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# Limitations of Lumber-Yield Nomograms for Predicting Lumber Requirements

Kristen Hoff

## Abstract

Lumber yield nomograms developed during the last 30 years have limited use when predicting the volume of rough lumber required to fill a particular cutting bill. Inaccuracies occur when nomogram yields are applied to situations in which processing technologies differ from those used during data collection, and when a variety of lengths and widths are specified in the cutting bill. Inaccuracies can occur when predicting yields for more than two lengths, cutting for a single width, or predicting yields based on the longest length rather than on a specific cutting bill. Most importantly, nomograms respond poorly to changes in processing technologies or in the hardwood resource. The impact of each of these problems associated with predicting lumber requirement is discussed.

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## Introduction

Traditional methods for determining the most cost-effective lumber-grade mix for a particular cutting bill are based on yield tables developed from nomograms prepared by the Forest Products Laboratory (FPL), Madison, Wisconsin, that predict yields for crosscutting lumber prior to ripping (Englerth and Schumann 1969). A similar set of nomograms for gang-rip-first operations was developed by Hallock (1980). The most recent least-cost-grade-mix programs use the results of a rough-mill simulation program as the source of input data (Harding 1991). This change in data source is an attempt to more accurately reflect specific rough-mill operations and overcome the limitations of nomogram data.

Estimated yields for both the gang-rip-first and crosscut-first nomograms are derived by the same methods. Initially, yield is estimated using the "best width" for the longest length in the cutting bill; this yield will be called $Y_1$. Then the yield ($Y_{12}$) is estimated (using the same width as before) for the case where the longest length and the second longest length are the only two lengths on the cutting bill. The difference between the two ($Y_1$ - $Y_{12}$) should represent the yield produced in the second longest length while also cutting the longest length. Next, yield is estimated for the situation in which the longest length and the third longest length are the only two lengths on the cutting bill. The difference between this yield ($Y_{13}$) and the yield achieved when only the two longest lengths are targeted ($Y_{12}$) should represent the yield produced in cuttings of the third longest length when already cutting as much of the first two lengths as possible. Subsequent shorter lengths are handled similarly. The single width is used to predict all of these yields.

The FPL nomograms and yield-calculation method have been used by wood-products manufacturers to predict lumber requirements and estimate raw material costs for their cutting orders. However, the use of nomograms seems more applicable to crosscut-first than to gang-rip-first operations. In crosscut-first operations, the longest length available is cut and this length limits the lengths of subsequent cuttings from the same board. In rip-first operations, the width is fixed first and the only restrictions on length are the defects within the strips and the size of the board. In addition, several assumptions were made in the development of the nomograms that limit their applicability to both crosscut-first and gang-rip-first operations. The following are some of the limitations discussed in this paper:

**Table 1.—Length and width distributions for 222 boards used in simulations**

| Length | Width (inches) | | | | |
|---|---|---|---|---|---|
| (feet) | 4-5 | 6-7 | 8-9 | ≥10 | Total |
| 4-6 | 3 | 9 | 3 | 3 | 18 |
| 7-8 | 13 | 14 | 7 | 5 | 39 |
| 9-10 | 9 | 22 | 11 | 9 | 51 |
| 11-12 | 12 | 11 | 6 | 7 | 36 |
| 13-14 | 18 | 15 | 10 | 3 | 46 |
| 15-17 | 8 | 10 | 8 | 6 | 32 |
| Total | 63 | 81 | 45 | 33 | 222 |

- The methodology bases predicted yields on the yield achieved when cutting for two lengths at a time.

- The nomograms reflect yields where the crosscut saw operator is attempting to obtain the longest possible piece regardless of remaining quantity requirements on the cutting bill.

- The methodology does not adjust for multiple widths adequately.

- The nomograms do not allow for variance in yield caused by differences in technologies used in various plants.

In the following sections, the importance of the assumptions that underlie the nomogram approach is discussed. The limitations of nomograms for predicting the least-cost lumber-grade mix can be significant. A discussion of these limitations sheds light on why new approaches for determining the least-cost lumber-grade mix that rely on yield simulation program output are warranted.

