Comparing Batch Log Studies to Individual Log Studies: Part 1 - Batch Studies

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Abstract

Batch log studies are frequently used by sawmills to provide insight into lumber grade yields and overrun for a given log grade. This information is then used to determine log pricing. These batches often contain logs with a wide range of diameters and clear faces. Little research has been done to determine the reliability of a batch log study for use in determining log break-even pricing.

A series of 16 batch log studies were conducted at a hardwood sawmill to gain insight into the accuracy and reliability of the batch log study method. Batch compositions were found to be statistically different in four of five log grades. These statistically different batches led to statistical differences in lumber grade yields and overrun.

The batch log study method does not provide accurate insights into lumber grade yields and overrun. As a result, these data are not reliable for mill management decisions such as the calculation of log prices. Several changes could be made to improve the batch log study method, but the individual log study method would be of much more use to mill managers.

Log yield studies allow mills to better understand the products they manufacture from a given log, as well as the potential profit from those products and consequently, the purchased log. This accurate log yield data is vital for mill profitability during periods when lumber prices are weak or log supplies are tight, which, individually or in combination, lead to smaller profit margins. With accurate estimates of lumber yields by grade, overrun, sawing costs, and product pricing, mill management can predict break-even prices and set the maximum price to pay for purchased logs to ensure that raw material costs for the mill are reasonable and can sustain a desired level of profitability.

Results obtained from sawmill-based log yield studies, when combined with log information such as log diameter and scale, can be used to accurately value a log of a given species and grade. This eliminates the guesswork that typically occurs when mills are assigning prices to the logs they purchase. Without accurate log yield data, there is no way to price logs that will ensure their acquisition is profitable prior to being processed through the sawmill.

Literature Review

The importance and utility of log yield data have been recognized since the early development of hardwood log grading systems. Benson and Wollin (1938) suggested using lumber yield data as the basis of a future hardwood log grading system. This was the beginning phase of development for the US Forest Service (USFS) hardwood log grading system. Their work focused on defining the relationship between log defects and lumber grade. To achieve this, logs were scaled, and the defects were diagrammed. Logs were then tracked individually through the mill and lumber data were recorded for each log.

The USFS hardwood log grading system was completed in 1949 (Wollin and Vaughan 1949). This system was based on the individual log study approach, with data being collected from approximately 11,000 logs. This publication was later revised to update and adjust some of the original lumber yield data (Vaughan et al. 1966).

Many more log yield studies were completed using the individual log study method. Herrick (1946), in conjunction

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with the Purdue University Agricultural Experiment Station, worked to better understand lumber grade yields and overrun–underrun in Indiana hardwood sawlogs. Sawing time per log was also recorded to incorporate sawing costs. Calvert (1956) detailed a study by the Forest Products Laboratories of Canada to determine whether the USFS log grading system was useful in Canadian hardwood species.

Schroeder and Hanks (1967) present the results from an individual log study of 556 red oak (*Quercus rubra*) factory-grade logs. This work was continued to subfactory-grade red oak logs (Schroeder 1968). Hanks (1973) published results from subfactory-grade logs, with most commercial species included. The last significant lumber yield data from the Forest Service were published by Hanks et al. (1980). Additional yield data were combined with the previously published yield information presented in Vaughan et al. (1966).

After this time, no further effort was made by the USFS to continue collecting individual log data. However, the Appalachian Hardwood Center (AHC) at West Virginia University, in 2005 began collecting individual log data from hardwood sawmills and currently has data on over 4,600 logs in the AHC database. In conjunction with Appalachian Hardwood Manufacturers Inc., the AHC developed a standardized hardwood log grading system that was released in 2019. This system is a clear-face grading system similar to those in use at most hardwood sawmills today (AHMI 2019).

Hassler et al. (2019) discussed the reasons that the USFS hardwood log grading system was never adopted by the hardwood industry. This has led the industry to alternative methods of assessing the economics of their hardwood logs. Mills in general gravitated to mill-specific grading and scaling rules, rather than a standardized system. In order to understand their lumber grade yields and overrun in an effort to establish log pricing, mills have relied on batch mill studies. A batch mill study is a data collection process whereby a group of study logs are processed together, with data gathered for the group rather than producing any specific individual log data (Govett et al. 2006). Batch mill studies are somewhat simplified and less labor intensive than an individual log study, making the batch mill study easier for sawmills to conduct in an inexpensive manner without additional assistance. A batch is typically defined by species and log grade (Govett et al. 2006).

In contrast, an individual log study involves tracking individual logs through the sawing process. Each log in the study is numbered and each board produced from that log is labeled with the same number. This allows every board to be traced back to the log from which it was produced. Individual log studies are labor intensive, and can lead to reduced production, especially in larger sawmills.

The purpose of this article is to determine whether batch mill studies provide consistent lumber grade yield and overrun data, which are vital for the accurate pricing of logs. A series of break-even analyses were then conducted using the data gathered from the batch mill studies to determine the efficacy of the batch study system in developing log prices.

Methods

In order to conduct this study, it was necessary to engage a hardwood sawmill partner that had interest in improving log yield study accuracy. For this study, a hardwood sawmill in Pennsylvania was interested in cooperating on a project focused on determining the reliability of the batch mill study method. The annual production of the participating sawmill is >12 million board feet (MMBF). That mill traditionally conducted batch studies to collect log yields and expressed a keen interest in improving the batch mill study approach. Data were collected at the participating sawmill from August 2019 through March 2020.

