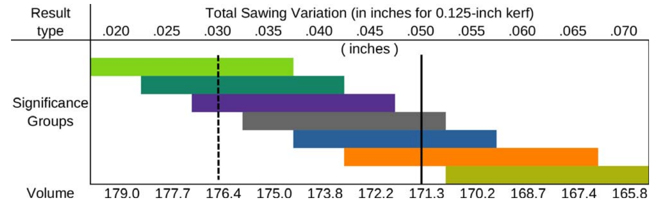

Figure 2.—Statistically equivalent lumber volume groupings by total sawing variation for the 0.125-inch kerf thickness and 18-inch small-end-diameter logs.

SVs from 0.035 to 0.065 in.), no statistically significant difference in volume recovery (e.g., board feet) is attributable to a change in SV. However, if SV is reduced, for example, to 0.030 inches, indicated by the vertical dashed line in Figure 2, a statistically significant improvement in volume recovery can be expected from 18-inch SED logs when sawn using a 0.125-inch kerf. Conversely, an increase in SV to 0.070 inches or more will result in a statistically significant decrease in volume produced for 18-inch SED logs sawn with a saw with a 0.125-inch kerf.

Table 2 reports the mean volume (total board footage) sawn by SED class and SV for the three kerf thicknesses (0.095, 0.125, and 0.162 in.) examined. Figure 3 displays the statistically equivalent lumber volume recovery group-

Table 2.—Mean volume (board ft) by kerf thickness, sawing variation, and small-end-diameter (SED) class obtained.

