

Rethinking the design of the furniture rough mill

Charles J. Gatchell

Abstract

This paper discusses the crosscut-first rough mill with emphasis on the effects of lumber quality, cutting bills, and operator efficiency on yields. Adding a gang-rip-first option is recommended, which will use more of the lower grades of lumber while meeting the needs of the furniture and cabinet industries. Current research that indicates why gang ripping to glue-line-quality edges should be effective is also discussed. A rough mill that uses log-run lumber (No.2 Common and Better) and allows a gang-rip-first or crosscut-first option is described.

The interactions among lumber quality, cutting bills, and operator efficiency require rethinking the design of the furniture or cabinet rough mill if the lower grades of lumber are to be used. The rough mill of a hardwood furniture or cabinet plant is the part of the process where kiln-dried lumber is converted into solid or glued-up rough-dimension pieces, panels, or parts. These pieces, panels, or parts will require subsequent machining to finished sizes and shapes before being assembled into specific products. The goal of the rough mill should be to provide rough-dimension parts for final machining at the lowest cost.

Rough mill design, with crosscutting as the first lumber breakdown step, reflects an earlier time when large quantities of long, wide, clear boards were readily available. Usually, crosscutting to length followed by ripping to width was all that was needed. But as boards became narrower and overall board quality decreased,

efficient use of the crosscut-first rough mill procedures became more difficult. In some mills, presurfacing before crosscutting, or between the crosscut and ripping steps, is done to improve efficiency.

Major changes in rough mill procedures are not always easy to initiate. If an existing manufacturing sequence was laid out based on the processing of only the best grades, then it may not be possible to easily change to processing the lower grades. Increases in the number of saws, the number of workers, the amount of salvage work necessary to sustain high yield, and the amount of waste to be handled can make it difficult to fit changes into existing plant space.

The purpose of this paper is to discuss the most important factors affecting the operation of the conventional crosscut-first rough mill, to discuss the gang-rip-first option, and to suggest a rough mill approach that appears suitable for today's hardwood resource if glue lines can be accepted in the final product.

Important crosscut-first rough mill factors

The most important factors affecting conventional crosscut-first rough mill operations and the yields of parts are 1) quality of lumber input, 2) cutting bill, and 3) operator efficiency. This is not to suggest that factors such as the quality of sawing during log breakdown, or the care with which lumber is handled between log sawing and kiln-drying, or the procedures used in kilndrying (including equalizing and conditioning) cannot be of equal importance. When done incorrectly, such factors can have important negative effects on rough mill yields.¹ This discussion of rough mill practices begins with the assumption that the input lumber is in acceptable condition.

¹In the December 1985 issue of *Furniture Design and Manufacturing*, in an article entitled "The Rough Mill- Improving Yield," eight factors that determine rough mill yields are listed: 1) lumber grade, 2) lumber grading rules, 3) lumber size, 4) drying quality, 5) cutting bill, 6) part quality, 7) rough mill machinery and material flow, and 8) operator skill and motivation.

The author is a Supervisory Forest Products Technologist, USDA Forest Serv., Northeastern Forest Expt. Sta., Forestry Sci. Lab., Princeton, WV 24740. This paper was received for publication in June 1986.

© Forest Products Research Society 1987.

Forest Prod. J. 37(3):8-14.

Lumber inputs

Most furniture and cabinet manufacturers prefer to use the higher grades of hardwood lumber as defined by the National Hardwood Lumber Association (17). The higher grades contain wider and longer specifications for both board and cutting sizes. Grades basically differ by the amount of clear material that must be present on the grading side (usually the poorest face) and by the number and size of pieces that are allowed to contain that clear material.

For example, the Firsts and Seconds (FAS) and Select grades must contain a minimum of 83-1/3 percent clear-face material. No.1 Common contains a minimum of 66-2/3 percent clear-face cuttings, No.2 Common contains a minimum of 50 percent, and No. 3A Common contains a minimum of 33-1/3 percent. The allowable cuttings making up these percentages are generally larger in size and fewer in number in the higher grades.