The participating sawmill utilizes a clear-face grading system. Logs are graded based on the diameter inside the bark (DIB) at the small end of the log and the number of clear faces on the log. The grading system has five options for log grades. They are Prime, 1, 2, 3, and Cull. Figure 1 shows how the log grade changes across diameters and clear faces. For example, a 12-inch log with three or four clear faces is graded based on the log's position in the tree. A butt log would be a Grade 1, while an upper would be a Grade 2 log. Specific grade requirements for these options follow:

- Prime logs must have four clear faces and a scaling diameter of ≥ 16 inches.
- Grade 1 logs are subdivided into two categories: four clear faced or three clear-faced logs with a scaling diameter (DIB) $\geq$ 12 inches, but $\leq$ to 15 inches; or logs with 3 clear faces and ≥ 16 inches scaling diameter.
- Grade 2 logs are subdivided into two categories: two clear faces with a scaling diameter $\geq$ 12 inches, but $\leq$ 15 inches; or 2 clear faces with a scaling diameter (DIB) of ≥ 16 inches.
- Grade 3 logs are those with one clear face and any scaling diameter or any log (regardless of the number of clear faces) that has a diameter (DIB) $<$ 12 inches.
- Cull logs are those logs with zero clear faces, regardless of diameter.

It is important to note that the Figure 1 grading table is applied without recognition of species. That is, a four-clear-face log that is ≥ 17 inches, regardless of species, is graded as a Prime Grade log, and then placed in the log inventory

Scaling Diameter	Clear Faces				
	4	3	2	1	0
≥17"	P	1	2	3	CULL
16"	P	1	2	3	CULL
15"	1	1	2	3	CULL
14"	1	1	2	3	CULL
13"	1	1	2	3	CULL
12"	B=1; U=2[1]	B=1; U=2	2	3	CULL
11"	3	3	3	3	CULL
10"	3	3	3	3	CULL

[1] B indicates a butt log, U indicates an upper

Figure 1.—Log grading specifications of the participating sawmill.

by species. Species comes into play when selecting batches to study. For a Prime Grade red oak batch, Prime Grade logs would be selected at random from the inventory of red oak logs.

When logs arrive at the mill, they are scaled and graded by a two-person log inspection crew. Logs are graded as they lay, so at best, the inspectors can observe three faces of the log. No logs are rolled to enable the inspectors to view the bottom face. The logs typically are bunched very closely together and in most situations the inspectors are only able to observe one or two of the faces.

For batch log studies conducted at the mill, the batches typically were organized by log grade. Logs were pulled from mill log inventory the day before the batch study. As such, they were added to the log inventory based on the standard grading and scaling processes practiced at the study mill. The logs included in the batches, like every other log inventoried at this mill, were not rolled as part of the log grading process. Prime Grade batches contained 20 logs each; all other log grades contained 25 logs per batch. As part of this study, log grades 1 and 2 were tested using two separate batches, with one batch containing a smaller set of diameters and the second batch containing larger diameter logs in that grade, as discussed above. Figure 1 is color coded to show how the batches were organized. For example, there were two batches that test Log Grade 2. One batch comprised logs 12 to 15 inches in diameter (orange cells in Fig. 1), the second batch contained logs classified as Log Grade 2 and comprised logs that are ≥ 16 inches DIB (green cells in Fig. 1). Grade 1 logs also were tested with two batches, one containing smaller diameter logs and the other containing larger diameter logs (Fig. 1). The smaller diameter Grade 1 logs are shown in red, while the large diameter Grade 1 logs are shown in yellow.

The participating sawmill collected all log scaling and grade data on a handheld computer. For each batch, a printout of batch data was provided. This printout provided the following information for each log: species, grade, length, scaling diameter, board foot volume, price per MBF, and price paid for the log. All logs were scaled using the Doyle log rule. A rule-of-thumb scaling deduction was used to account for log defects, where either log length or scaling diameter is reduced to account for the volume lost as a result of log defects (the exact rules-of-thumb were not disclosed). However, there was no indication in the printouts of when a scaling deduction was taken on a log, so only the revised scaling diameter or length was recorded. Additionally, the number of clear faces was not indicated on the tally sheets, so clear face information was assumed based on the assigned grade. For example, if the scalers classified a log as Grade 2, then only two clear faces should have been observed on the graded log. However, Grade 1 Small Diameter batches ($\geq$12 in and $\leq$15 in) could contain either three or four clear faces in the grade. The number of clear faces on the logs was not recorded on the tally sheets, so there was no way to determine the number of clear faces for logs in these batches.

Logs in each batch were processed through the sawmill, with data collected for the batch as a whole. Each log was slabbed at the headsaw, producing a few boards during this process. All boards went to an optimizing edger. After primary breakdown at the headrig, flitches were sent to a gangsaw, where they were further processed into boards or small cants. Flitches are logs that have been sawn on two faces, with the other two faces still rounded as part of the log. Products were then cut to length at the trimmer and progressed to the lumber inspector, where National Hardwood Lumber Association (NHLA) grade, surface measure, and thickness were recorded. For each batch, lumber yield by grade and overrun were collected and analyzed.

Batch composition

A primary goal of this work was to determine the amount of variability between the batches in the study by comparing the frequencies in each cell of the grading table (Fig. 1) for batches of the same grade. For example, all Grade 1 small diameter batches, regardless of species, were analyzed to determine whether the batches were statistically different from each other. Comparing batches of the same log grade provided insight into how consistent the batch selection process was. Significance criterion for all tests was $\alpha = 0.05$. Data were analyzed using JMP® Pro 14.0 (SAS Institute Inc., Cary, NC; Copyright 2015) and SAS® 9.4 (SAS Institute Inc.; Copyright ©2002–2012) software.

