Effect of Sawing Variation on Hardwood Lumber Recovery—Part II: Board Count

Edward Thomas
Urs Buehlmann

Abstract

Sawing variation (SV) describes all variations that exist in the production of lumber due to machine, material, set works, feed works, and cutting parameters. The necessary oversizing of board thickness due to SV diminishes sawmill profits and hence efforts must be made to reduce the variation. However, such efforts are costly and sawmill personnel generally do not know at which point efforts to reduce (SV) become more costly than oversizing the boards. In an accompanying paper we examined the impact of SV on lumber volume recovery and found that volume recovery increased comparatively more for thinner than for thicker kerfs and that the effect of reduced SV became more pronounced as diameter increased. In this second manuscript, the effect of SV on the quantity of boards sawn for a range of hardwood log diameters using the US Forest Service's LOg ReCovery Analysis Tool sawmill simulation software was researched and compared with the volume improvement from an earlier paper. Results showed that significant differences in the number of boards obtained was dependent on the log diameters sawn, the lumber target thickness, and the change (reduction) in SV. A minimal average recovery improvement of 3 percent due to reduced SV was observed across all kerf thicknesses, equating to a potential production value improvement of $336,000 for an 8 million board feet mill. All sawmills can benefit from reducing SV, but mills that saw large-diameter logs might consider pursuing SV reduction more aggressively than a sawmill sawing mostly small-diameter logs.

Sawing variation (SV), the degree of deviation from a specified target lumber size in the sawing process (Brown 2000), forces hardwood sawmills to forgo yield to assure that only a minimal number of boards is less than the required target thickness (scant). SV is composed of within-board and between-board variation, which combine for total SV, the measure commonly referred to as SV. Factors contributing to SV in the sawing process include set works and feed works (Vuorilehto 2001). Sawmills, to increase their salable primary products, strive to reduce SV but must make trade-offs because of increasing costs for further SV reductions. At one point, the cost of reducing SV may exceed the gains from being able to reduce the oversizing of the lumber, nullifying the return on investment of improving the sawing process.

To help mills find the target thickness of their lumber depending (among other things) on a given mill's SV, Brown (2000) created the target thickness equation (Eq. 1).

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

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 1997, Brown stated that oversizing of lumber can cost a mill as much as $250,000 per year in 1997 dollars or $466,000 in today's dollars when adjusted for inflation (InflationTool 2022), indicating the magnitude of the opportunity. However, despite some attention on the impact of SV on mill yield and hence profitability (Steele et al. 1992; Brown 1997, 2000; Vuorilehto 2001; Young et al. 2007), sawmill personnel have limited knowledge of the implications of reducing SV in their operation and few, if any, studies exist showing the impact of reducing SV on raw lumber recovery.

Part I of this study focused on volume improvements due to SV reductions (Thomas and Buehlmann 2023). In one scenario, using saw kerfs of 0.095, 0.125, and 0.162 inches, respectively, when reducing SV from 0.055 to 0.03 inches, volume improvements of more than 4 percent were found in

The authors are, respectively, Research Scientist, USDA Forest Products Lab., Princeton, West Virginia (Ralph.Thomas@usda.gov [corresponding author]); and Associate Professor, Virginia Tech Brooks Forest Products Center, Blacksburg, Virginia (buehlmann@gmail.com). This paper was received for publication in September 2022. Article no. 22-00058.
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some cases. On average, volume improvements of 3.25, 3.07, and 3.25 percent for saw kerfs of 0.095, 0.125, and 0.162 inches, respectively, when reducing SV from 0.055 to 0.03 inches were observed. In 2019, the average hardwood annual sawmill production rate in the eastern United States was approximately 8 million board feet (Hardwood Market Report 2020). A volume improvement of 3 percent due to a reduction in SV results in an increase of 240,000 board feet. Assuming an average value of the lumber products of $1,400 per thousand results in an increase of $336,000 in production value, a 4 percent volume improvement would be an increase of $448,000.

Testing for significant yield improvements ($\alpha = 0.05$) within each small-end-diameter (SED) class due to SV reductions showed that significant volume recovery improvements exist in all scenarios with a SED larger than 15 inches (table 3 in Thomas and Buehlmann 2023). However, although statistically significant yield gains by volume (board feet) were found, it is unclear if similar improvements exist by board count, as an additional board can either be cut because of the savings from reducing SV or not.

Additional boards materialize depending on the diameter of the log and the number of cuts made in that particular log, combined with the reduction of the necessary target thickness (Brown 2000) due to a reduction of SV. Although a reduction of SV always results in slightly wider boards to be sawn (and hence in improvements to volume recovered), the reduction may not be enough to permit an extra board to be sawn. Returning to the example developed in Thomas and Buehlmann (2023), decreasing the SV from the mean value of 0.047 to 0.030 inches, the mean and smallest SVs, respectively, found by Steele et al. (1992), the latest and most complete survey of sawing variation reduces the target thickness from 1.218 to 1.184 inches, a 0.034-inch difference per board. For an 18-inch SED log, a minimum of 6 boards are sawn from each face, for a total of 12 boards across the diameter of the log. This reduction in SV results in the conservation of 0.408 inches (12×0.034). To illustrate the potential impact of the extra 0.408-inch thickness conserved in this 18-inch SED log, Figure 1 compares the live-sawing of an 18-inch SED log with a 1-inch target thickness using the original mean total SV of 0.047 inches found by Steele et al. (1992), with the smallest SV of 0.030 inches observed by Steele et al. (1992) for a live-sawing scenario. Figure 1a shows the boards that result from SV of 0.047 inches. Figure 1b shows the boards that result from a 0.030-inch SV. For the 18-inch log in this