Grade differences can be illustrated by comparing No.1 and No.2 Common lumber. Each grade allows boards that are 3 inches or wider and 4 to 16 feet long. Consider a 4/4 board that contains 6 feet of surface measure (a board 12 ft. long and 6 in. wide, for example). If No.1 Common, the board must be at least 66-2/3 percent clear on the poor side in no more than two pieces, with the smallest piece at least 4 inches by 2 feet or 3 inches by 3 feet in size. If No. 2 Common, the board must be at least 50 percent clear on the poor side with no more than three cuttings, and the minimum piece size is 3 inches by 2 feet. One additional cutting may be made in each grade if the resulting clear-face yield will be at least 75 percent for No.1 Common and 66-2/3 percent for No.2 Common. Thus, No.1 Common is easier and faster to process because there are fewer decisions to be made by the saw operator, and there is a higher percentage of usable surface area for each unit of input.

If that same board (6 ft. of surface measure) were FAS, the entire 83-1/3-percent clear area would have to be contained in one cutting. Two cuttings are allowed if the clear-face yield is at least 91-2/3 percent. The minimum size of cutting for this grade is either 4 inches by 5 feet or 3 inches by 7 feet. This minimum can be deleted if the total yield is 97 percent in two cuttings. In any event, an FAS board is a better piece of wood than a Common board and should be easier to process in the conventional crosscut-first rough mill.

The amount of high-grade lumber as a percentage of the overall resource is small. Recent estimates (15) of log quality available in 17 (unnamed) Eastern States give the following distribution:

USDA Forest Service	Percent of sawtimber
Factory 1	13
Factory 2	20
Factory 3	47
Factory 4	20
	100

According to Araman (2), sawmillers try to limit the amount of Grades 3 and 4 logs they process and the grades delivered to a sawmill are more likely to be: Grade 1: 20 percent; Grade 2: 35 percent; and Grades 3 and 4: 45 percent. Using lumber yield data supplied by Hanks et al.

(0) and Araman's more optimistic estimates of log quality, the available lumber supply of oak and the prices by grade are:

Lumber grade	Lumber supply (%)	January 31, 1987 4/4 market price (21) of plain red oak (\$)
FAS	8	885
Select	7	865
No.1 Common	25	575
No.2 Common	28	265
Below No.2 Common	32	210

While these grade distributions will vary depending on the grades of logs processed at a given sawmill (pallet mill or grade mill, for example), overall there is relatively little high-grade material available.

The prices reflect the demand for the lumber product. The average FAS and Select prices are 152 percent of the No.1 Common price, and the No.1 Common price is 217 percent of the No.2 Common price. But why should the demand be so sharply different? There is only a 16-percent increase in minimum potential yield between No.2 Common and No.1 Common. The same is true between No.1 Common and FAS/Select.

The usual answers to the demand question include the ease with which the higher grades can be processed in the crosscut-first rough mill, the fact that larger pieces of clear material can be sawed from the higher grades, and considerations of production control. More lumber and labor input, machinery, and waste handling capacity will be required for a given amount of output from the lower grades. Habit and tradition sometimes account for the preferred use of No. 1 Common and Better lumber.

But a more pervasive reason may be that the prices are set by the technology available to process the raw material. Because it is often thought to be impractical to process No.2 Common into furniture and cabinets with crosscut-first technology, the demand for this grade is low. In the past, when Factory Grade 1 logs were more plentiful and the amount of No.2 Common and poorer lumber produced was considerably less, there were no great problems. As average log quality decreased, the amount of No. 2 Common and poorer lumber increased, and the amount of the higher grades decreased. But there was little change in the technology to convert the raw material. Companies locked into the crosscut-first approach with little opportunity to modify their manufacturing sequences had little choice but to pay the increasing prices for the higher grades. So long as these price increases could be passed on to the consumer, there was little incentive to change. Now, with the increased competition that is occurring in the 1980s from overseas furniture imports, U.S. firms will need the most efficient rough mill systems possible.