The Cochran–Mantel–Haenszel (CMH) test was selected over the Pearson chi-square test to identify significant differences between the composition of the batches (Stokes, 2012). Both tests use a chi-square distribution to test for significance, but the CMH test requires no expected cell frequencies in order to conduct the test. If a Pearson chi-square test had been used for this analysis, diameters would need to be grouped for the testing to ensure that at least 80 percent of the cells had an expected frequency of at least five. In contrast, the CMH test allows each diameter represented in the batch to be tested without any need to combine the diameters into groupings.

Grade yield analysis

Lumber grade yields between batches were analyzed to determine whether batch composition had a statistically significant impact on lumber grade yields. This was done using the nonparametric Wilcoxon and Kruskal-Wallis tests. A Shapiro-Wilk *W* test was used to determine whether the distribution was normally distributed or nonparametric. Results from this test indicated that most distributions were nonparametric, which led to the use of the Wilcoxon and Kruskal-Wallis tests over a one-way ANOVA.

Both tests are nonparametric alternatives to the one-way analysis of variance (ANOVA). These two tests are similar to each other, with one major difference. The Wilcoxon test is used when there are two groups. The Kruskal-Wallis test is a nonparametric test like the Wilcoxon test, but it can accommodate more than two groups. Both the Wilcoxon and Kruskal-Wallis compare the test statistic with a chi-square distribution to determine statistical significance.

Certain species, specifically soft maple (*Acer rubrum*) and cherry (*Prunus serotina*) in this case, have color-based sorts (which could be considered a grade) of the higher quality lumber grades to meet market demand. These color-based lumber grades are unique to these species—no other species in this study were color sorted in this manner. To make similar lumber grades between species, lumber grades were classified into three broad categories. These categories were One Face and Better (1F+), 1 Common (1C), and finally, 2 Common and Below Plus Cants (2C - CANT).

The cants were combined with the two common and below grade lumber because different-sized cants were manufactured depending on species, and the size of the cant would have affected the yield percentage of both lumber and cants. For example, cherry cants were 3.5 inches by 6 inches, while for most other species, 5.5 inches by 6 inches cants were sawn.

If cant yield were tested in the analysis as a separate grade, the size of the cant would have skewed the yield percentage of both lumber and cants. Grouping cants with 2 Common and lower lumber minimized the effect of producing different size cants on grade yield percentages.

Overrun analysis

Overrun, usually expressed as a percentage, is the difference between the volume of lumber produced from a log and the estimated volume of the log obtained through scaling (Lin et al. 2011). Overrun was analyzed for each of the batch categories. Analysis of overrun was conducted in the same manner as lumber yields. The Shapiro-Wilk W test was used to determine whether the data were normally distributed or nonparametric. Results indicated that most distributions were nonparametric, leading to the use of the Wilcoxon and Kruskal-Wallace.

Break-even pricing analysis

The ultimate goal of any batch or individual log study is to collect data that can help establish log prices that most accurately and consistently reflect the ability of the mill to achieve a profit from the production of lumber products from those logs. The mill wants to make sure that as many logs as possible make a positive contribution to the mill's bottom line. For the purpose of analyzing log pricing, a break-even pricing analysis was conducted on the five Grade 1 Small Diameter batches. Break-even pricing avoids any reference to profit because that factor varies from mill to mill.

The grading system in Figure 1 does not distinguish between species, so the participating sawmill assumes that lumber grade yields and overrun, for each cell of the grading table, are the same regardless of species. Therefore, to illustrate the impact that variations in batch composition have on lumber grade yields and overrun, break-even prices were calculated for each batch using red oak lumber prices from the time of the study in 2019–2020, as provided by the participating sawmill. For soft maple and cherry, where color differentiations are made for first and second grade (FAS) or One Face and 1 Common lumber, the percentages were combined to provide a single FAS or One Face and a single 1 Common lumber price.

The goal of this analysis is not to determine whether lumber grade yields are different by species, but rather to illustrate the impact that batch composition has on break-even pricing. The break-even pricing analysis uses only red oak lumber prices and sawing costs because the underlying assumption of the participating sawmill's log grading system is that species has no impact on lumber grade yields or overrun. Simply put, for this break-even analysis, species plays no role in the analysis.

For the break-even analysis, four figures are needed. They are lumber grade yields, lumber prices (US$/MBF), percent overrun, and sawing cost (US$/MBF). All break-even prices were reported in US$/MBF. The percent overrun increases the actual amount of lumber produced from 1MBF of log input. For example, if 1MBF of logs were put through the sawmill and the overrun was 20 percent, there would have been 1,200 board feet of lumber produced. For each lumber grade, this actual lumber yield was multiplied by the lumber yield percent (obtained from the batch log study) and lumber price to provide the actual value of the lumber produced. Sawing cost, provided by the study mill on a cost per MBF basis, and accounting for overrun, was subtracted from the value of the finished lumber to determine the break-even price of the log.

Results

Batch sample frequencies of logs

Prime Grade.—Three batches were tested in the Prime Grade. This grade contained logs that are 16 inches DIB and greater at the small end with four clear faces. Each batch consisted of a different species, specifically red oak, yellow-poplar (*Liriodendron tulipifera*), and soft maple, and contained 20 logs per batch. An overview of batch compositions in the Prime Grade is presented in Table 1.

For the CMH analysis, the calculated test statistic was 15.52, with a corresponding P value of 0.0004. This P value suggests that at least one of the three Prime Grade batches, specifically the soft maple batch, was statistically different from the others.