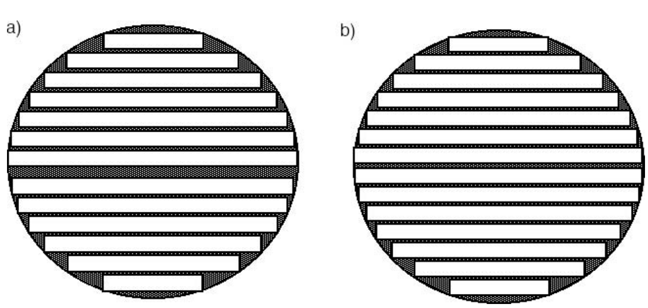

Figure 1.—Comparison of sawing recovery for a live-sawing scenario. (a) Total sawing variation of 0.047 yields a target thickness of 1.2176 inches and yields 13 boards. (b) Total sawing variation of 0.030 yields a target thickness of 1.1841 inches and yields 14 boards.

example, given the target thicknesses of 1.218 inches when the SV is 0.047 inches and 1.184 inches when the SV is 0.030 inches, respectively, the 0.030-inch SV will permit an extra board to be sawn over the 0.047-inch SV (a 7.7% gain in number of boards, e.g., 13 vs. 14 boards and a 4.8% gain in volume recovered, e.g., 174.1 vs. 182.5 board ft). In addition, the 0.030-inch SV leaves a shim cut of 0.25 inches (Figure 1b), whereas the 0.047-inch SV results in a remainder of 0.90 inches (Figure 1a).

This example explores the potential benefits of reducing SV for board count. This study used the LOg ReCovery Analysis Tool (LORCAT; Thomas et al. 2021) and a range of realistic scenarios to research the impact of SV on raw lumber recovery by board count and contrasts its findings with the improvements found when investigating the impact of SV on raw lumber recovery by volume (Thomas and Buehlmann 2023).

Methods

This second part of a two-part manuscript on the effect of SV on hardwood lumber recovery follows the same methodology used in part one (Thomas and Buehlmann 2023). Therefore, only a summary is given here; for details see Thomas and Buehlmann (2023). Whereas part one dealt with the effect of SV on hardwood lumber recovery by volume, this second part deals with the effect of SV on hardwood lumber recovery by the number of boards obtained.

LORCAT sawmill process simulation software (Thomas et al. 2021) was used to research the impact of varying amounts of SV on lumber recovery by number of boards obtained. The selection of logs for this study are described by (1) SED, (2) large-end diameter (LED), (3) length, and (4) grade. A sample of logs represented by this data was created to simulate the sizes of logs commonly sawn in industry. All logs sawn in this study were 12 feet long and US Forest Service factory log Grade 2. Factory Grade 2 is a medium log quality that is characterized by a minimum diameter of 10 inches, with the three best faces having at least 66 percent of the length in two clear cuttings. Log diameters used ranged from 8 to 27 inches and taper-per-foot measurements are based on Wiedenbeck's (2004) study of 34 mills. Using these data, a log data bank that represented actual log diameters and taper amounts found by Wiedenbeck (2004) was created with the LED of each log calculated as $\text{LED} = \text{SED} + \text{taper} \times \text{log length}$. For each 1-inch SED class from 8 to 27 inches, 10 logs for each 0.1-inch increment were created for a total of 100 logs for each 1-inch SED class, for a total of 2,000 logs reflecting the diameter and the taper distribution found by Wiedenbeck (2004). By creating an even distribution of logs with equal numbers of logs in each diameter class avoids potential problems with skewed distributions within each diameter class. Such skewed distribution issues may mask the influence of SV. The approach described above will yield a better analysis of the influence of SV on recovery.

The simulation was set up to grade-saw for 4/4 lumber. A minimum opening face size of 5 inches by 8 feet and a cant thickness of 5 inches was used for logs with a SED less than 12 inches; a minimum opening face size of 6 inches by 8 feet with a cant thickness of 6 inches for logs with a SED of 12 inches or more was required. The produced cants were then subsequently sawn into boards. Three kerf thicknesses were simulated: 0.095, 0.125, and 0.162 inches, on the basis

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of work from Panko (2020), Lin et al. (2011), and Steele et al. (1992), respectively. The SVs analyzed ranged from 0.020 to 0.070 inches in 0.005-inch increments on the basis of the research of Steele et al. (1992), Brown (2000), and Young et al. (2000). The target lumber thicknesses sawn were calculated using Brown's (2000) equation with the planer allowance set to 0 as we were simulating the production of 4/4 dried rough-dimension lumber, whereas the shrinkage allowance was set at 0.125 inches. *Z*, the standard normal variation variable in Brown's (2000) equation, was set at 1.97, permitting 2.5 percent of all boards to be scant. The National Hardwood Lumber Association grading rules state that 0.375- to 1.75-inch-thick lumber may be at most 0.0625 inches scant and 2 inches-and-thicker lumber can be as much as 0.125 inches scant (NHLA 2019). As such, any lumber whose thickness falls below the threshold should be rejected. By minimizing the number of scant boards, the revenue loss from rejected boards is also minimized. Hence, we simulated sawing a total of 11 target thicknesses with the maximum target thickness difference between the smallest (1.1644) and largest thickness (1.2629) being 0.0985 inches (Thomas and Buehlmann 2023).

A total of 66,000 log-sawing simulations was performed using LORCAT (Thomas et al. 2021) and the total lumber recovery by volume (board feet) and by board count captured. Using the R statistical program (R Core Team 2020) we compared the variances of the board count simulation results 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 sawing variations 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 performed. Post hoc pairwise comparisons were conducted using ART-C (Elkin et al. 2021, Kay et al. 2021). ART-C showed the instances where the volume or number of boards recovered differences between any SVs within an SED class were significant ($\alpha = 0.05$). A more thorough discussion of the methods used in this research can be found in Thomas and Buehlmann (2023.