Kerf thickness	Sawing variation	SED class 8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
0.095	0.020	30.7	44.2	56.6	70.9	82.3	97.8	130.1	130.1	146.1	164.7	183.5	202.6	222.8	244.9	269.2	290.5	313.4	334.8	361.2	390.6
	0.025	30.4	43.8	56.0	70.3	81.4	96.7	129.5	129.5	145.0	163.0	182.2	201.4	221.3	242.9	266.9	288.6	311.1	332.5	358.1	386.9
	0.030	30.0	43.3	55.3	69.7	80.8	95.8	128.5	128.5	143.8	161.8	180.6	199.8	219.5	240.3	264.0	285.9	308.2	329.2	355.7	383.1
	0.035	29.8	43.0	54.8	69.1	79.9	95.1	127.3	127.3	142.8	160.8	178.8	198.3	218.5	239.2	262.3	283.5	305.5	326.3	352.6	379.5
	0.040	29.3	42.6	54.4	68.3	79.0	94.1	126.6	126.6	141.7	159.3	177.8	196.4	216.7	237.9	260.2	280.8	303.8	323.3	349.3	375.5
	0.045	29.0	42.3	54.1	67.6	78.6	93.8	125.6	125.6	140.7	158.1	176.4	195.0	215.1	236.3	257.5	279.6	301.7	321.7	345.9	372.8
	0.050	28.8	41.5	53.7	66.9	77.9	93.2	124.6	124.6	139.7	157.3	175.1	194.1	213.4	233.9	256.2	277.9	299.8	319.2	343.4	369.9
	0.055	28.4	41.3	53.0	66.4	77.3	92.6	123.9	123.9	138.4	156.2	173.9	192.6	211.2	232.8	254.8	275.7	297.5	317.4	341.6	367.5
	0.060	28.2	41.1	52.7	66.1	76.9	91.9	122.9	122.9	137.5	155.5	172.2	191.1	210.0	230.9	252.0	273.1	295.1	316.0	338.8	364.7
	0.065	27.9	40.6	52.2	65.6	76.3	91.0	121.5	121.5	136.4	154.3	171.3	189.6	208.9	229.0	249.4	270.7	292.9	314.2	336.2	361.4
	0.070	27.6	40.0	51.6	65.1	75.9	90.5	120.6	120.6	135.1	153.1	170.2	188.2	207.3	226.9	247.0	268.3	291.9	311.8	333.5	358.8
0.125	0.020	29.8	43.0	54.8	69.0	80.3	95.3	109.4	127.3	142.8	160.8	179.0	198.3	218.5	239.1	262.2	283.3	305.6	326.0	352.5	379.3
	0.025	29.3	42.6	54.4	68.3	78.9	94.1	108.7	126.6	141.7	159.2	177.7	196.4	216.6	237.8	260.1	280.7	303.7	323.2	349.1	375.4
	0.030	29.0	42.2	54.0	67.5	78.2	93.4	107.9	125.6	140.7	158.1	176.4	194.9	215.0	236.3	257.4	279.4	301.6	321.6	346.0	372.7
	0.035	28.8	41.5	53.7	66.9	77.6	92.9	107.3	124.5	139.5	157.2	175.0	194.1	213.3	233.9	256.2	277.8	299.6	319.0	343.3	369.8
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	0.060	27.3	39.6	51.1	64.4	75.2	89.6	103.2	119.7	134.0	151.5	168.7	187.3	205.8	225.3	244.7	266.6	289.9	309.5	332.1	355.6
	0.065	27.1	39.1	50.8	63.9	74.4	88.9	102.7	118.8	133.2	150.7	167.4	185.9	204.5	223.6	243.0	264.2	288.5	307.3	330.6	353.4
	0.070	26.8	38.7	50.5	63.6	73.5	88.0	101.4	117.9	132.5	149.9	165.8	184.4	203.2	222.4	241.6	262.8	286.6	304.9	329.5	351.8
0.162	0.020	28.6	41.3	53.2	66.5	77.4	92.7	106.3	123.9	138.7	156.4	174.0	192.8	211.6	232.7	255.2	276.2	297.7	317.8	341.8	368.1
	0.025	28.2	41.1	52.7	66.1	76.6	91.7	105.6	123.1	137.7	155.7	172.6	191.4	210.3	231.3	252.4	273.7	295.7	316.2	339.5	365.2
	0.030	28.0	40.7	52.3	65.6	76.0	90.8	105.0	121.8	136.6	154.4	171.4	189.8	209.0	229.4	250.0	271.1	293.5	314.4	336.5	361.9
	0.035	27.7	40.1	51.7	65.2	75.4	90.2	104.5	120.8	135.4	153.4	170.3	188.5	207.6	227.3	247.3	268.5	292.0	312.4	334.1	358.9
	0.040	27.4	39.7	51.2	64.5	75.0	89.5	103.4	119.9	134.3	152.0	169.2	187.5	206.2	225.8	245.3	267.0	290.1	309.9	332.3	356.3
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	0.050	26.9	38.8	50.5	63.7	73.7	88.3	101.7	118.0	132.6	150.1	166.4	184.8	203.4	222.7	242.1	263.2	287.0	305.5	329.3	352.1
	0.055	26.5	38.4	50.1	63.2	73.2	87.3	100.9	117.3	131.9	148.7	165.0	183.0	202.1	220.9	240.4	261.3	284.7	303.6	327.4	349.1
	0.060	26.2	38.1	49.7	62.8	72.6	86.5	100.0	116.0	131.0	147.2	163.8	182.0	200.4	218.9	238.7	259.6	282.4	302.4	326.0	346.7
	0.065	26.0	37.6	49.3	62.3	72.1	85.9	99.2	115.0	130.5	146.3	162.9	180.5	198.3	217.5	237.2	257.6	280.5	300.5	324.7	344.9
	0.070	25.7	37.3	48.7	62.0	71.7	84.9	98.4	114.3	129.5	145.3	162.0	179.3	196.4	216.2	236.4	255.4	278.4	298.4	323.0	343.0