Grade 1 Small Diameter.—Five batches with 25 logs per batch were constructed and studied in this log grade. This grade consists of logs that were 12 to 15 inches DIB at the small end with either three or four clear faces. As mentioned earlier, there was no way to know how many clear faces the log inspectors at the mill observed for this grade. Four species were tested in this log grade, red oak, soft maple, cherry, and yellow-poplar. There were two yellow-poplar tests that were distinguished based on the month the study was conducted. The first yellow-poplar study was completed in November, while the second was completed in January. Table 2 illustrates the composition of all Grade 1 Small Diameter batches.

The CMH analysis generated a test statistic of 13.80, which corresponds to a P value of 0.0079. This suggests that at least one of the batches was statistically different from the others.

Grade 1 Large Diameter.— Grade 1 Large Diameter logs are 16 inches DIB and greater scaling diameter with three clear faces. Three batch studies were constructed and studied in this log grade. Each study batch was composed of a different species; red oak, soft maple, and yellow-poplar. There were 25 logs in the soft maple and red oak batches. There were only 24 logs in the yellow-poplar test because one log had to be removed from the study on account of metal contamination in the log. Table 3 illustrates the batch composition of all Grade 1 Large Diameter batches.

The CMH analysis yielded a test statistic of 2.55. This corresponds to a P value of 0.28, which suggests that the three batches were not statistically different from each other.

Grade 2 Small Diameter.—Grade 2 Small Diameter logs are 12 to 15 inches DIB with two clear faces. There were three batch studies completed in this grade. Each batch was of a different species, with red oak, yellow-poplar, and cherry being tested. There were 25 logs per batch. Table 4

Table 1.—Composition of Prime Grade batches of logs of four clear faces.[a] *Cells contain number of logs per batch.*

Scaling diameter	Red oak	Yellow-poplar	Soft maple
≥17	18	18	13
16	2	2	7

[a] $\chi^2 = 15.52$; $P = 0.0004$.

Table 2.—Composition of Grade 1 Small Diameter batches of logs of three and four clear faces.[a] *RO is red oak, YP is yellow-poplar, SM is soft maple, and CH is cherry. Cells contain number of logs per batch.*

Scaling diameter	RO	YP Nov	YP Jan	SM	CH
15	7	4	10	5	7
14	7	13	13	6	14
13	10	8	2	9	2
12	1	0	0	5	2

[a] $\chi^2 = 13.8$; $P = 0.0079$.

Table 3.—Composition of Grade 1 Large Diameter batches of logs of three clear faces.[a] *Cells contain number of logs per batch.*

Scaling diameter	Red oak	Yellow-poplar	Soft maple
≥17	15	13	18
16	10	11	6
15	0	1	0

[a] $\chi^2 = 2.55$; $P = 0.28$.

illustrates the batch composition of all Grade 2 Small Diameter batches.

The CMH analysis of the Grade 2 Small Diameter batches had a test statistic of 27.49, with a corresponding *P* value of <0.0001. This suggests that at least one of the three batches was significantly different from other batches.

Grade 2 Large Diameter.—Grade 2 Large Diameter logs are ≥16 inches, with two clear faces. There were two batches completed in this log grade; red oak and yellow-poplar. There were 25 logs per batch. Table 5 illustrates the batch composition of all Grade 2 Large Diameter batches.

The CMH analysis generated a test statistic of 19.99, with a *P* value of <0.0001, suggesting that the two batches were significantly different from each other. A number of small logs were improperly placed in the red oak Grade 2 Large Diameter batch, with 15 (60%) of the 25 logs in the batch having a scaling diameter of 14–15 inches and were actually Grade 2 Small Diameter logs. Without the improper inclusion of the smaller diameter logs, these batches may not have been significantly different. As a result, the true significance of this test is unknown.

Analysis of batch lumber yields

Normality results.—A Shapiro-Wilk *W* test was used to determine whether the batch distributions were normally distributed or represented a nonparametric distribution. The null hypothesis of the Shapiro-Wilk test is that the data are normally distributed. Therefore, any significant *P* value indicates that the data are not drawn from a normal distribution.

Table 4.—Composition of Grade 2 Small Diameter batches of logs of two clear faces.[a] *Cells contain number of logs per batch.*

Scaling diameter	Red oak	Yellow-poplar	Cherry
15	0	3	4
14	0	6	7
13	4	14	9
12	21	2	5

[a] $\chi^2 = 27.49$; $P < 0.0001$.

Table 5.—Composition of Grade 2 Large Diameter batches of logs of two clear faces.[a] *Cells contain number of logs per batch.*

Scaling diameter	Red oak	Yellow-poplar
≥17	4	18
16	6	7
15	5[b]	0
14	10	0

[a] $\chi^2 = 19.99$; $P < 0.0001$.

[b] This batch was improperly constructed by the participating sawmill. The batch should not have contained any 14-inch- or 15-inch-diameter logs. The improper batch selection led to, at least in part, the significant *P* value.

In the Prime Grade, only one of nine distributions (11.1%) was not normally distributed. For Grade 1 Small Diameter, 6 of 15 distributions (40.0%) were nonparametric. For both Grade 1 Large Diameter grade and Grade 2 Small Diameter, four of the nine distributions (44.4%) were nonparametric. Finally, for Grade 2 Large Diameter, two of six distributions (33.3%) were nonparametric.

The use of nonparametric statistics is recommended when 20 percent or more of the distributions are nonparametric (I. Holaskova, personal communication, 9 April 2020). Instead of mixing parametric and nonparametric methods, all lumber yield data were analyzed using the nonparametric Wilcoxon or Kruskal-Wallis tests.

Prime Grade.—No statistically significant differences were noted between batches in any lumber grade. For the One Face and Better lumber grade yields, the mean yield per batch consisted of red oak with a mean yield of 54.5 percent, soft maple with a mean yield of 53.5 percent, and yellow-poplar with a mean yield of 59.4 percent. The Kruskal-Wallis test generated a test statistic of 1.35 and a *P* value of 0.51, indicating that no mean differences existed between the three batches.