A gang-rip-first lumber cut-up simulation program called ROMI-RIP (Thomas 1995) was used to determine yields obtained when processing 1 Common red oak lumber. The lumber data file processed by the simulation program consisted of 222 boards; their length and width distributions are given in Table 1. The simulation results were compared with readings from the gang-rip-first 1 Common nomograms developed at the FPL (Hallock 1980). The nomograms and simulation studies predict clear, two-face cutting yields and are used to illustrate the points discussed in this section.

## Predicting Yields for More than Two Lengths

With the nomogram approach, the yield for the longest length is based on obtaining as many pieces as possible in that length regardless of what other lengths are specified on the cutting bill. This yield remains constant throughout the analysis. Subsequent yields are calculated as the difference between the yield obtained using the current length and the longest length and the yield obtained using the previous length and the longest length. This calculation of yield is not entirely accurate.

For example, the nomogram method suggests that the total yield when cutting 76- and 18.5-inch pieces will be identical to that when cutting 76-, 62-, 21.5-, and 18.5-inch lengths together, in this example, a predicted yield of 67.4 percent. To determine whether this was true, a nonoptimizing gang ripsaw was simulated. All boards processed entered the fixed-blade arbor against the fence; all parts were cut to a 2-inch width. Simulated processing for only the two lengths resulted in a 55.6-percent yield of lumber in parts, but processing for all four lengths at the same time increased the yield to 57.2 percent.

A partial explanation for the difference of 10.2 percent between nomogram-projected and simulation yields is that the rip-first nomograms assume that edge-glued joints are acceptable in all cuttings. Since this suggests that cuttings of a given length can be edge-glued into panels and subsequently ripped into desired widths with no loss in value, salvage cuttings 1 inch and wider of the specified length are included in the nomogram yields. Some edge-glued joints are found unacceptable by the customer, so the predicted yield is higher than the actual yield. Throughout this paper, simulation results reflect only the yield in primary cuttings; edge-glued joints were considered unacceptable. As a result, it would be reasonable to expect nomogram yields that are higher than simulation yields.

Another likely explanation for some of this difference in yield is the resource used to project yields. Specifically, differences in the distribution of lumber lengths and widths used in nomogram development versus today's resource as reflected in the "1998 Data Bank for Kiln-Dried Red Oak Lumber" (Gatchell et al. 1998). The percentage of boards 14 feet long and longer in the 1 Common data set used to develop the nomograms (Dunmire and Englerth 1967) was much higher than in the 1998 data bank — 43 versus 27 percent. Similarly, the average width of the Dunmire and Englerth's 1 Common boards was greater in all length classes. In the dominant 10- to 11-feet and 12- to 13-feet lumber-length classes, average board widths were 1.2 and 0.8 inches greater than current data-bank boards. To address nomogram-specific questions, these data differences must be factored out. Therefore, simulation was used to estimate the yield achieved when processing current lumber using only two lengths at a time. This provides an additional point of comparison between the nomogram approach and the actual yield achieved when processing lumber. Taking this approach, differences in input lumber are excluded from the analysis.

Nomograms are less accurate in predicting part yields as the number of intermittent lengths between the longest length and the shortest length increases—even after potential differences in input lumber are excluded (Table 2). This can be demonstrated by comparing the yields obtained when simulating the processing of all required lengths at once and simulating the processing of two lengths at a time and then applying nomogram-type calculations. In the case where yields are to be predicted for 76-, 62-, and 18.5-inch cuttings, processing with only the 76- and 18.5-inch lengths resulted in a lower yield (55.6 percent) than processing with all three lengths (56.4 percent). This implies that there were instances in which a 2-inch-wide clear area was at least 62 inches long to accommodate one 2- by 62-inch piece (144 $in^2$ of surface area) or three 2- by 18.5-inch pieces (111 $in^2$ of surface area) but less than the 74-inch length necessary for a fourth 2- by 18.5-inch piece.