Results and Discussion

Research into the volumetric improvement of sawmill yield due to a reduction of SV showed significant differences ($\alpha = 0.05$) among the SED classes created for this research (Thomas and Buehlmann 2023). However, as increases to the number of boards sawn are incremental, significant improvements could be less common for boards recovered than with volume. After reporting and discussing the impact of SV reductions on board count, the improvements due to a reduction of SV found by volume and by board count are contrasted and discussed below.

Impact on board count

SV is a key component when determining the target thickness of lumber (Brown 2000). The smaller the SV, the greater the possibility of obtaining an extra board from a given log. This is because more material remains after cutting a given board, with the effect being cumulative (Figure 1). However, the gains are incremental, and the sum of cumulative gains may or may not allow an additional board to be cut from any given log. For example, with a SV of 0.030, the target sawing thickness is 1.1841 inches, whereas the target sawing thickness is 1.2334 inches for a SV of 0.055, a difference of 0.049 inches. An additional board is only gained if the number of times the 0.049-inch reduction per cut accumulates and the remaining material from the log adds up to 1.1841 inches or more. If this happens, one more board can be sawn from a log and, given the methodology chosen for this study, the minimum volume increase from an additional board is 3.3 board feet (5 in. minimum width by 8 ft minimum length). As the SED increases, so does the number of boards sawn and hence the opportunities for gaining a board. However, if the cumulative gains from the reduced target thickness sawn due to a lower SV is not greater than or equal to the target thickness, the gains incurred from the reduced sawing thickness will not improve the board count (but will improve the volume slightly).

Using the ART statistical test ($\alpha = 0.05$, Wobbrock et al. 2011), it was determined that SV had a significant effect on the numbers of boards recovered within the three kerf thicknesses examined. A contrast test of main effects (Wobbrock et al. 2011) was conducted across all diameters to determine which differences in board counts were significant at the 5 percent significance level. The results of this test allowed statistically equivalent board count groups to be determined within each diameter group. Figure 2 shows the statistically equivalent board count groupings as horizontal bars for 18-inch SED class logs by total SV for the 0.125-inch kerf thickness. The bars group together numbers of boards recovered that are not statistically significantly different ($\alpha = 0.05$). The solid vertical line in Figure 2 crosses all the bars that contain statistically equivalent results for the 0.050-inch SV. The 0.050-inch SV is contained in four bars with a total range from 0.035- to 0.070-inch SVs. Thus, within the range of these four bars, there is no statistically significant difference in the number of boards sawn 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 the number of boards sawn can be expected from 18-inch SED logs when sawn using a 0.125-inch kerf.

Figure 3 displays the statistically equivalent board count groupings by total SV, kerf thickness, and SED. Table 1

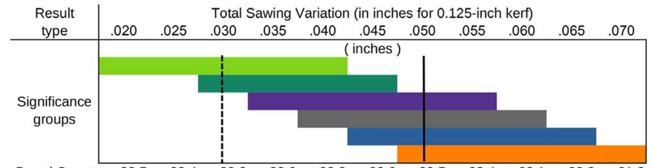

Figure 2.—Statistically equivalent board-count groupings by total sawing variation for the 0.125-inch kerf thickness and 18-inch small-end-diameter logs.

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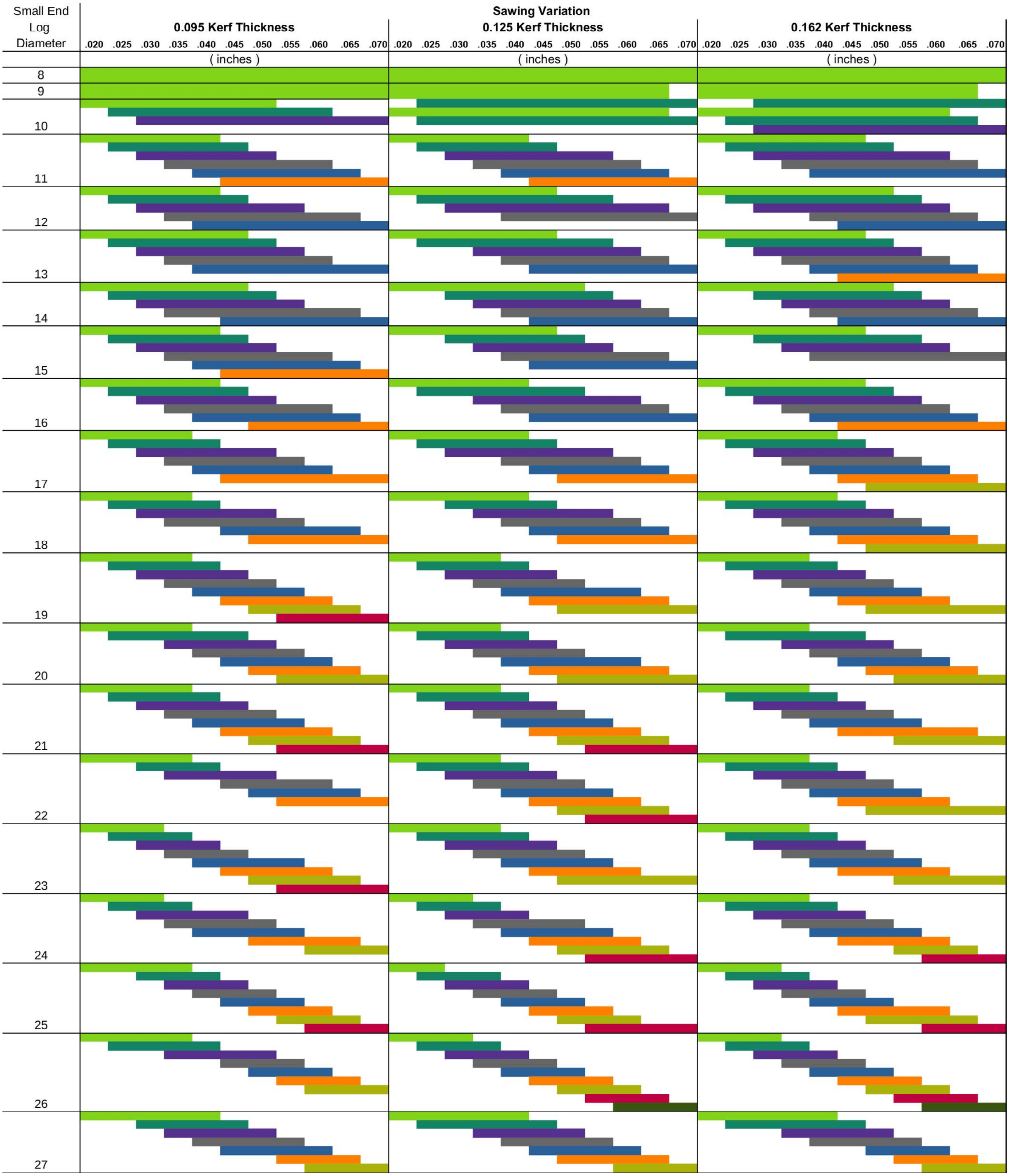