For the 1 Common lumber grade yield, red oak had a mean yield of 23.2 percent, soft maple had a yield of 20.8 percent, and yellow-poplar had a yield of 17.8 percent. The Kruskal-Wallis test statistic was 2.09, with a *P* value of 0.35, suggesting that no significant differences existed between batches for this lumber grade.

For the 2 Common and Below Plus Cants, red oak yielded 22.3 percent, soft maple yielded 25.7 percent, and yellow-poplar yielded 22.8 percent. The Kruskal-Wallis test produced a test statistic of 2.27, with an associated *P* value of 0.32. Again, no statistically significant differences existed for the yields by species in this lumber grade.

Grade 1 Small Diameter.—For this log grade, five batch studies were completed: red oak, soft maple, cherry, and two yellow-poplar batches. The yellow-poplar batches were identified by the month in which they were completed.

For the One Face and Better lumber grade, the yields were as follows: ed oak was 32.1 percent, cherry was 37.0 percent, soft maple was 20.5 percent, yellow-poplar November (YP NOV) was 30.4 percent, and yellow-poplar January (YP JAN) was 40.0 percent. The Kruskal-Wallis test produced a test statistic of 13.45 and a significant P value of 0.0093. Additionally, pairwise comparisons identified several statistically significant differences between batches. Specifically, soft maple yield was significantly different from all other batches. Also, yellow-poplar November and yellow-poplar January were statistically different from each other ($P = 0.0488$).

For the 1 Common lumber grade, the mean yields were as follows: red oak was 23.6 percent, cherry was 30.0 percent, soft maple was 21.8 percent, yellow-poplar November was 22.5 percent, and yellow-poplar January was 16.0 percent. The Kruskal-Wallis test produced a test statistic of 11.33, which equates to a significant P value of 0.0231. Pairwise comparisons show that the yield from yellow-poplar January was statistically different from red oak ($P = 0.0446$) and cherry ($P = 0.0006$).

Yields for the 2 Common and Below Plus Cants were as follows: red oak was 44.3 percent, cherry was 33.0 percent, soft maple was 57.7 percent, yellow-poplar November was 47.1 percent, and yellow-poplar January was 44.0 percent. The Kruskal-Wallis test produced a test statistic of 19.08, with a significant P value of 0.0008. Pairwise comparisons indicated that cherry yield was statistically different from all other batches in the Grade 1 Small Diameter category.

Grade 1 Large Diameter.—Three batch studies were completed in this log grade. Each batch was composed of a different species, with red oak, soft maple, and yellow-poplar being tested.

For the One Face and Better lumber grade, the mean yields by species were as follows: red oak was 34.3 percent, soft maple was 48.8 percent, and yellow-poplar was 50.7 percent. The Kruskal-Wallis test produced a test statistic of 9.09, with a significant P value of 0.0106. Pairwise comparisons show that red oak yield was statistically different from soft maple ($P = 0.0199$) and yellow-poplar ($P = 0.0056$).

For the 1 Common lumber grade, the mean yields by species were as follows: red oak was 27.8 percent, soft maple was 18.0 percent, and yellow-poplar was 17.8 percent. The Kruskal-Wallis test produced a test statistic of 4.77, with a nonsignificant P value of 0.0921. This indicates that the yields between batches were not statistically different from each other.

For the 2 Common and Below Plus Cants grade, the mean yields by species were as follows: red oak was 37.9 percent, soft maple was 33.2 percent, and yellow-poplar was 31.5 percent. The Kruskal-Wallis test produced a test statistic of 1.59 with a nonsignificant P value of 0.4508, which again indicated that no batch yields were statistically different in this lumber grade.

Grade 2 Small Diameter.—Three batch studies were completed in this log grade, with each batch representing a different species. The three species were cherry, red oak, and yellow-poplar.

For the One Face and Better lumber grade, the yields were as follows: cherry was 20.4 percent, red oak was 8.7 percent, and yellow-poplar was 16.9 percent. The Kruskal-Wallis test produced a test statistic of 7.45, with a significant P value of 0.0241. Pairwise comparisons showed a statistically significant difference between red oak and cherry ($P = 0.0049$).

For the 1 Common lumber grade, the yields were as follows: cherry was 30.6 percent, red oak was 21.6 percent, and yellow-poplar was 22.1 percent. The Kruskal-Wallis test generated a test statistic of 5.22, with a nonsignificant P value of 0.0734.

For the 2 Common and Below Plus Cants, the yields were as follows: cherry was 49.0 percent, red oak was 69.7 percent, and yellow-poplar was 61.0 percent. The Kruskal-Wallis test generated a test statistic of 16.42, with a significant P value of 0.0003. Pairwise comparisons show that cherry yield is significantly different from red oak ($P = < 0.0001$) and yellow-poplar ($P = 0.0313$).

Grade 2 Large Diameter.—For this log grade, two batches were tested. One batch was red oak and the second was yellow-poplar. It is important to note that the red oak batch was improperly selected. Logs in this grade should be $\geq$16 inches with two clear faces. Overall, 15 out of 25 logs in this batch (60%) were $\leq$15 inches and should not have been included in this batch. The significance of these results would likely be different if the red oak batch contained all logs that are truly this grade.

For the One Face and Better lumber grade, the yields were as follows: red oak was 16.0 percent and yellow-poplar was 15.3 percent. The Wilcoxon test generated a test statistic of 0.1443 with a P value of 0.7040. No statistically significant differences existed in lumber yields between the two batches.