Processing for a variety of lengths should result in improved yields over those obtained when processing only the longest and shortest lengths so long as the shortest length is not a common denominator to all other lengths. Even if this were true, savings in reduced kerf occasionally could result in sufficient clear area to produce an additional piece. This shortcoming of nomograms in estimating yield is becoming more important because optimizing crosscut saws and chopsaws allow manufacturers to cut more lengths at a time.

## Yields Based on Seeking Long Lengths Versus Meeting Cutting Bills

Yields in different sizes will vary according to the proportion of the cutting bill that they comprise. Three simple cutting bills are given in Table 3. Cutting bill 2 calls for more of the longest (76-inch) length parts than cutting bill 1, and cutting bill 3 requires more 76-inch parts than cutting bill 2. As expected, simulation results for the test lumber data using ROMI-RIP's Complex Dynamic Exponent part prioritization strategy (Thomas 1995, 1996) show that as more 76-inch lengths were required, the amount of lumber needed to meet the cutting bill increased. However, the yield in 76-inch pieces ranged from 18.2 to 30.5 percent for the optimizing ripsaw, and from 16.8 to 26.8 percent for the nonoptimizing ripsaw. The number of 76-inch cuttings between cutting bills 1 and 2 did not significantly affect yields. However, when the required 76-inch cuttings increased to 183 (cutting bill 3) and became disproportionately high relative to the number of short cuttings, yield was affected. This demonstrates how results can be misleading when a single value is used to represent the yield obtained on a cutting bill without considering the required quantity of pieces (especially longer pieces) on the cutting order. Further, the nomograms predict that total yield will remain unchanged among the three cutting bills. Again, the reason for this is that nomograms assume that the goal is to always take the longest length without varying the feed position of the board.

**Table 2.—Comparison of expected yields using simulation yields for processing two lengths at a time and for processing all lengths at once[a]**

| Lengths to be cut (inches) | Length | Simulation: Two lengths at a time: Total yield | Two lengths at a time: Calculated yield for each length | All lengths at once: Total yield | All lengths at once: Reported yield for each length |
|---|---|---|---|---|---|
| | *Inches* | *Percent* | | | |
| 76, 62, 21.5 | 76 | 54.5 | 25.4 | 54.9 | 25.4 |
| | 62 | | 9.4 | | 9.4 |
| | 21.5 | | 19.7 | | 20.1 |
| 76, 62, 18.5 | 76 | 55.6 | 25.4 | 56.4 | 25.4 |
| | 62 | | 9.4 | | 9.4 |
| | 18.5 | | 20.9 | | 21.7 |
| 76, 62, 21.5, 18.5 | 76 | 55.6 | 25.4 | 57.2 | 25.4 |
| | 62 | | 9.4 | | 9.4 |
| | 21.5 | | 19.7 | | 20.1 |
| | 18.5 | | 1.2 | | 2.3 |

[a]1,435.59 board feet of 1 Common red oak used for each run.

**Table 3.—Part yields for three cutting bills with varied quantities of longest length part required**

| Cutting bill | Width | Length | Quantity required | | Part yields (percent): Optimizing ripsaw | Part yields (percent): Nonoptimizing ripsaw |
|---|---|---|---|---|---|---|
| | *Inches* | *Inches* | *Number* | | (353.52 board feet) | (383.71 board feet) |
| 1 | 2 | 18.5 | 413 | | 30.02 | 27.66 |
| | 2 | 62 | 50 | | 12.18 | 11.22 |
| | 2 | 76 | 61 | | 18.21 | 16.78 |
| | | | | Total | 60.41 | 55.66 |
| | | | | | (453.11 board feet) | (497.64 board feet) |
| 2 | 2 | 18.5 | 413 | | 23.42 | 21.32 |
| | 2 | 62 | 50 | | 9.50 | 8.65 |
| | 2 | 76 | 120 | | 27.95 | 25.45 |
| | | | | Total | 60.87 | 55.42 |
| | | | | | (634.33 board feet) | (721.51 board feet) |
| 3 | 2 | 18.5 | 413 | | 16.73 | 14.71 |
| | 2 | 62 | 50 | | 6.79 | 5.97 |
| | 2 | 76 | 183 | | 30.45 | 26.77 |
| | | | | Total | 53.97 | 47.45 |