Cutting bill

The cutting order for a particular production run or time period is a listing of all needed parts for a particular suite or grouping of furniture pieces. It can contain several hundred combinations of part sizes and qualities, with quantities for each combination. The cutting order is broken down into a series of cutting bills

containing up to six part lengths that the crosscut saw operator uses to process the lumber. As requirements for parts in the initial cutting bill are met, those requirements are deleted and other cutting sizes are added. Ideally, there is a wide range of lengths in each cutting bill so that numerous opportunities to maximize yield are available.

A basic rough mill problem is how best to cut up the lumber in each grade to the dozens of parts needed. It would be economic folly to cut F AS lumber to the short lengths found in children's furniture parts on Monday and try to process No.2 Common into the long lengths found in king-size bed parts on Tuesday. Fortunately, there are tools such as OPTIGRAMI (14) that are available to assist in matching lumber grades to cutting bills. OPTIGRAMI is a linear programming model developed by the USDA Forest Service. The inputs to OPTIGRAMI include the cutting order (up to 50 sizes), the lumber grades available and their prices, and rough mill costs. The outputs include a listing of inputs, the optimum or least-cost grade mix, and cutting instructions to the rough mill telling which part sizes to cut from which grade. Also included is a sensitivity analysis that tells at what new price for a given grade of lumber a new optimum set of values should be calculated. The ultimate value of such a tool depends on how well mill management knows its costs and lumber inventory.

Operator skill

Operator skill is a subjective but nonetheless critical factor in developing rough mill yields. Huber et al. (13) state that rough mill employees must 1) see and recognize defects, 2) properly locate saw cuts, 3) be strong enough to position the board, 4) stay mentally alert, and 5) be able to remember the location of defects on one side while looking at the other side. Factors such as fatigue, low morale, lack of knowledge, and poor work habits can have an important negative bearing on results. Many consultants offer motivational training programs to help solve problems in these areas (20).

A back gauge will improve the efficiency of the crosscut saw operator. The back gauge allows the operator to analyze several feet of the incoming board length and choose the crosscuts that will maximize yield. The operator can decide where to put any necessary waste and where the last cut on the board will be made. And all of this will occur before the cutting locations are past the crosscut saw.

The back gauge is constructed by color-coding the specific cutting bill lengths that are installed on the outfeed side of the crosscut saw. These color codes are then placed at appropriate distances from the sawblade on the infeed side. Combinations of cutting lengths are also indicated on the infeed side. Once set, the operator does not have to consider lengths in inches—just match the colors on the outfeed side with the colors selected on the infeed side.

There are several commercially available computer programs that will calculate and print out the optimum back gauge lengths for particular lumber grade mixes and cutting bills, and allow management to assign priorities to specific lengths. An electronic self-contained back gauge is also available.

Operator skill is considered so important by some that sophisticated systems have been developed to eliminate the crosscut saw operator. Defects are marked with a fluorescent chalk or crayon. A computer then calculates the optimum cuts between the defects according to cutting bills and any biasing or prioritizing instructions. When the equipment senses the mark, the crosscut is made. These systems keep a running inventory that can be printed out at any time and can process 4,000 to 5,000 lineal feet per hour.

A new automated lumber processing system named ALPS has been proposed by McMillin et al. (16) to further reduce the effects of manpower on yield. In ALPS, logs would be sawed automatically after being scanned by computerized axial tomography and positioned for optimum yield. After drying and surfacing, boards would be scanned for defects by video image analysis and processed to parts with a numerically controlled high-powered laser. Much of the needed technology is now available.