Figure 3.—Statistically equivalent board-count groupings by total sawing variation, kerf thickness, and small-end diameter.

reports the mean number of boards sawn by SED class and SV for the three kerf thicknesses (0.095, 0.125, and 0.162 in.) investigated. Table 1 and Figure 3 combine to provide an understanding of the interactions between SED and SV for the sawing operations with respect to numbers of boards produced.

Table 2 shows the results when sawing with SVs of 0.030 and 0.050 inches to illustrate the board count differences across SED classes among the three kerf thicknesses (0.095, 0.125, and 0.162 in.) investigated. Comparing the two SVs investigated (0.030 and 0.050 in.) for the three kerf widths used, a significant difference ($\alpha = 0.05$) in board count was

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Table 1.—Mean board counts by kerf thickness, sawing variation, and small-end diameter (SED) class obtained for 1-inch lumber.

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	7.5	9.5	11.2	13.1	13.3	15.2	16.9	18.9	20.2	20.2	24.2	25.6	26.9	29.1	30.9	32.7	34.1	36.2	37.4	39.0
	0.025	7.5	9.4	11.1	13.0	13.1	15.0	16.7	18.7	20.1	20.1	24.0	25.4	26.7	28.8	30.6	32.4	33.7	36.0	37.1	38.8
	0.030	7.4	9.3	10.9	12.9	13.0	14.9	16.5	18.5	19.9	19.9	23.8	25.3	26.5	28.6	30.4	32.1	33.5	35.7	36.8	38.4
	0.035	7.4	9.3	10.8	12.8	12.9	14.7	16.3	18.4	19.7	19.7	23.6	25.0	26.3	28.3	30.1	31.8	33.2	35.5	36.6	38.1
	0.040	7.3	9.2	10.8	12.7	12.8	14.6	16.2	18.3	19.6	19.6	23.4	24.8	26.2	28.1	29.9	31.6	32.9	35.2	36.2	37.8
	0.045	7.3	9.1	10.7	12.5	12.7	14.5	16.1	18.1	19.5	19.5	23.2	24.6	26.0	27.9	29.6	31.3	32.7	34.9	35.9	37.5
	0.050	7.2	9.0	10.7	12.4	12.6	14.4	16.0	18.0	19.3	19.3	23.0	24.5	25.8	27.6	29.4	31.1	32.4	34.6	35.7	37.2
	0.055	7.2	8.9	10.5	12.3	12.5	14.3	15.8	17.9	19.1	19.1	22.9	24.3	25.5	27.4	29.2	30.9	32.1	34.3	35.4	37.0
	0.060	7.1	8.9	10.5	12.2	12.5	14.2	15.7	17.7	19.0	19.0	22.6	24.1	25.3	27.3	29.0	30.6	31.9	34.1	35.2	36.7
	0.065	7.1	8.8	10.4	12.1	12.4	14.1	15.6	17.5	18.9	18.9	22.5	23.8	25.2	27.1	28.7	30.4	31.7	33.8	34.9	36.4
	0.070	7.0	8.7	10.3	12.0	12.3	14.0	15.5	17.4	18.7	18.7	22.4	23.7	25.0	26.8	28.5	30.2	31.4	33.5	34.6	36.1
0.125	0.020	7.4	9.3	10.8	12.8	13.0	14.8	16.3	18.4	19.7	21.6	23.5	25.0	26.3	28.3	30.1	31.8	33.1	35.4	36.5	38.1
	0.025	7.3	9.2	10.8	12.7	12.8	14.6	16.2	18.3	19.6	21.3	23.4	24.8	26.1	28.1	29.8	31.5	32.9	35.2	36.2	37.8
	0.030	7.3	9.1	10.7	12.5	12.6	14.4	16.1	18.1	19.5	21.1	23.2	24.6	26.0	27.9	29.6	31.3	32.7	34.9	35.9	37.5
	0.035	7.2	9.0	10.7	12.4	12.6	14.4	16.0	18.0	19.2	21.0	23.0	24.5	25.8	27.6	29.4	31.1	32.4	34.6	35.6	37.2
	0.040	7.2	8.9	10.5	12.3	12.5	14.3	15.8	17.9	19.1	20.9	22.8	24.3	25.5	27.4	29.2	30.9	32.1	34.3	35.4	36.9
	0.045	7.1	8.9	10.5	12.2	12.5	14.2	15.7	17.7	19.0	20.7	22.6	24.1	25.3	27.2	29.0	30.6	31.9	34.1	35.1	36.7
	0.050	7.1	8.8	10.4	12.1	12.4	14.1	15.6	17.5	18.9	20.5	22.5	23.8	25.2	27.1	28.7	30.4	31.7	33.8	34.9	36.4
	0.055	7.0	8.7	10.3	12.0	12.3	14.0	15.5	17.4	18.7	20.4	22.4	23.7	25.0	26.8	28.5	30.2	31.4	33.5	34.6	36.1
	0.060	7.0	8.7	10.3	11.9	12.2	13.8	15.3	17.3	18.5	20.2	22.1	23.6	24.8	26.6	28.3	30.0	31.2	33.3	34.4	35.8
	0.065	7.0	8.6	10.2	11.8	12.1	13.7	15.2	17.2	18.4	20.0	22.0	23.4	24.6	26.4	28.1	29.7	31.0	33.1	34.1	35.6
	0.070	6.9	8.5	10.2	11.7	12.0	13.6	15.0	17.1	18.3	19.9	21.8	23.2	24.4	26.3	27.9	29.5	30.8	32.8	33.8	35.3