The nomograms were developed without specific cutting bills in mind. They reflect yields where the crosscut-saw operator is attempting to obtain the longest possible piece regardless of remaining quantity requirements on the cutting bill. Table 4 demonstrates that the yields achieved in certain lengths can vary considerably depending on whether cutting quantities are restricted by a cutting bill or no cutting bill restrictions are enforced (i.e., cutting to inventory is acceptable). Since the part prioritization strategy used in meeting cutting bill 1 is effective in balancing maximizing yield and meeting cutting bill requirements, there is little difference between the total yields achieved in each set of simulations. However, because the nomograms were not developed for specific cutting bills, individual-part yields that would be predicted and actual yields achieved could differ widely. Thus, the nomograms should not be used to predict lumber requirements for specific cutting bills without additional interpretation and adjustment of the nomogram yields. Two methods for using nomogram yields to

**Table 4.—Comparison of yields using a variable-feed optimizing ripsaw when processing to meet a specific cutting bill and when no quantity is specified**

| Length on chopsaw (inches) | No. cutting bill quantities specified for 1,435.59 board feet) | | Cutting bill 1 | |
|---|---|---|---|---|
| | Number produced | Yield in each length | Number produced | Yield in each length |
| 76 | 409 | 30.1 | 61 | 27.3 |
| 76 | 402 | 30.0 | 61 | 23.9 |
| 62 | 171 | 10.3 | 50 | 16.0 |
| | | 40.3 | | 39.9 |
| 76 | 390 | 28.7 | 61 | 18.0 |
| 62 | 169 | 10.1 | 50 | 12.0 |
| 18.5 | 1188 | 21.3 | 413 | 29.6 |
| | | 60.1 | | 59.6 |
| 76 | 398 | 29.3 | 61 | 22.4 |
| 18.5 | 1673 | 29.9 | 413 | 35.7 |
| | | 59.2 | | 58.1 |

**Table 5.—Differences in yield based on feed position of board—cutting quantities not specified**

| Length on chopsaw (inches) | Nonoptimizing chopsaw | | Optimizing chopsaw | |
|---|---|---|---|---|
| | Number produced | Yield in each length | Number produced | Yield in each length |
| 76 | 345 | 25.4 | 409 | 30.1 |
| 76 | 345 | 25.4 | 402 | 29.6 |
| 62 | 156 | 9.4 | 171 | 10.3 |
| 76 | 345 | 25.4 | 390 | 28.7 |
| 62 | 156 | 9.4 | 169 | 10.1 |
| 18.5 | 1212 | 21.7 | 1188 | 21.3 |

predict lumber requirements for specific cutting bills have been developed. These are discussed elsewhere.

## No Allowance for Differences in Processing Technologies

Yields obtained when cutting lumber differ according to the processing technologies used. For example, consider the case where a fixed-blade arbor is used on the gang ripsaw and the operator feeds the boards through the ripsaw by aligning the edge of the board against the edge of the fence (nonoptimizing ripsaw). This was simulated with ten 2-inch saw spacings mounted on a fixed-blade arbor. No cutting quantities were specified. A second simulation using the same boards was run with only one difference: the boards could be fed in anywhere along the arbor (optimizing ripsaw). Varying the feed position of the board increased the quantities of nearly every part (Table 5).

The yield of 76-inch parts from the optimizing ripsaw ranged from .301 to .287 depending on the addition of shorter lengths on the chopsaw. Figure 1 demonstrates the source of this variation. The board in Figure 1 was processed as if the only usable part length was 76 inches. The same board was then processed as if the usable lengths included 18.5 inches and 62 inches in addition to the 76 inches. To increase overall yield, the feed position was shifted 1/4 inch. Shifting the feed position of the boards resulted in a loss of opportunity to obtain the 76-inch piece, but the overall yield increased. After the shift, a 62-inch part could be obtained from the first strip, but the longest length that could be obtained from the second strip was 62 inches. However, one 18.5-inch part could be obtained in the second strip, so the total length of parts in the second strip (80.5 inches) was greater than the single 76-inch length. Therefore, overall yield was improved, but the yield for 76-inch pieces changed since shorter lengths were added to the chopsaw. As the cutting bill becomes more complicated