A modified crosscut-first approach: standard-size blanks

Rather than process lumber directly into specific rough-dimension parts in the usual way, managers may want to consider converting lumber into standard-size blanks. Standard-size blanks are glued-up rough-dimension panels of specified lengths, widths, thicknesses, and qualities. These specifications were developed in a computer analysis of the overall needs of 32 major manufacturers of furniture and kitchen cabinets (3). For example, 4/4 clear-quality blanks are made to lengths of 15, 18, 21, 25, 29, 33, 45, 50, 60, 75, and 100 inches. These blanks can be ripped and trimmed to specific rough-dimension sizes. A feature of this approach is that crosscutting is based on taking the longest length first without regard to a conventional cutting bill.

A crosscut-first rough mill that converts 16 thousand board feet (MBF) of log-run lumber (No.2 Common and Better) per shift into 9.6 MBF of standard-size blanks has been designed and evaluated (4). A small mill that converts 2 MBF of No.1 and No.2 Common into 1.2 MBF of blanks per shift has also been described (11).

A new rough mill system named System 6 (12,18,19) uses no standard lumber at all. Instead, roundwood that is 6 feet long and 7-112 to 12 inches in diameter is processed directly into standard-size blanks. These short logs are cut into two cants that are gang-sawed to narrow (4-in. maximum width) boards. The System 6 boards are then gang-crosscut and gang-edged to remove about 80 percent of the defects. A dip chain-fed gang rip saw is used that produces ripped surfaces of a glueable quality that equal those from a straight-line rip saw (8). The boards are then crosscut to a longest-length-first basis, salvage ripped if necessary, and glued-up to standard-size blanks.

Gatchell and Hansen (7) concluded that System 6 rough mills provide an excellent opportunity to profitably produce standard-size blanks because the value of the raw material is low (about \$100 per MBF) and the value of the

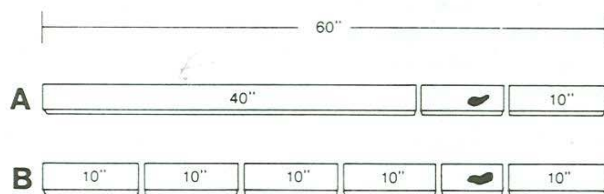


Figure 1. - Yield and waste of strip A equals yield and waste of strip B.

blanks is high (about \$2,000 per MBF of 4/4 clear-one-face panels). They also concluded that making blanks from lumber is economically less certain and works best when 4/4 No.1 Common lumber prices are \$350 or more per MBF and where the price difference between No.1 and No.2 Common is around 100 percent. The reason for this is that there is higher yield from the No.2 Common than the price suggests. In a real sense, the No.2 Common lumber will provide a subsidy for the use of the No.1 Common when a mix of the two grades is used as a raw material for standard-size blanks.

Gang-ripping first

The decision whether to gang-rip or crosscut first is usually based on the final products being made and whether gluelines are acceptable. If gluelines are unacceptable, gang-ripping will usually be limited to the production of narrow parts, and the highest grades of lumber will be required in a crosscut-first operation. Not much improvement can be made in rough mill design under this restraint.

Gang-ripping followed by crosscutting is far more than simply the reversal of the first two steps in a conventional rough mill. The effect on yields of long parts is significant. And the process itself can be set up in several ways that affect yields. Multiple sawblades on a single arbor can be spaced evenly, resulting in a single piece width and edgings. Processing edgings is an expensive way to achieve maximum yield. One way to eliminate edgings is with a series of blades mounted on a single arbor and spaced such that at least one combination will account for the full width of the board. Another way is to space all blades a specified width apart and to move the last blade in or out as needed.

Gang-ripping to glueline-quality edges is assumed in this paper. With dip chain-fed gang rip-saws, glueline-quality edges equal to those from straight-line rip-saws can be produced (8). Additional yield loss at a molder or straight-line rip-saw is thereby eliminated when glued-up stock is the rough mill objective. Perhaps of equal importance, gang-ripping to glueline-quality edges eliminates at least one extra machining step and all of the associated materials handling.