For the 1 Common lumber grade, the yields were as follows: red oak was 27.4 percent and yellow-poplar was 36.7 percent. The Wilcoxon test produced a test statistic of 4.3506 with a P value of 0.0370. This suggests that the yields between the two batches were significantly different from each other.

For the 2 Common and Below Plus Cants, the yields were as follows: red oak was 56.6 percent and yellow-poplar was 48.0 percent. The Wilcoxon test generated a test statistic of 1.9517 with a P value of 0.1624. This indicates that the yields between the two species were not statistically different.

Batch overrun analysis

Prime Grade.—For the Prime log grade, three batches were tested. Red oak overrun was 24.8 percent, soft maple was 22.8 percent, and yellow-poplar was 23.4 percent. The Kruskal-Wallis test generated a test statistic of 1.1992, with a nonsignificant P value of 0.5490 indicating that there were no statistically significant differences in overrun between the three batches.

Grade 1 Small Diameter.—Five batches were tested for the Grade 1 Small Diameter log grade. Cherry overrun was 44.9 percent, red oak was 51.5 percent, and soft maple was 66.9 percent, yellow-poplar November was 55.0 percent, and yellow-poplar January was 48.7 percent. The Kruskal-Wallis test produced a test statistic of 17.9193, with a significant P value of 0.0013. Pairwise comparisons showed that the soft maple overrun was significantly different from all other batches.

Grade 1 Large Diameter.—Three batches were tested for the Grade 1 Large Diameter log grade. Red oak overrun was 27.9 percent, soft maple was 43.4 percent, and yellow-poplar was 28.2 percent. The Kruskal-Wallis test produced a test statistic of 6.2156, with a significant *P* value of 0.0447. Pairwise comparisons showed that soft maple overrun was significantly different from both red oak ($P = 0.0270$) and yellow-poplar ($P = 0.0394$).

Grade 2 Small Diameter.—Three batches were tested for the Grade 2 Small Diameter log grade. Overrun in cherry was 42.2 percent, red oak was 58.2 percent, and yellow-poplar was 54.5 percent. The Kruskal-Wallis test produced a test statistic of 5.1582, with a nonsignificant *P* value of 0.0758.

Grade 2 Large Diameter.—Two batches were tested for the Grade 2 Large Diameter log grade. Overrun for red oak was 47.2 percent and overrun for yellow-poplar was 29.5 percent. The Wilcoxon test produced a test statistic of 7.4327, with a significant *P* value of 0.0064 indicating that the mean overrun between the two batches was significantly different.

However, the red oak batch was improperly selected by the participating sawmill. Fifteen of the 25 logs (60%) were either 14-inch- or 15-inch-diameter logs. This could account for the statistical difference between the mean overruns because higher overrun is to be expected with smaller diameter logs.

Batch break-even analysis

The five Grade 1 Small Diameter batches were used to illustrate the impact of batch composition, lumber grade yields, and overrun. The following lumber prices were used: FAS: US$740.00; 1F: US$740.00; 1C: US$585.00; 2C: US$570.00; 3C: US$394.00; and Cant: US$470.00. The sawing cost used for the break-even analysis was US$275.00 per MBF, as provided by the mill. Lumber yield percentages and overrun used for the batch break-even analysis are provided in Table 6, along with the break-even pricing. All lumber grade yields are from green lumber, and prices used in the analysis are green lumber prices. To provide a better illustration of the differences in lumber yield percentages, overrun, and break-even results between batches, the data from Table 6 also are provided graphically. Figure 2 provides lumber grade yield percentages for each batch, Figure 3 shows overruns for each batch, and Figure 4 illustrates the differences in the calculated break-even price by batch.

Discussion

Accurate and consistent pricing of sawlogs is vital to ensure a profitable sawmill operation, and when a mill is utilizing batch studies for that purpose there are two fundamental factors to consider. First, is the structure of the batches, over the range of log grades, sufficient for providing accurate grade yield, overrun, and pricing results? In the case presented here, is the breakdown of grades for a batch, as detailed in Figure 1, going to provide a sufficient level of accuracy and consistency?

Second, given the structure of the batch protocol, as reflected in Figure 1, are the batches configured to produce the most consistent results? In other words, are the samples within a batch skewed to one diameter and clear face combination, as opposed to a uniform set of sample logs across the diameter and clear face combinations for that grade?

The batch structure for the mill was already set as illustrated in Figure 1; therefore, then the actual composition of the batches effectively defined the efficacy of the structure. In effect, the batch composition defines the expected lumber grade yields and overrun and whether they in turn provide sufficient consistency and accuracy in pricing sawlogs.

Variation in batch composition

The Cochran–Mantel–Haenszel analysis tested to determine whether log diameter frequencies were different between batches of the same grade designation (e.g., Prime Grade batches, of which there were three). Table 7 summarizes the results. It is clear that all of the batch compositions, except for Grade 1 Large Diameter, were significantly different, suggesting that accuracy and consistency may be compromised. The question then is whether statistically differing batch compositions lead to statistically different lumber grade yields and overrun.

Table 8 summarizes the lumber grade yield results. Seven of 15 lumber grade yields were statistically different, while 8 instances were not. In the latter eight instances, seven of those were from batch types that include only two diameter classes. In all but one case, where four diameter classes were included in the batch, the lumber grade yields were statistically different. The one exception was for the Grade 2 Small Diameter, One Common batch, which had a nearly significant *P* value of 0.0734.

The implication of these analyses is that *the fewer combinations of diameter and clear faces in a batch, the more likely that the variation will be smaller*. Similarly, three of the batch grade designations (Table 9) showed overrun to be statistically significant, with one of those showing a pairwise difference, without an overall significant result. Although the statistical differences were not uniformly significant, the actual differences were a concern

Table 6.—Break-even price analysis in US$ per million board feet (MBF) for Grade 1 Small Diameter batches.