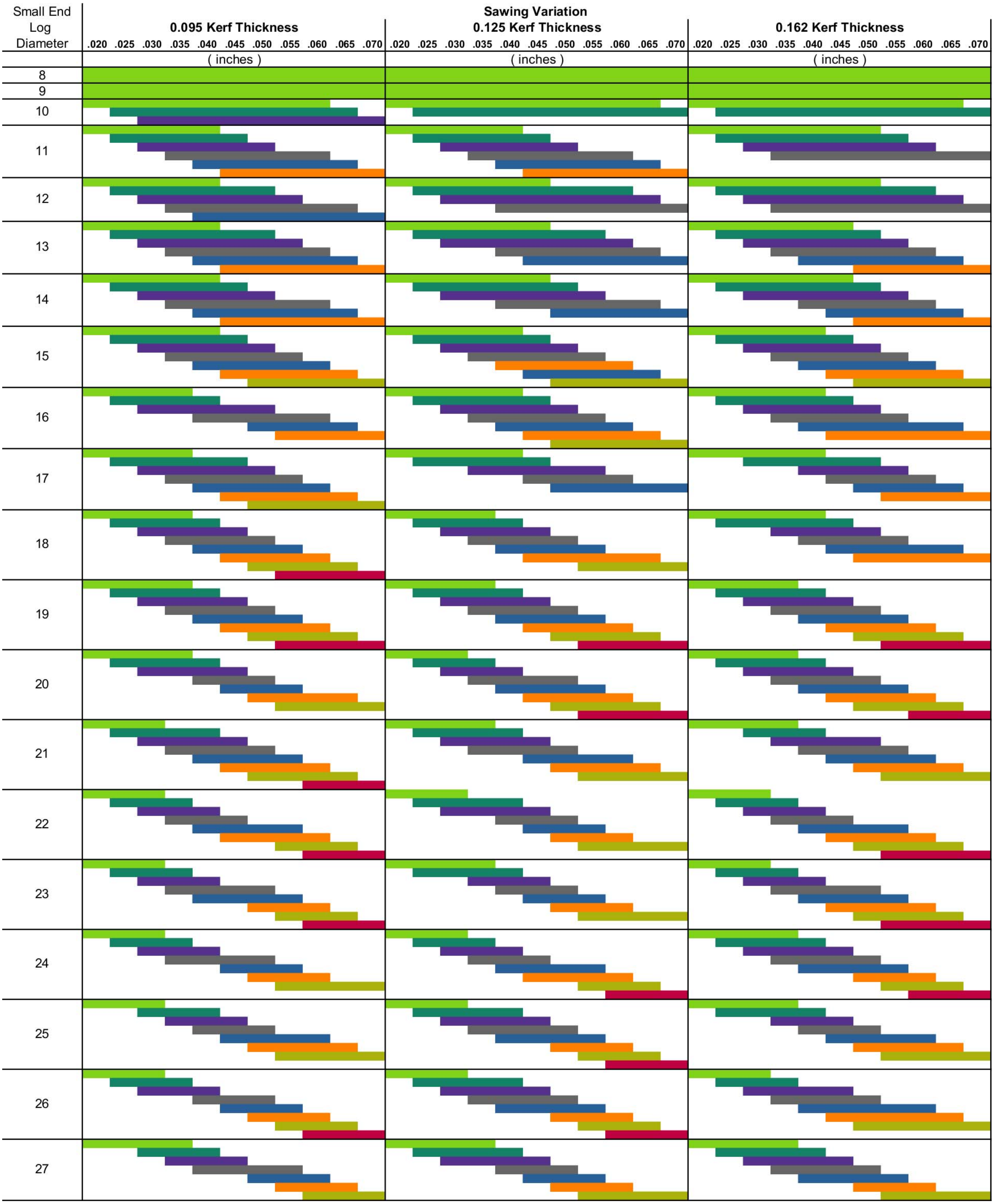

Figure 3.—Statistically equivalent lumber volume recovery groupings by total sawing variation, kerf thickness, and small-end diameter.

ings by total SV, kerf thickness, and SED. Table 2 and Figure 3 combine to provide an understanding of the interactions between SED and SV for the sawing operations modeled in this paper.