The advantages of gang-ripping include high yields in long lengths from the lower, less expensive grades of lumber. Hall et al. (9) showed similar yields, between crosscut-first and gang-rip-first processing of No.1 Common red oak. Gatchell et al. (6) showed that varying

TABLE 1. — Distribution of yield from 4/4 No. 2 Common red oak, by cutting bill (surface area of output/surface area of input).

Cutting type	Bill		
	Short	Long	Standard blanks
Primary ^a	35.5	35.5	35.5
Salvage ^b	15.0	15.0	15.0
Edgings	5.5	5.5	5.5

^aPrimary cuttings are obtained by crosscutting full-width strips.

^bSalvage cuttings are obtained by crosscutting and salvage ripping full-width strips.

the width of the gang-rip between 2 and 3 inches did not affect the overall random-length yield of 60 percent from No.2 Common red oak, but did affect the distributions of part lengths with wider rips giving shorter lengths. The 60-percent random-length yield was reduced to 55 percent when a fixed-length cutting bill was used.

A key finding of Gatchell et al. was that gangripped No.2 Common red oak lumber will yield more than the amount of long lengths needed by the furniture and cabinet industries and not enough short pieces. Considering that the No.2 Common furniture hardwoods are generally half the price of No.1 Common, with only a 16-percent reduction in minimum yield, gang-ripping first and No.2 Common can be a profitable combination. The thin strips resulting from gangripping can be inspected quickly and easily and crosscut to rough-dimension or panel stock.

Disadvantages of gang-ripping include the need for straight, flat boards to gang-rip to glueline-quality edges. Proper conventional drying will prevent unacceptable warp or twist; however, it will be necessary to examine boards for excessive crook and to crosscut excessively crooked boards in or near the middle of the length before gang-ripping.

Gang-ripping first, why does it work?

Consider current Forestry Sciences Laboratory research on fixed-length gang-ripping (5) of No.2 Common red oak. In a computer simulation of gang-ripping, where all blades were spaced to saw 2-1/2-inch-wide strips, a 56-percent yield was obtained regardless of the cutting bills. The cutting bills used were:

Cutting bill	Lengths (in.)
1. Short	10,20
2. Long	10,20,30,40,50,60,70,80,90
3. Standard blanks	15,18,25,29,33,38,45,50,60,75

Why similar yields? Cutting bill 1 is contained in cutting bill 2, but neither is very similar to cutting bill 3. Because the computer simulation program always ripped the boards to the same pattern across the width, differences in yield could only be the result of the cutting bill lengths chosen. Figure 1 shows why the long and short bills were similar. The chances are very small that two defects will be spaced exactly equal to the length of a cutting or a combination of cuttings. A waste piece of solid wood will be left. The total waste from any strip will be made up of

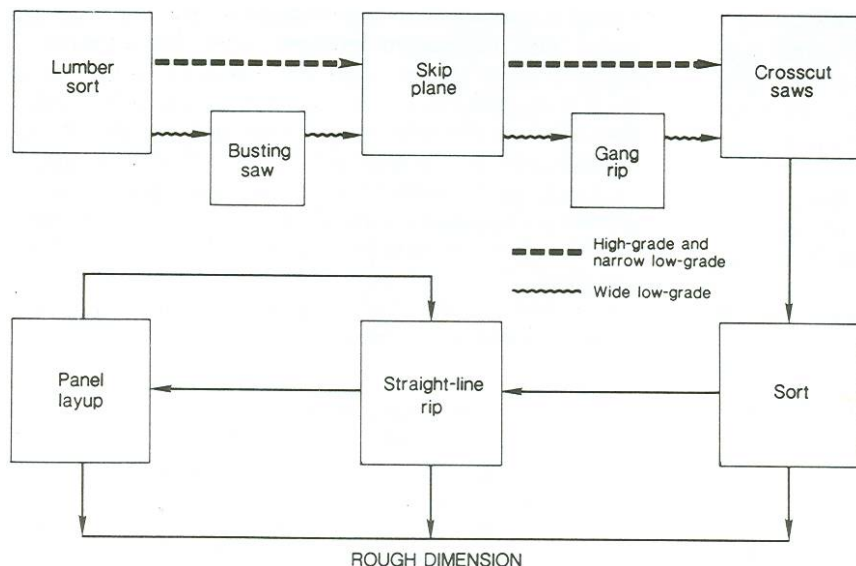


Figure 2. - An either-way rough mill.

crosscut sawkerf and solid pieces. Increasing the number of short cuttings increases the amount of kerf and decreases the amount of solid wood waste. The total surface area of cuttings remains the same.