	NHLA[a] lumber grades (grade yield proportions [%])							
Batch[b]	FAS[c]	1F[d]	1C[e]	2C[e]	3C[e]	Cant	Overrun (%)	Break-even price ($/MBF)
Red oak	16.0	17.3	23.2	6.3	7.1	30.1	43.7	449.05
YP JAN	26.3	14.0	16.8	10.3	2.4	30.2	36.6	452.97
YP NOV	16.3	15.8	22.4	12.1	1.7	31.7	45.5	463.04
Soft maple	23.6	0.0	23.5	20.1	5.2	27.6	58.0	476.99
Cherry	39.9	0.0	28.5	9.2	3.9	18.5	44.2	492.79

[a] NHLA is National Hardwood Lumber Association.

[b] YP JAN is yellow-poplar January; YP NOV is yellow-poplar November.

[c] FAS is first and second grade.

[d] 1F is One Face.

[e] 1C is One Common; 2C is Two Common; 3C is Three Common.

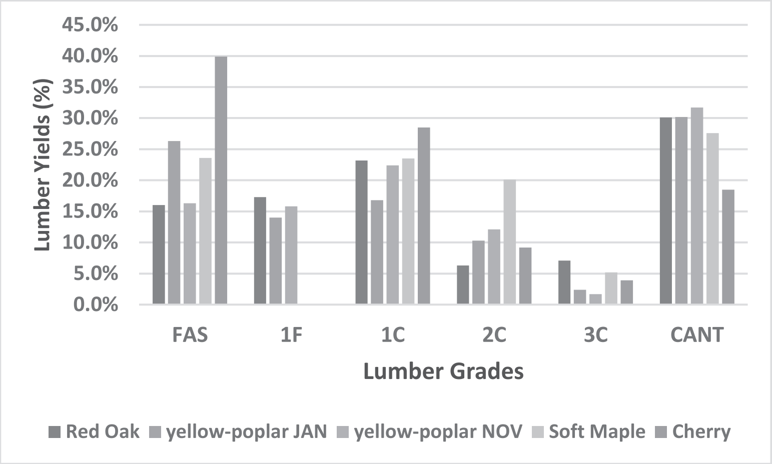

Figure 2.—Lumber grade yield comparison by batch.

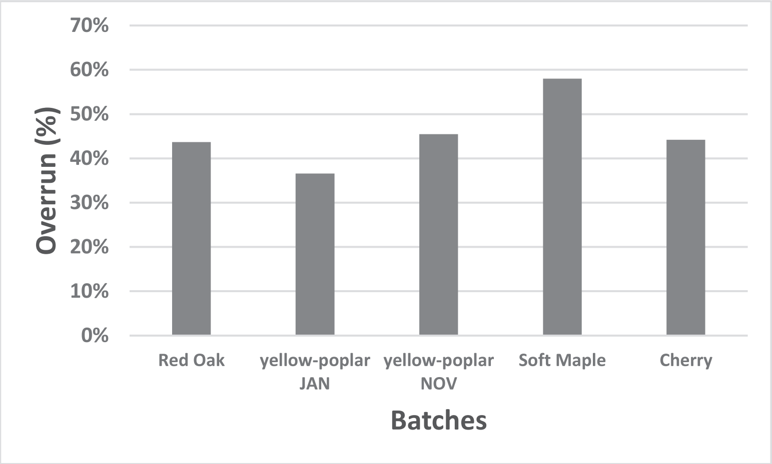

Figure 3.—Percent overrun by batch.

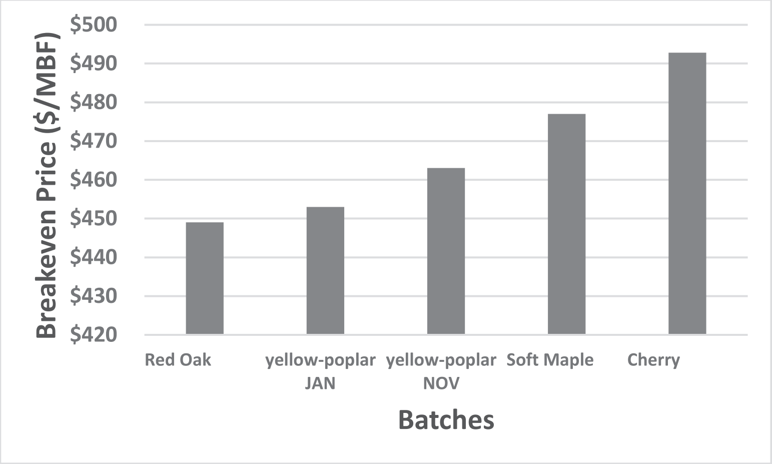

Figure 4.—Calculated break-even price by batch.

Table 7.—Summary of batch composition results.

Batch type	No. of batches	P value[a]
Prime	3	Significant
Grade 1 Small Diameter	5	Significant
Grade 1 Large Diameter	3	Not significant
Grade 2 Small Diameter	3	Significant
Grade 2 Large Diameter	2	Significant

[a] Significant differences are tests with a $P \leq 0.05$.

for all batches except the Prime Grade batches, ranging from 15.5 to 22.0 percent. The magnitude of these differences is a concern because such wide swings in overrun directly affect log pricing, as illustrated in the wide swings in price for a given batch type.