0.162	0.020	7.2	8.9	10.6	12.3	12.5	14.4	15.8	17.9	19.1	20.9	22.9	24.3	25.5	27.4	29.2	30.9	32.2	34.4	35.4	37.0
	0.025	7.1	8.9	10.5	12.2	12.4	14.2	15.7	17.8	19.0	20.7	22.7	24.1	25.3	27.3	29.0	30.6	32.0	34.2	35.2	36.7
	0.030	7.1	8.8	10.4	12.1	12.4	14.1	15.6	17.6	18.9	20.6	22.5	23.9	25.2	27.1	28.7	30.4	31.7	33.9	34.9	36.5
	0.035	7.1	8.7	10.3	12.0	12.3	14.0	15.5	17.4	18.7	20.4	22.4	23.7	25.0	26.9	28.5	30.2	31.5	33.6	34.6	36.2
	0.040	7.0	8.7	10.3	11.9	12.2	13.9	15.3	17.3	18.6	20.2	22.2	23.6	24.8	26.7	28.4	30.0	31.2	33.3	34.4	35.9
	0.045	7.0	8.6	10.2	11.8	12.1	13.7	15.3	17.2	18.5	20.1	22.0	23.4	24.7	26.4	28.1	29.8	31.1	33.1	34.2	35.7
	0.050	6.9	8.5	10.2	11.8	12.0	13.7	15.1	17.1	18.4	19.9	21.9	23.2	24.4	26.3	27.9	29.6	30.8	32.9	33.9	35.4
	0.055	6.9	8.4	10.1	11.7	11.9	13.5	15.0	17.0	18.2	19.8	21.7	23.0	24.2	26.1	27.8	29.4	30.6	32.6	33.7	35.1
	0.060	6.8	8.4	10.0	11.6	11.8	13.4	14.8	16.8	18.1	19.6	21.5	22.9	24.0	25.9	27.6	29.1	30.4	32.4	33.5	34.9
	0.065	6.8	8.2	10.0	11.5	11.7	13.3	14.7	16.7	18.0	19.5	21.4	22.7	23.8	25.8	27.4	28.9	30.1	32.2	33.2	34.6
	0.070	6.7	8.2	9.9	11.5	11.7	13.2	14.6	16.6	17.8	19.4	21.2	22.5	23.7	25.5	27.1	28.7	29.9	31.9	33.0	34.3

observed when the mean difference was 0.8 or more boards between results (Table 2). Although 0.8 boards may not seem to be a meaningful amount when sawing a 19-inch SED log, consider that the SED and SV comparisons within each kerf size are each made over 100 paired samples. For each 19-inch SED log sample the board count difference due to a smaller SV is either 0 or 1. However, when sawing larger-diameter logs the board count difference can be as much as 2 boards. An average of 0.8 more boards means that in 80 of the 100 simulations, the smaller SV resulted in the production of an extra board. Overall, the mean differences between SV (0.050 vs. 0.030) ranged from 0.2 boards when sawing 8-inch SED logs to 1.2 when sawing 27-inch SED logs. The more boards that are sawn from a log, the larger the cumulative effect of a narrower target thickness due to a smaller SV on board count. The greatest total sum of mean differences for board recovery (Table 2), across all SED classes, was 14.2 boards with the smallest kerf (0.095 in.) investigated, whereas the lowest total sum of mean differences (12.3 boards) was with the largest kerf thickness (0.162 in.) investigated. Board count recovery thus follows the observation made with volume recovery (table 3, Thomas and Buehlmann 2023), that board count improvement due to SV reduction is larger with thinner kerfs.

Volume versus board count improvement

The consequences of reducing SV on volume and board count follow similar trends. Both benefit from reducing total SV (and hence, lumber target thickness; Brown 2000), but the benefits are not equal. In Figure 4, the volume improvement due to reducing the SV from 0.050 to 0.030 inches is plotted for all SED classes and kerf thicknesses. For the smallest SEDs, e.g., 8, 9, and 10 inches, there is little to no volume difference due to a decrease in SV across all three kerfs. This is simply because there is too little extra wood gained from a reduction in SV, regardless of kerf thickness, when sawing small-diameter logs to result in a significant increase in board volume.