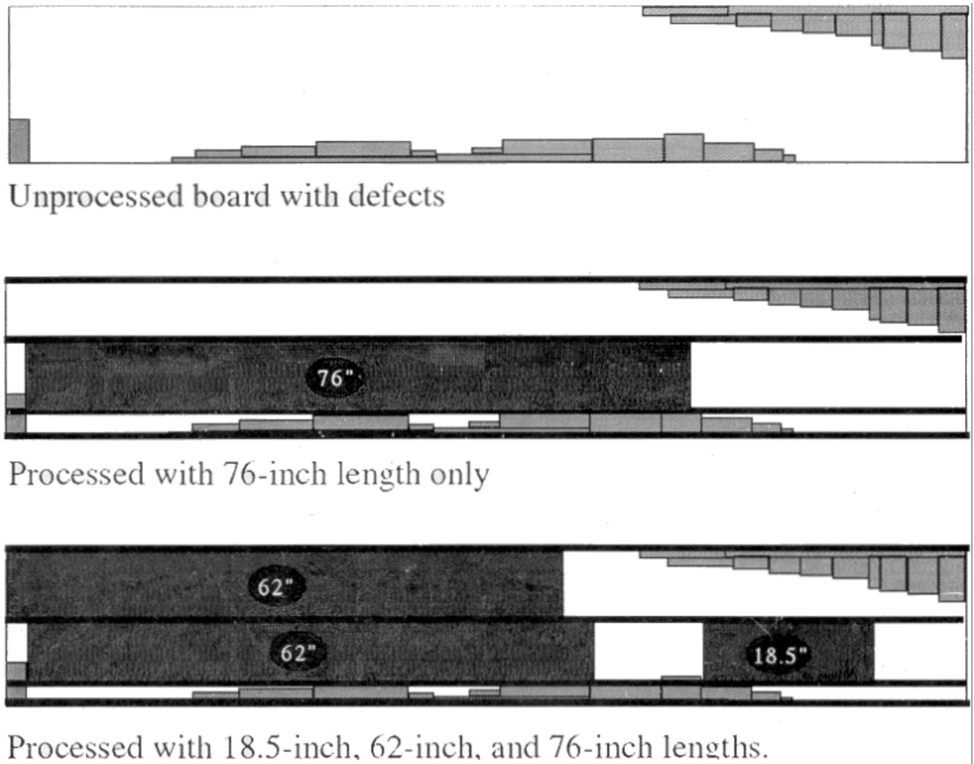


Figure 1.—Comparison of board processed with a single length and with three lengths.

with additional lengths and widths, differences in feed position, arbor type, and arbor configuration become more important, and their impact on yield becomes more significant.

Part yields from simulated operations where the board is consistently fed against the fence remained constant regardless of the addition of shorter usable lengths. Again, boards are processed by cutting the longest length from each strip. This time, the feed position remains the same, so the strips generated during each simulation run do not vary. Therefore, the yield for the longest part size does not change when shorter lengths are added to the chopsaw.

Yields predicted by the gang-rip-first nomograms are compared against simulated yields for the nonoptimizing and optimizing ripsaws as applied to the cutting situations in Table 2 (Table 6). The yields from gang-rip-first nomograms reflect the same characteristic of consistent part yields regardless of the addition of shorter lengths as seen in the nonoptimizing ripsaw simulations. This consistency is inherent in the method for calculating nomogram yields described earlier.

The similarity in the way the yields are calculated using the nomograms and the nonoptimizing ripsaw would seem to indicate that nomograms can be used to predict yield when using a nonoptimizing fixed-blade ripsaw. Table 6 shows that the gang-rip-first yields and the nonoptimizing ripsaw part yields for this example (processed with 1/4-inch edging on each side of the board) appear similar even though the nomogram part yields are greater than the nonoptimizing ripsaw simulation results in every instance. Without edging, simulated part yields were slightly lower than those shown in Table 6.