The reasons for the similarity between the yields of the standard blanks bill and the short and long cutting bills are less apparent. Yet to the nearest 0.5 percent, the yields were identical (Table 1).

The reasons for these similarities appear to lie in the randomness of chance. For a given board, one bill will usually give a better yield than another. The randomness of defect location accounts for that. But given enough boards of different lengths in the sample, these differences will even out, provided that each cutting bill contains a sufficient number of different lengths, including some short lengths. The similarity of total yields regardless of cutting bill lengths is considered a key to the value of gang-ripping first when processing the lower grades of lumber.

In another simulation, all blades were spaced a fixed width apart initially (2-1/2 in. in this study) and the last blade was moved in or out depending on the width of the last strip. If the last strip was 2 to 2-1/2 inches wide, it was ripped out. If narrower than 2 inches, the strip was added to the preceding 2-1/2-inch strip by moving the last blade out. There was a slight increase in overall yield from 56 to 58.5 percent from fixed-blade spacing to variable last-blade spacing. This was attributed mainly to the elimination of those edgings from the fixed-width simulation that were too narrow (less than 1 in. wide) to yield a salvage cutting.

Summary width and length yield distributions are given in Tables 2 and 3. Moving the last blade on the arbor to eliminate edgings has a significant impact on yield distributions. While 2-1/2 inches was the target width, the elimination of edgings resulted in 20 percent of the surface area yield in pieces 3.0 inches wide or wider. And there was a 3.5-percent yield decrease in widths under 2-1/2 inches. There was also a 4.5-percent yield decrease in the longest lengths (60 and 75 in.) and a similar increase in the shorter lengths (16, 18, 25, and 29 in.). As a rule, wider cuttings from the lower lumber grades will not be as long

TABLE 2. — Fixed- and adjustable-blade gang-rip width distributions of surface area yields.^a

Width	Fixed 2-1/2	Adjustable 2-1/2
(in.)	----- (%) -----	
1.0	11.2	7.5
1.5	10.6	9.5
2.0	15.0	16.3
2.5	63.2	45.3
3.0		7.3
3.5		8.6
4.0		5.5
Total	100.0	100.0

^aTotal surface yield was 56 percent for the fixed-blade and 58.5 percent for the adjustable-blade.

TABLE 3. — Fixed- and adjustable-blade gang-rip length distributions of surface area yields for the standard blanks cutting bill.^a

Length	Fixed 2-1/2	Adjustable 2-1/2
(in.)	----- (%) -----	
15, 18	19.6	20.6
25, 29	11.0	14.6
33, 38	17.3	17.2
45, 50	16.9	17.0
60, 75	35.2	30.6
Total	100.0	100.0

^aTotal surface yield was 56 percent for the fixed-blade and 58.5 percent for the adjustable-blade.

because of the increased chances of encountering a defect as we proceed along the length of a strip.

The results of this limited computer simulation study (425 board feet of 4/4 No.2 Common red oak in 56 boards in widths from 4-1/2 to 12 in. and lengths from 7 to 14 ft.) show that gang-ripping of No.2 Common continues to provide more long lengths than are needed by the furniture and cabinet industries. Further, gangripping with variable spacing of the last blade should be considered in new rough mill designs provided that a glue-line-quality edge is produced.