Significant positive differences in lumber volume were found starting with SEDs of 14, 15, and 15 inches for kerf widths 0.095, 0.125, and 0.162, respectively (table 3, Thomas and Buehlmann 2023). As SED increases, the highest volume improvement shifts between the 0.095- and 0.125-inch kerf thicknesses because of the interactions among SV, SED, and kerf thickness. This is because an increase in SED, combined with the SV reduction and kerf thickness, may result in extra volume being obtained. However, by and large, the benefits of reducing SV are steadily increasing with larger SED between kerf thickness (0.095, 0.125, and 0.162). Above SED 23, improvements for kerf thicknesses 0.125 and 0.162 inches become unsteady.

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Table 2.—Comparison of numbers of boards sawn by small-end diameter (SED) class for 0.030 and 0.050 sawing variations (SVs).

	Board counts								
	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	7.4	7.2	0.2*	7.3	7.1	0.2*	7.1	6.9	0.2*
9	9.3	9.0	0.3*	9.1	8.8	0.3*	8.8	8.5	0.3*
10	10.9	10.7	0.2*[a]	10.7	10.4	0.3*	10.4	10.2	0.2*[a]
11	12.9	12.4	0.5*	12.5	12.1	0.4*	12.1	11.8	0.3*
12	13.0	12.6	0.4*[a]	12.6	12.4	0.2*[a]	12.4	12.0	0.4*
13	14.9	14.4	0.5*	14.4	14.1	0.3*	14.1	13.7	0.4*
14	16.5	16.0	0.5*	16.1	15.6	0.5*	15.6	15.1	0.5*
15	18.5	18.0	0.5*	18.1	17.5	0.6*	17.6	17.1	0.5*
16	19.9	19.3	0.6*	19.5	18.9	0.6*	18.9	18.4	0.5*
17	19.9	19.3	0.6*	21.1	20.5	0.6*	20.6	19.9	0.7*
18	23.8	23.0	0.8	23.2	22.5	0.7*	22.5	21.9	0.6*[a]
19	25.3	24.5	0.8	24.6	23.8	0.8	23.9	23.2	0.7*
20	26.5	25.8	0.7*[a]	26.0	25.2	0.8	25.2	24.4	0.8
21	28.6	27.6	1.0	27.9	27.1	0.8	27.1	26.3	0.8
22	30.4	29.4	1.0	29.6	28.7	0.9	28.7	27.9	0.8
23	32.1	31.1	1.0	31.3	30.4	0.9	30.4	29.6	0.8
24	33.5	32.4	1.1	32.7	31.7	1.0	31.7	30.8	0.9
25	35.7	34.6	1.1	34.9	33.8	1.1	33.9	32.9	1.0
26	36.8	35.7	1.1	35.9	34.9	1.0[a]	34.9	33.9	1.0
27	38.4	37.2	1.2	37.5	36.4	1.1	36.5	35.4	1.1
Total mean difference			14.2			13.2			12.3

* Not significantly different ($\alpha = 0.05$).
[a] Denotes a decrease in average number of boards sawn from previous difference.

However, these graphs consist of the increase in volume for the 0.030 versus the 0.050 SV and therefore, such increases in volume may not persist as SED increases. For all saw kerfs, the overall trend is that the larger the SED, the greater the improvement due to a reduction of the SV, as seen most pronounced by the smallest saw kerf (0.095 in.) researched.

Figure 5 plots the increase in board count due to the reduction of SV from 0.050 to 0.030 inches for all SED