Potential financial impact of improper batch results

Statistically significant differences in batch composition led to statistically significant differences in both lumber grade yields and overrun in many batches. This in turn produced relatively large differences in batch break-even pricing. The lowest batch break-even price was US$449.05 per MBF, while the highest break-even price result was US$492.79. The difference between the highest and lowest batch break-even prices was US$43.74 per MBF or a 9.7 percent increase from lowest to highest.

In the highly competitive hardwood market with its small profit margins, accurate and reliable log pricing information is critical. When the difference of US$43.74 per MBF is compounded through a year of sawmill production, it amounts to a large sum of money. A small difference in log purchase price could very easily be the difference between a profitable or unprofitable operation.

Drawbacks of the batch study method and suggestions for improvement

The batch mill study approach has several problems related to the collected data when trying to accurately price logs. In combination, these factors work to limit the reliability and accuracy of the batch mill study approach as it relates to determining break-even pricing of logs. Problems with the batch study approach include the following:

- *The lack of log-specific data:* In the batch study approach, there is no way to track lumber yields by log. At the end of the batch study, the main results are lumber yields by grade and overrun. These data are gathered for the entire batch, not for each log, which is a major issue when batches have a wide range of diameters and clear faces. Small variations may exist in sawing patterns that will undoubtedly lead to changes in lumber grade yields. This is a potential problem in both the batch and individual log study methods. If a mill is serious about gathering log yield data, these small variations in sawing pattern would have minimal effect with a sufficiently large data set.
- *Limited statistical options:* The batch study approach provides only one result at the conclusion of the analysis. *As such, a batch study is essentially* ***one observation***. Even though the batches contained 20 or 25 logs each, the results provide one observation into lumber grade yield percentages and overrun. No statistical information, such as mean, standard deviation and confidence intervals, can be computed for a single observation.
- *Break-even price is heavily influenced by log diameter frequencies:* Each batch generally contains a range of diameters rather than one single diameter, so the break-even price is weighted toward the log diameter occurring most frequently in the developed batch. This is of particular concern because overrun increases with decreasing diameter when using the Doyle log rule, so that a heavy proportion of smaller diameter logs will increase overrun from that batch. This has the net effect of skewing the break-even price and minimizes the pricing impact of log diameters that were less frequent in the batch.
- *Large amounts of variability within batches of the same log grade:* When incorrectly graded logs are included in a batch, even though they should not be in that batch,

Table 8.—Summary of lumber grade yield results.

		Lumber grade or type, P value[a]		
Batch type	No. of batches	One face & better	One common	Two common & below + cants
Prime	3	Not significant	Not significant	Not significant
Grade 1 Small Diameter	5	Significant	Significant	Significant
Grade 1 Large Diameter	3	Significant	Not significant	Not significant
Grade 2 Small Diameter	3	Significant	Not significant	Significant
Grade 2 Large Diameter	2	Not significant	Significant	Not significant

[a] Significant differences are tests with a $P \leq 0.05$.

Table 9.—Summary of batch overrun results.

Batch type	No. of batches	P value[a]	Actual difference, High − Low (%)
Prime	3	Not significant	2.00
Grade 1 Small Diameter	5	Significant	22.00
Grade 1 Large Diameter	3	Significant	15.50
Grade 2 Small Diameter	3	Not significant	16.00
Grade 2 Large Diameter	2	Significant	17.70

[a] Significant differences are tests with a $P \leq 0.05$.

break-even price will be adversely affected by the presence of those logs. An example of this is in the Red Oak Grade 2 Large Diameter batch. A majority of logs in this batch were incorrectly included in the study. This batch undoubtedly led to unreliable estimates of lumber grade yields and overrun for this log grade, which in turn affects the accuracy of break-even price estimates.

If a mill is constrained to conducting only batch studies, there are several ways to improve the batch study approach to improve accuracy and reliability.

- *Each batch should be composed of logs of the same grade, with a very narrow diameter range*. An ideal batch is one that is focused in one cell of the grading table. For example, a well-defined batch would be a 12-inch, four-clear-face batch. A batch with a wide range of diameters or clear faces does not produce reliable, accurate results.
- *Ensure logs to be included in a batch study are correctly scaled and graded*. Ideally, logs should be rolled so that all four faces of every log can be observed.
- *More than one batch study should be conducted for each cell in the grading table*. This will allow statistics, specifically the means and standard deviations to be calculated, further verifying the reliability of the batch study results. However, conducting enough batch studies to develop an adequate number of observations may be too expensive for a mill to undertake. The alternative is to take the time to collect individual log data so that each study contributes multiple observations to the mill's individual log data set.
- *Ensure that the mill and head sawyer are consistent in the way each log is sawn*. This allows the mill to avoid suboptimal yields from individual logs and improve the ability of both batch and individual log studies to accurately estimate log yield.

Conclusion

Based on this study, the batch mill study approach is not a reliable way to set log prices, especially using the methods detailed here. With some of the recommended improvements in data collection, the batch mill study has the potential to improve the reliability and accuracy of break-even log pricing estimates but further study is needed to confirm this.

A major issue with the batch study, as observed in this study, is that logs were not rolled as part of the log inspection process. When using a clear-face grading system, it is absolutely critical that all four faces of the log be observed by the log inspectors.

Further study is needed to determine if the batch study method can provide more accurate and reliable log pricing results when the batch is composed of logs of a single log grade and diameter. Based on the results from this study, batch study data can potentially lead to log purchases at costs well above their actual break-even value. Hardwood sawmills would be better served to use individual log studies, even though these studies are more time consuming, to improve mill profitability.

Part Two of this study will compare the batch results presented here with an individual log study conducted on these same logs. In the individual log study, logs were rolled as part of the log inspection process. Lumber grade yield and overrun data were collected for every log, which allows for a direct comparison of the results from the two mill study methods.

Acknowledgment

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