A proposed either-way rough mill

The discussion that follows is intended to stimulate thinking about the roughmill possibilities when both a crosscut-first and a gang-Crip-first option are available in what may be called an either-way rough mill (Fig. 2). Attempts should be made to use some No.2 Common lumber because of its yield potential and low price. I recommend that log-run lumber (all No.2 Common and Better) be considered. For red oak, log-run lumber is about 20 percent Select and Better, 40 percent No.1 Common, and 40 percent No.2 Common. Such a grade mix should contain enough of the highest grades for special parts requirements, while lowering the overall costs for raw materials. Gang-ripping to glueline-quality edges is assumed.

The easiest procedure would be to gang-rip all grades. All edges would be ready for gluing and no sorting for rough or machined edges would be required. But some managers may feel ripping clear boards, edge gluing strips to panels, and reripping panels to rough dimension widths is too wasteful. The combination of log-run lumber, some gluelines in the finished product, and a gang rip saw that produces glueline-quality edges provides enough flexibility in rough mill design and operation so that other options are possible.

In the either-way rough mill, the decision whether to gang-rip or crosscut first should be based on the width and quality of each board. The highest grades, including the best of the No.1 Common lumber, should be crosscut first to obtain long, wide pieces free of gluelines. Compared with parts from glued-up panels, these parts will require the least amount of processing time and will cost less within a grade (1). All other parts should be produced by gang-ripping the lower grades.

There is a minimum width below which gangripping first is useful for little more than producing glueline edges; that is, gang-ripping will not aid appreciably in improving yield from the board. When a board is narrow, the crosscut operator can easily determine where to place the crosscuts. On the basis of work with thousands of narrow System 6 boards, I suggest 4-1/2 inches to be the minimum board width for gangripping No.2 Common and Better lumber.

Boards that are mostly clear will be crosscut first, as should all narrow boards, regardless of grade. As the boards are unstacked from the dry kiln, they will be sorted into two quality-size groups. All high-grade and the narrow No.1 and No.2 Common will be sorted for crosscutting first. No.1 and No.2 Common lumber that is wider than 4-1/2 inches will be sorted for gang-ripping first. High-grade and narrow low-grade boards will be skip planed and crosscut, and the resulting pieces fed through the straight-line rip saw to be ripped either to rough-dimension or panel stock.

The wider, lower grade boards will be gang-ripped. They first pass by a busting saw where boards with excess crook are crosscut into shorter, straighter lengths (one crosscut per board should suffice). The boards are then skip planed and gang-ripped to glueline-quality edges with a saw that contains an adjustable outer blade or other blade arrangement that will eliminate the generation of edgings.

The gang-ripped strips will then be defected and crosscut to length using back gauges on crosscut saws. The number of operator decisions, a major disadvantage to the use of the lower grades in a crosscut-first mill, will be greatly simplified on the relatively narrow gang-ripped strips. Gang-ripped pieces that meet rough-dimension specifications can be sorted out and the remainder will be glued-up into panels. Straight-line rip saws will produce glueable edges as needed on pieces from the crosscut-first operation. They will also be used as salvage saws following the cut-to-length operation and to process the glued-up panels into rough-dimension parts.

Summary

The conventional crosscut-first rough mill is most effective when processing the highest grades of hardwood lumber to furniture or cabinet rough-dimension parts. The interactions of lumber quality, cutting bills, and operator efficiency make alternatives to the crosscut-first approach necessary when processing the lower grades. One result is high prices for a limited amount of raw material for crosscut-first processing. Differences in prices among the grades do not reflect the potential value of the lower grades for making furniture and cabinet parts.

Gang-ripping first is a viable alternative when processing the lower grades of hardwood lumber to furniture and cabinet rough dimension. No.2 Common red oak contains more than enough long lengths to satisfy the needs of the furniture and cabinet industries. Manufacturers who can accept gluelines in the finished product should seriously consider providing a gang-rip-first option. Gang-ripping to glueline-quality edges should be done to increase rough mill efficiency.