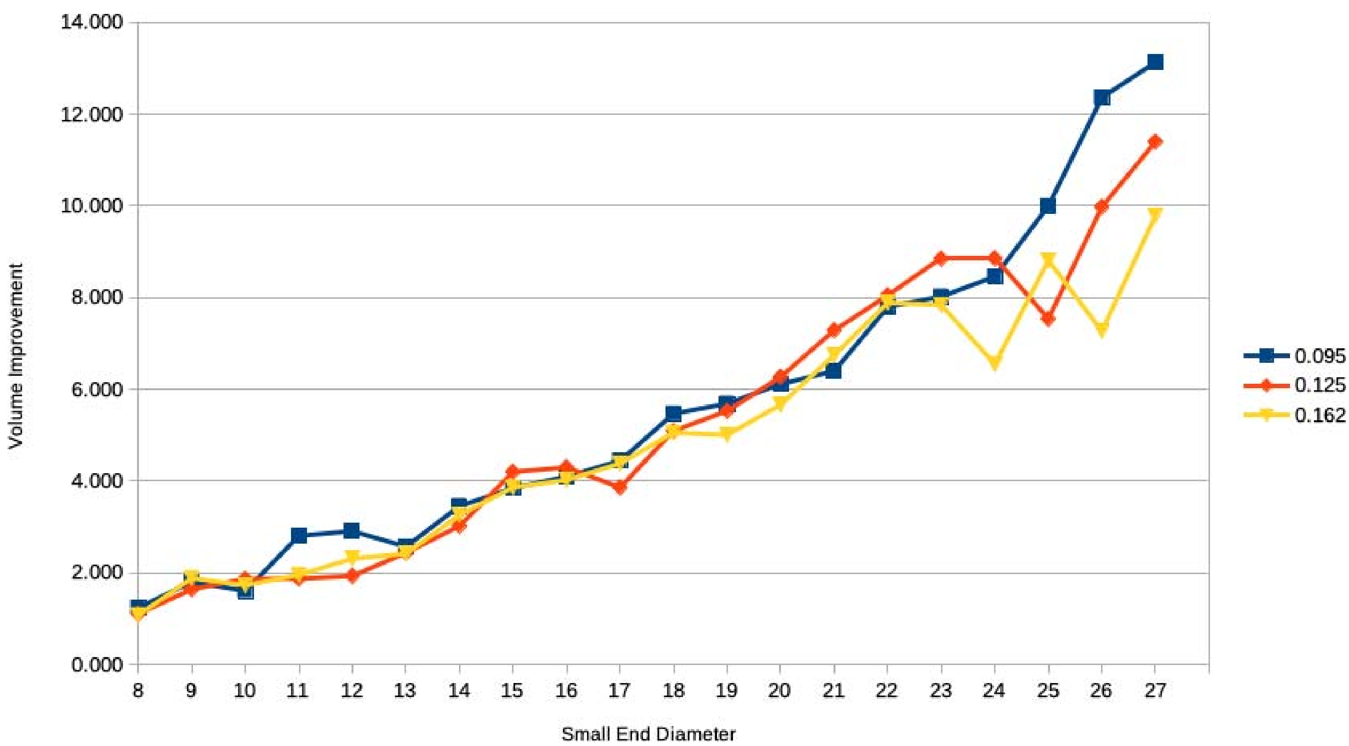

Figure 4.—Increase in volume for the 0.030 versus 0.050 sawing variation by kerf thickness and small-end diameter class.

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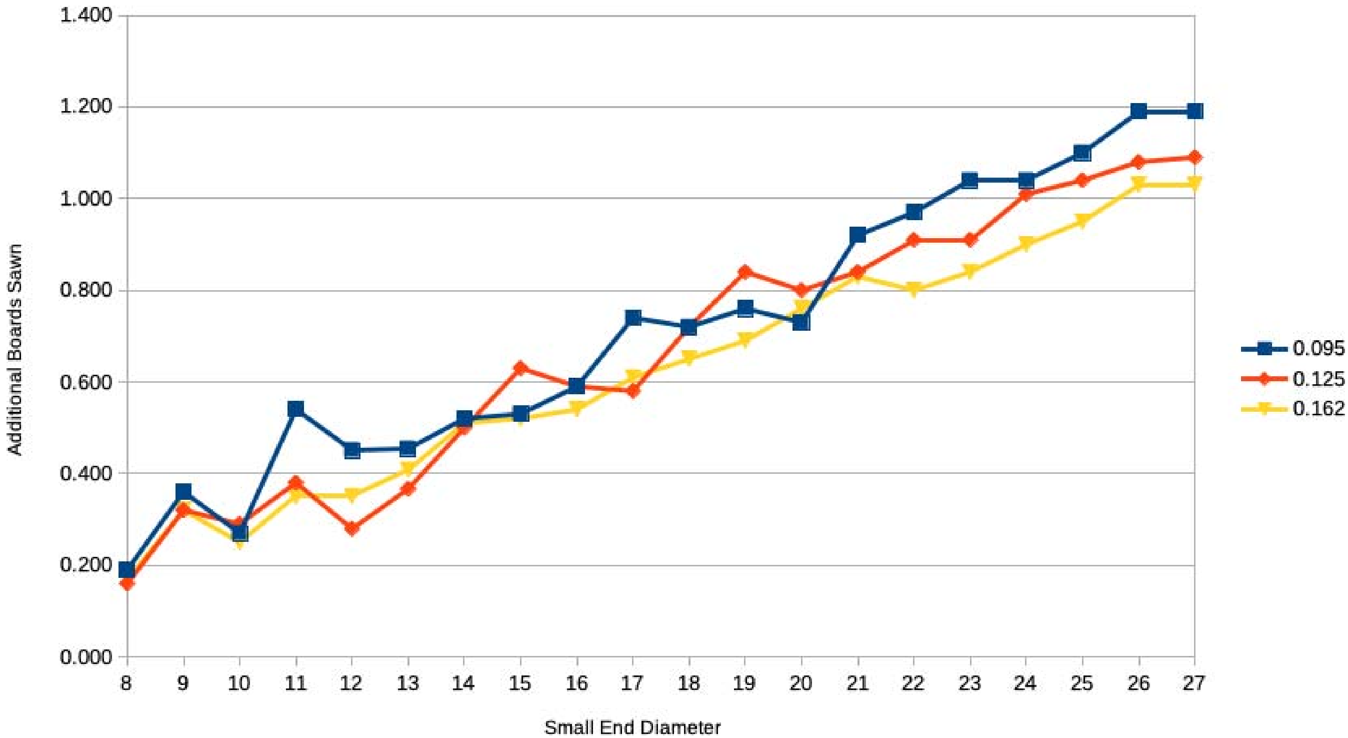

Figure 5.—Increase in board count for the 0.030 versus 0.050 sawing variation by kerf thickness and small-end diameter class.

classes and kerf thicknesses researched. When the interactions of SED, SV, and kerf thickness combine to result in an improvement in board count (Figure 5), a related improvement in board volume is generally observed (Figure 4). The improvements for board count among SED are more erratic at the lower end of SED but become more regular as SED increases. In Figure 5, the difference in SV treatments for an 8-inch SED log results in about 20 percent of the logs producing an extra board. This percentage changes to approximately 35 percent and 27 percent with 9-inch and 10-inch SED logs, respectively. For smaller SED logs, however, the chances of producing an extra board are always infrequent. Further, when the factors of SV, SED, and kerf combine to allow an extra board to be sawn for a particular SED, the likelihood of obtaining an extra board for the next largest SED is reduced until the SED allows for an additional extra board to be sawn. For example, for the 0.095-inch kerf thickness in Figure 5, the probability of adding another board jumps from approximately 60 percent at SED 16 to 75 percent at SED 17, but the step increases remain about the same (approximately 75%) until SED 21, where the probability goes to 95 percent. Another example of this occurrence is with saw kerf 0.095 and SED 11, where the probability reaches close to 60 percent, but then stays below that for SEDs 12, 13, 14, and 15, before resuming the increase in probability obtaining boards with SED 16. This phenomenon is seen in Figure 5 as a sinusoidal curve with up-and-down trends of board count for the three kerfs examined. These decreases are also denoted with a superscript a in Table 2. Also, sometimes two boards can be added because of the reduction of the SV from 0.050 to 0.030. However, this only happens for SED above 22, where there is a probability that sometimes two extra boards can be added (Figure 5).