Table 3 shows the results from the 0.030- and 0.050-inch SVs to illustrate the lumber recovery differences across SED classes and kerf thicknesses. Comparing the two SVs (0.030 and 0.050 in.) for the three kerf widths investigated, significant differences ($\alpha = 0.05$) exist for all SEDs larger than 14-inches (larger than 13 in. for 0.095 kerf width), regardless of kerf width. An interesting aspect of this analysis is that the volume (board feet) difference between the 0.030- and 0.050-inch SVs increases and decreases depending on SED. That is, the volume difference does not steadily increase as SED increases (decreases in volumetric differences with increasing SED are denoted with a superscript a in Table 3); sometimes the volume difference decreases with increasing SED. This is due to the interaction of SV and kerf thickness with the SED. For example, simulations with the 0.162-inch kerf thickness show that the volume difference between the SV for the 24-inch SED is less than the difference observed with the 23-inch SED (6.6 vs. 7.8 board ft, Table 3). The increased volume from the smaller SV (0.030 in. in this example) in the 24-inch SED logs was not sufficient for extra volume compared with the larger SV (0.050 in.) in the 23-inch SED logs. However, overall, the general trend is for the difference in recovery to increase with SED independent of the SV size (Table 3).

Volume recovery increased comparatively more for thinner than for thicker kerfs, as the total sum of mean differences for volume recovery for the three kerf widths researched (0.095, 0.125, and 0.162 in.) shown in Table 3 (total mean difference 112.6, 105.1, and 97.5 board ft, respectively) confirms. Figure 3 also confirms this observation, as the variation groupings (e.g., bars) are progressively larger with increasing kerf size, i.e., the significance groups contain a wider range of SVs as kerf size increases. In other words, smaller kerfs or smaller SVs result in more volume being extracted given the same SED, with the effect being additive. Hence, one can expect larger volume recovery gains due to reduction in SV with thin kerfs than with thicker kerfs.

Summary

The analysis of the effect of SV on lumber recovery is an example of a geometric fitting problem, much like the classic box-fitting problem, except in this case, we are fitting boxes (lumber) into a truncated cone (log). Changes to the size of the boxes, or the distances between the boxes (kerf thickness and SV), or the size of the truncated cone change the results (lumber recovery). An investigation into all possible interactions among lumber thickness, cant size, kerf thickness, and SVs would require considerable effort. As such, the main goal of this paper was to investigate the interactions at play between varying SV and the resulting impact on lumber recovery in terms of volume. For that, the LORCAT sawmill simulation tool (Thomas et al. 2021) provided an easy-to-use tool to model these factors and predict what effect, if any, a change might cause. The focus of this study was on the effects of SV on lumber recovery by volume produced for red oak logs with diameters ranging from 8.0 to 27.9 inches being sawn to 4/4 lumber target thickness.

Both SED and SV had a significant effect ($\alpha = 0.05$) on volume recovery within the three kerf thicknesses examined. For example, for a kerf thickness of 0.125 inches and

Table 3.—Comparison of volume recovery by small-end-diameter (SED) class for 0.030 and 0.050 sawing variations (SVs).