The difference in yields might be due to: 1) differences in the resource itself (primarily in width) since the early 1970's; 2) differences in grading rules since the early 1970's; 3) differences in the acceptance of edge-glued pieces; or 4) improvements in the validity of simulation results over the simulations used to derive the nomograms. Regardless, the slight differences in part yields can escalate into substantial differences as the number of different part sizes increases. When processing for 76-inch parts only, the difference in

**Table 6.—Comparison of yields when all parts are 2 inches wide—cutting quantities not specified**

| Length on chopsaw (inches) | Nonoptimzing ripsaw yield | Optimizing ripsaw yield | Gang-rip-first nomogram yield |
|---|---|---|---|
| 76 | 25.4 | 30.1 | 26.0 |
| 76 | 25.4 | 29.6 | 26.0 |
| 62 | 9.4 | 10.3 | 10.8 |
| 76 | 25.4 | 28.7 | 26.0 |
| 62 | 9.4 | 10.1 | 10.8 |
| 18.5 | 21.7 | 21.3 | 30.6 |

total primary yields was only 0.6 percent. When processing for 76- and 62-inch parts, the difference in total primary yields between the nonoptimizing ripsaw and the nomogram methodology was 2 percent. When processing 76-, 62-, and 18.5-inch parts, the difference was 10.9 percent! Thus, the nomograms seem to overestimate part yields from at least some grades of lumber, and the cumulative effect of these errors can have profound adverse effects on the estimation of total yield.

## Variance in Application of Nomogram Yields

With respect to the shortcomings of the nomogram methodology, a key question is: "do these shortcomings affect predictions of lumber requirement?" I have discussed the reasons why the nomogram yields cannot be used directly. But how do these factors affect published methods that translate nomogram yields into lumber requirements? To answer this question, one must investigate the methods used to determine board-footage requirements.

The method of interpreting the nomogram yields with respect to lumber board-footage requirements to fill a cutting order is another source of variation. There are two methods for making the leap from the predicted yields to predicting board-footage requirements. The first, described by Englerth and Schumann (1969), converts board footage to numbers of parts before lumber requirements are determined. The second, a yield-based method used by Hallock (1980) and Martens and Nevel (1985), does not convert board footage to numbers of parts until all clear lumber has been distributed among part sizes.

The Englerth and Schumann Iterative Adjustment Method (IAM) considers the expected yield for the longest piece. The amount of lumber needed to obtain the required quantity of that size piece is determined and then the quantities of pieces of other sizes that would be produced from that amount of lumber are calculated. Extra pieces are redistributed to smaller pieces if possible, as though they were recut to the smaller dimensions. Therefore, care must be taken to make sure that the piece being redistributed is as wide and as long as the alternate cutting size. Once shortages, if any, have been identified, the entire nomogram process is repeated with only those pieces for which shortages exist. This process is repeated until there are no shortages in any required part size.

Note that this methodology does not allow for a higher yield in the longest piece than what the nomogram predicts. Recall that simulated processing of cutting bill 3 (Table 3) resulted in a yield of 30.45 percent in 76-inch pieces when cutting with an optimizing ripsaw versus 26.77 percent when cutting with a nonoptimizing ripsaw. However, the nomogram method would suggest that a yield of 25.4 to 26.0 percent (Table 2) is the highest that could be obtained when cutting 76-inch pieces.

Hallock's (1980) method, the Surface Measure Equivalent Method (SMEM), determines the surface measurement equivalent of the quantity required in a certain part size. Starting with the longest part size, the surface measurement equivalent is divided by the nomogram yield to determine the amount of board footage needed to satisfy demand for this size part. Once this amount of board footage is determined, subsequent yields are used to determine the board footage concurrently produced in smaller sizes. If overages occur, the extra board footage is added to the board footage produced in the next smaller size without regard to the noncontiguous nature of the "leftover" lumber. If any shortages exist, the entire nomogram process is repeated with only those sizes experiencing shortages.