However, when reducing SV (and hence, lumber target thickness; Brown 2000), both volume and board count increase, but not at the same rate. For example, when sawing an 18-inch SED log using a 0.125-inch kerf thickness, reducing the sawing variation from 0.060 to 0.040 inches resulted in a statistically significant improvement ($\alpha = 0.05$) of volume recovered (gain of 5.1 board ft; table 3 and figure 2 in Thomas and Buehlmann 2023). However, when measuring the same change by the number of boards produced, no statistically significant improvement of board count recovered is achieved (mean gain of 0.7 boards; Table 2 and Figure 2). Hence, although volume, which increases without the addition of a board because of the sawing geometry, can benefit significantly, board count may not. For board count recovery to show a statistically significant improvement with 18-inch SED logs, SV would need to be reduced to 0.035 inches.

Overall, significant differences in the number of boards obtained begin with approximately 19-inch SED logs (Table 2), whereas improvements to the volumetric yield from sawing those same logs occur at 12-inch or 13-inch SED (table 3 in Thomas and Buehlmann 2023). Hence, a sawmill sawing mostly large-diameter logs might consider pursuing SV reduction more aggressively than a sawmill sawing mostly small-diameter logs, if they are looking at board count. However, although this statement is true with respect to improvements in number of boards obtained (Figure 5 and Table 2), significant volume recoveries (figure 4 and table 3 in Thomas and Buehlmann 2023) were found for smaller-diameter logs (12 or 13-in. SED) compared with number of boards sawn (20-in. SED), giving reason for sawmills that saw mostly small logs to reduce their SV too, as lumber is sold by volume (board feet) and not by number of boards.

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The trends found in this study show that in general, the greatest improvements in volume recovery and numbers of boards produced occur with the thinnest kerf (table 3 in Thomas and Buehlmann 2023 and Table 2). That is, the effect of a decrease in SV and a reduction in kerf size is additive. This observation is also evident when comparing the volume (figure 3 in Thomas and Buehlmann 2023) and board count (Figure 3); the groups are more numerous and contain fewer SVs as the kerf thickness decreases. This points to the effect of an additive impact of decreased SV and kerf thickness on recovery.

Limitations

In this study, we examined log diameters by SED in 1-inch classes—the diameter class increments in which logs are traded. However, it is not known if the trends found for 1-inch increments are like those at, say, 0.10- or 0.25-inch SED increments. Questions also remain about the influence of sawing thicker or thinner lumber, the effects of sawing different thicknesses of lumber from the same log, or the consequences of producing cants of various sizes from a batch of logs.

This study examined the effect of sawing variation on 12-foot-long US Forest Service factory Grade 2 logs—a medium log quality. As this part of the study focused on numbers of boards sawn, not quality or value, a change in SV would not be expected to have a great effect on board counts across grades for the same-size logs. However, longer or shorter logs could cause a significant change in the numbers of boards sawn. 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. This would also move the opening board closer to the log surface and farther from the center of log, increasing the thickness of the potential remaining area to the point that an extra board may be obtained, However, the effect would be strictly influenced by the size of the minimum opening-face board setting.

Summary

This two-part manuscript investigated the interactions at play between varying SV (from 0.020 to 0.070 in. in 0.005-in. increments) in terms of volume (part I, Thomas and Buehlmann 2023) and board count (this work) using the LORCAT (Thomas et al. 2021) sawmill simulation tool when sawing 4/4 lumber. The simulation used saw kerfs of 0.095, 0.125, and 0.162 inches used in other studies (Steele et al. 1992, Lin et al. 2011, Panko 2020) and SED diameters ranging between 8.0 and 27.9 inches with the Wiedenbeck (2004) taper distribution.

Whereas the first manuscript (Thomas and Buehlmann 2023) examined volume increases due to reduced SV, the second manuscript looks at board count increases due to reduced SV. Unlike volume increases, board count increases are incremental where the sum of cumulative gains either allows an additional board (or more) to be cut or not from any given log. For example, when looking at SVs of 0.030 versus 0.050 inches among the three kerf thicknesses (0.095, 0.125, and 0.162 in.) investigated, only SEDs above 17, 18, and 19 for the three kerf thicknesses, respectively, were able to produce significant results. Overall, the mean differences between SV (0.050 vs. 0.030) ranged from 0.2 boards when sawing 8-inch SED logs to 1.2 when sawing 27-inch SED logs using a 0.095-inch kerf thickness. This shows that as more boards are sawn from a log, the larger the cumulative effect of a narrower target thickness, due to a smaller SV, on board count.

Volume and board count improvement due to reducing SV follow similar trends, but the benefits are not equal. Significant positive differences in lumber volume were found starting with SEDs of 14, 15, and 15 inches for kerf widths 0.095, 0.125, and 0.162 inches, respectively (table 3, Thomas and Buehlmann 2023), whereas only SEDs above 17, 18, and 19 for the same scenario were able to produce significant results for board count (Table 2). However, for volume and board count for all saw kerfs, the larger the SED, the bigger the gain that can be expected from reducing SV. Sawmill personnel often do not know what reduction in SV will increase their yield (in volume or board count). Although it is known that a smaller SV tends to be beneficial to yield, this research has shown the benefit of reducing SV by SEDs, with larger SEDs benefitting the most from the decrease. However, more work is needed to investigate the influence of sawing thicker or thinner lumber, the effects of sawing different thicknesses of lumber from the same log, or the consequences of producing cants of various sizes from a sample of logs. However, 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 significant difference in lumber grade distributions between two SV treatments.

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