	Lumber volume recovery (board ft)								
	0.095-inch Kerf			0.125-inch Kerf			0.162-inch Kerf		
	SV			SV			SV		
SED class	0.030	0.050	Difference	0.030	0.050	Difference	0.030	0.050	Difference
8	30.0	28.8	1.2*	29.0	27.9	1.1*	28.0	26.9	1.1*
9	43.3	41.5	1.8*	42.2	40.6	1.6*	40.7	38.8	1.9*
10	55.3	53.7	1.6*[a]	54.0	52.2	1.9*	52.3	50.5	1.7*[a]
11	69.7	66.9	2.8*	67.5	65.6	1.9*	65.6	63.7	2.0*
12	80.8	77.9	2.9*	78.2	76.3	1.9*	76.0	73.7	2.3*
13	95.8	93.2	2.6*[a]	93.4	91.0	2.4*	90.8	88.3	2.4*
14	128.5	124.6	3.8	107.9	104.9	3.0*	105.0	101.7	3.3*
15	128.5	124.6	3.8	125.6	121.4	4.2	121.8	118.0	3.9
16	143.8	139.7	4.1	140.7	136.4	4.3	136.6	132.6	4.0
17	161.8	157.3	4.4	158.1	154.2	3.9[a]	154.4	150.1	4.4
18	180.6	175.1	5.5	176.4	171.3	5.1	171.4	166.4	5.1
19	199.8	194.1	5.7	194.9	189.4	5.5	189.8	184.8	5.0[a]
20	219.5	213.4	6.1	215.0	208.7	6.3	209.0	203.4	5.7
21	240.3	233.9	6.4	236.3	229.0	7.3	229.4	222.7	6.8
22	264.0	256.2	7.8	257.4	249.4	8.1	250.0	242.1	7.9
23	285.9	277.9	8.0	279.4	270.6	8.8	271.1	263.2	7.8[a]
24	308.2	299.8	8.5	301.6	292.7	8.9	293.5	287.0	6.6[a]
25	329.2	319.2	10.0	321.6	314.1	7.5[a]	314.4	305.5	8.8
26	355.7	343.4	12.4	346.0	336.1	10.0	336.5	329.3	7.3[a]
27	383.1	369.9	13.1	372.7	361.3	11.4	361.9	352.1	9.8
Total mean difference			112.6			105.1			97.5

* = Not significant ($\alpha = 0.05$).

[a] Denotes a decrease in lumber volume recovery difference (board feet) from previous difference.

18-inch SED log, seven different log volume groupings by total SV were found. Hence, within the space of volumetric recovery from these logs, the smallest SV (0.020 in.) yielded 179 board feet and the largest SV (0.070 in.) used in this study yielded 165.8 board feet. Although this example is theoretical, as an immediate improvement from the largest to the smallest SV is nearly impossible, it does show the benefit of realizing the smallest SV in a sawmill (an 8.0% gain). For example, going from an 0.050-inch SV to a 0.035-inch SV will increase recovery by 3.7 board feet (171.3 vs. 175.0 board ft) for the 18-inch SED log (Table 2). However, reducing the total SV to 0.030 inches increases recovery 5.1 board feet (171.3 vs. 176.4 board ft), which is a statistically significant improvement (Table 2).

This study examined the effect of SV on 12-foot-long US Forest Service factory Grade 2 logs—a medium log quality. As this study focused on board volume, not quality or value, a change in SV would not be expected to have a great effect on volume across grades for the same-sized logs. However, longer or shorter logs could cause a significant change in lumber volume. Shorter logs would necessarily have shorter tapered areas from which boards could be sawn in the initial opening cuts. Longer logs would offer longer tapered areas from which there would be a greater likelihood of obtaining a board during the initial opening cuts. However, the effect would be strictly influenced by the size of the minimum opening-face board setting. Last, although this analysis did not examine any aspects of board quality, any additional board(s) gained will be sawn from the same area in the log as when a larger SV is tolerated. Hence, there should be no difference in lumber grade distributions between two SV treatments.

In the end, the industry does what allows it to profit from its efforts, and hence, if reducing the SV is costing less than incurring the gains from this effort, clearly there is a case for such an effort. This paper provides the first insight into the correlation of kerf thickness (0.095, 0.125, and 0.162 in.), SED class (from 8 to 27 in.), and SV thickness (from 0.070 to 0.020 in. in half a thousand regression) on volume. The question of board count, another important metric in the hardwood lumber business, will be discussed in another paper (Thomas and Buehlmann 2023).

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