Consider the case where there are 50 excess 2- by 21.5-inch pieces, and the remaining cutting bill requirement is 58 2- by 18.5-inch pieces. The SMEM would assume that the surface area of the excess pieces could be reconfigured with no loss in value to produce all 58 pieces since the surface-area measure for the 2- by 18.5-inch pieces, 2,146 $in^2$, is less than the 2,150 $in^2$ of the excess pieces. Eight of the 2- by 18.5-inch pieces would be composed of six 3-inch pieces and one 1/2-inch piece glued together. If finger-jointed parts are unacceptable, then the most 2- by 18.5-inch pieces that could be obtained from the excess pieces is 50. The SMEM would estimate that the cutting bill requirements would be filled when, in fact, eight 2- by 18.5-inch parts still would be required.

A "shortcut" version of the SMEM is used in OPTIGRAMI (Martens and Nevel 1985) and OPTIGRAMI V2 (Lawson et al. 1996). Since board footage produced is not identified by dimensions and is assumed to be usable, SMEM is eliminated. Extra pieces produced in longer lengths by processing more lumber are redistributed among smaller pieces in terms of board footage.

Predicted and actual lumber requirements (based on ROMI-RIP simulations using 1 Common red oak data) are given in Table 7. Since simulation runs using cutting bills halt execution as soon as the cutting bill is met, the required volume of lumber can be taken directly from the simulation output. A first set of predicted lumber requirements was based on the gang-rip-first nomograms. The second set was based on the nomogram approach but used the red oak data files to generate simulated yields that were comparable.

It appears that differences in yields due to different processing technologies are not accounted for by the three methods for translating predicted yields into lumber requirements. Yields developed in a manner similar to the development of nomogram yields but from newer simulation of a nonoptimizing ripsaw were obtained by considering only two lengths at a time on the cutoff saw. Predicted lumber requirements from simulations using two lengths at a time to calculate yield approximated the actual lumber requirements of a nonoptimizing ripsaw. However, these predicted requirements significantly exceeded the actual requirements of an optimizing ripsaw. Table 7 shows that differences in processing technologies used in data collection and those used in actual operations can invalidate lumber-requirement predictions.

**Table 7.—Comparison of predicted and actual lumber requirements**

| Cutting bill | | | Predicted lumber requirements (board feet) | | | | | | Actual lumber requirements (board feet) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Gang-rip-first nomograms | | | Simulations: two lengths at a time[a] | | | Simulations: all lengths at once | |
| Width | Length | Quantity | IAM[b] | SMEM[c] | Optigrami shortcut | IAM[b] | SMEM[c] | Optigrami shortcut | Nonoptimizing | Optimizing ripsaw |
| *Inches* | *Inches* | *Number* | | | | | | | | |
| 2 | 76 | 61 | 247.65 | 247.65 | 247.65 | 253.80 | 253.80 | 253.80 | 283.25 | 236.08 |
| 2 | 76 | 61 | 323.09 | 296.92 | 291.97 | 316.82 | 315.21 | 309.37 | 306.32 | 269.16 |
| 2 | 62 | 50 | | | | | | | | |
| 2 | 76 | 61 | 326.36 | 318.16 | 316.86 | 381.36 | 380.14 | 378.52 | 379.96 | 358.57 |
| 2 | 62 | 50 | | | | | | | | |
| 2 | 18.5 | 413 | | | | | | | | |

[a]Input-lumber differences excluded for comparison with simulation results when all three lengths are processed at once.
[b]Iterative Adjustment Method.
[c]Surface Measure Equivalent Method.

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**Keywords:** Rough mill; hardwood; lumber grade mix; lumber cost; simulation

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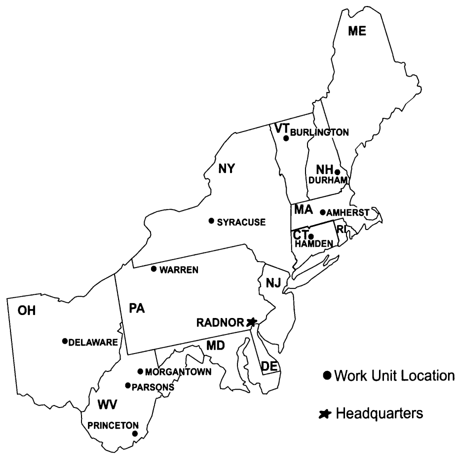


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