Literature cited

1. ANDERSON, R.B. 1985. Computerization in the rough mill. *Furnit. Manuf. Manage.* 31(2): 12-14.
2. ARAMAN, P.A. 1984. Good potential seen for hardwood exports. *Forest Ind.* 111 (11):34-36.
3. _____ C.J. GATCHELL, and H.W. REYNOLDS. 1982. Meeting the solid wood needs of the furniture and cabinet industries: standard-size hardwood blanks. USDA Forest Serv. Res. Pap. NE-494. 27 pp.
4. _____ and B.G. HANSEN. 1983. Conventional processing of standard-size edge-glued blanks for furniture and cabinet parts: a feasibility study. USDA Forest Servo Res. Pap. NE-524. 11 pp.
5. GATCHELL, C.J. 1986. Impact of rough mill practices on yields. In: *Eastern Hardwoods: The Resource, the Industry and the Markets*. Proc. 47345. Forest Prod. Res. Soc., Madison, Wis.
6. _____ R.B. ANDERSON, and P.A. ARAMAN. 1983. Effect of gang-ripping width on C IF yields from No.2 Common oak lumber. *Forest Prod. J.* 33 (6):43-48.
7. _____ and B.G. HANSEN. 1986. Standard blanks-a good value added opportunity. *Northern Logger* 34(10): 26-31.
8. _____ and J.O. OLSON. 1986. Comparison of glue-line quality between gang edging and straight-line ripping. USDA Forest Servo Res. Pap. NE-588. 7 pp.
9. HALL, S.P., R.A. WYSK, E.M. WENGERT, and M.H. AGEE. 1980. Yield distributions and cost comparisons of a crosscut-first and a gangrip-first rough mill producing hardwood dimension stair parts. *Forest Prod. J.* 30(5): 34-39.
10. HANKS, L.F., G.L. GAMMON, R.L. BRISBIN, and E.D. RAST. 1980. Hardwood log grades and lumber grade yields for factory lumber logs. USDA Forest Servo Res. Pap. NE-468. 92 pp.

11. HANSEN, B.G. and P.A. ARAMAN. 1985. Low-cost opportunity for small-scale manufacture of hardwood blanks. USDA Forest Serv. Res. Pap. NE-559. 6 pp.
12. _____ and H.W. REYNOLDS. 1984. System 6 alternatives: an economic analysis. USDA Forest Serv. Res. Pap. NE-551. 14 pp.
13. HUBER, H.A., C.W. McMILLIN, and J.P. McKINNEY. 1985. Lumber defect detection abilities of furniture rough mill employees. Forest Prod. J. 35(11/12): 79-82.
14. MARTENS, D.G. and R.L. NEVEL, JR. 1985. OPTIGRAMI: optimum lumber grade mix program for hardwood dimension parts. USDA Forest Serv. Res. Pap. NE-563. 10 pp.
15. McLINTOCK, T.F. 1982. The resource: nationwide perspective. *In*: Proc., Society of American Foresters, Sept. 19-22, Cincinnati, Ohio, Soc. Am. Foresters, Washington, D.C. pp. 6-10.
16. McMILLIN, C.W., R.W. CONNERS, and H.A. HUBER. 1984. ALPS--a potential new automated lumber processing system. Forest Prod. J. 34 (1): 13-20.
17. NATIONAL HARDWOOD LUMBER ASSOCIATION. 1982. Rules for the measurement and inspection of hardwood and cypress. Memphis, Tenn.
18. REYNOLDS, H.W. and C.J. GATCHELL. 1979. Marketing low-grade hardwoods for furniture stock-a new approach. USDA Forest Serv. Res. Pap. NE-444. 7 pp.
19. _____ 1982. New technology for low-grade hardwood utilization: System 6. USDA Forest Serv. Res. Pap. NE-504. 8 pp.
20. ROSS, V.R. 1982. Circling up-American style. Furnit. Manuf. Manage. 28(4): 22-24; 28(5):10-12.
21. SETZER, W.F., JR. 1987. Hardwood market report. 65(5):1-28.