CHARACTER-MARKED FURNITURE: POTENTIAL FOR LUMBER YIELD INCREASE IN CROSSCUT-FIRST ROUGH MILLS

URS BUEHLMANN†
JANICE K. WIEDENBECK†
D. EARL KLINE†

ABSTRACT

Including character marks in dimension parts of the furniture, cabinet, and dimension industries offers an opportunity to increase lumber yield substantially. However, little quantitative knowledge exists as to how the incorporation of character marks in parts influences yield when processing lumber in a crosscut-first rough mill. Using computer simulation, this study researched the theoretical attainable yield increases in a crosscut first rough mill due to the incorporation of character marks in furniture parts. Also, the performance of the crosscut-first system was compared to the performance of a rip-first system studied earlier. When character marks up to 2 inches in diameter (3.1 in. Z) are allowed in dimension parts produced in a crosscut-first rough mill, yield increased by 11.0 percent (52.7% to 63.7%) and 5.1 percent (63.8% to 68.9%) for 2A Common lumber and 1 Common lumber, respectively. Compared to the previous rip-first mill study, crosscut-first yield trends were only found to be significantly different than rip- firs when allowing character mark sizes of less than 1 inch in diameter for 1 Common lumber, with rip-first showing greater yield improvements.

Improved utilization of America's forest resources is necessary to meet the continual rise in demand for wood products. For its part, the secondary wood products industry has to find a means to improve the utilization of the available lumber resource. Several authors (e.g., 1,9) stress that increasing lumber yield is one way to offset rising lumber prices (11) and supply shortages (12).

While it is known that allowing character marks in furniture parts increases yield, the magnitude of these yield increases and the importance of the allowable character-mark size has not been established for crosscut-first systems. An earlier study (2) on rip-first rough mills found that including character marks in dimension parts results in significant yield increases. Processing 2A Common lumber (National Hardwood Lumber Association (NHLA) grades (13)) and allowing character marks on both faces up to 2 inches diameter (3.1 in?) led to a 13.8 percent rise (50.9% to 64.7%) in furniture part yield. The yield increase was 6.5 percent (50.9% to 57.4%) when character marks were allowed only on one face. For 1 Common lumber, the yield increases were 6.1 percent (65.2% to 71.3%) and 3.2 percent (65.2% to 68.4%), respectively.

Even though rip-first rough mills get more attention today, many rough mills use crosscut-first systems or combinations of both. Therefore, it is important to gain a better understanding of the yield gains achievable by the inclusion of character marks when using crosscut-first sawing systems. This report is a continuation of the character-marked furniture yield study on rip-first systems published earlier (2). However, the focus of this new report is to present findings about the influence of character-mark inclusion on yield in a crosscut-first rough mill system. Also, we compare the relative yield response of the two different rough mill systems (crosscut-first and rip-first) due to the inclusion of character marks in furniture part production. Knowing this information will enable secondary wood products manufacturers to make better decisions when evaluating product design and processing options.

OBJECTIVES

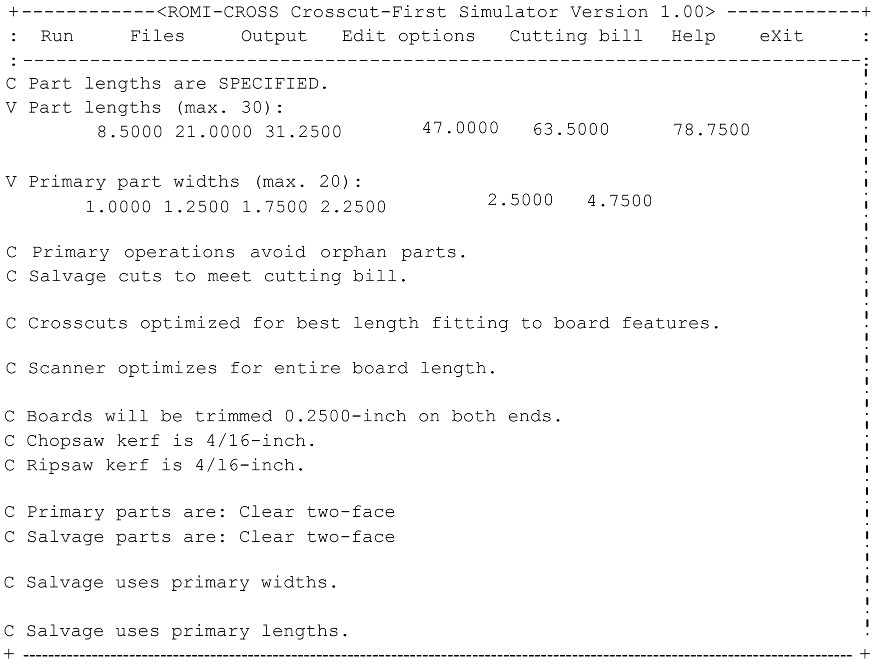
Our research objective was to predict the magnitude of the yield gain when character marks are included rather than removed from furniture and dimension parts for a

---

The authors are, respectively, Assistant Professor, Dept of Wood Sci., Univ. of British Columbia, Vancouver, BC, Canada V6T lZ4; Associate Professor of Wood Utilization, Univ. of Kentucky, Lexington, KY 40546-0073; and Associate Professor, Dept. of Wood Sci. and Forest Prod., Virginia Tech., Blacksburg, VA 24061-0323. The authors would like to thank RE. Thomas and E.S. Walker, USDA Forest Serv., Northeastern Forest Expt S13., USDA Forest Serv., Forestry Sciences Lab., Angela Neff, Dept of Statistics, Virginia Tech, and the four furniture manufacturers from Southwestern Virginia for their contributions to this project Also, thanks go to the reviewers for their helpful suggestions. This research was supported by the National Res. Initiative (NRI) Competitive Grants Program and the USDA Forest Serv., Northeastern Forest Expt. S13. This paper was received for publication in June 1998. Reprint No. 8826.

† Forest Products Society Member.

Forest Prod. 1. 49(2):65-72.



```
+------------<ROMI-CROSS Crosscut-First Simulator Version 1.00> ------------+
:  Run     Files     Output   Edit options   Cutting bill  Help    eXit     :
:---------------------------------------------------------------------------:
C Part lengths are SPECIFIED.
V Part lengths (max. 30):
        8.5000 21.0000 31.2500      47.0000   63.5000      78.7500

V Primary part widths (max. 20):
       1.0000 1.2500 1.7500 2.2500        2.5000   4.7500

C Primary operations avoid orphan parts.
C Salvage cuts to meet cutting bill.

C Crosscuts optimized for best length fitting to board features.

C Scanner optimizes for entire board length.

C Boards will be trimmed 0.2500-inch on both ends.
C Chopsaw kerf is 4/16-inch.
C Ripsaw kerf is 4/l6-inch.

C Primary parts are: Clear two-face
C Salvage parts are: Clear two-face

C Salvage uses primary widths.

C Salvage uses primary lengths.
+ ---------------------------------------------------------------------------- +
```

Figure 1. - Set-up of ROMI-CROSS simulation input; a "C" in the left margin indicates a parameter that was constant for all simulations; a "V" indicates a parameter that was varied between simulations.

TABLE 1. - *Character-mark size allowed and restrictions applied in the dimension parts.*

Test no.	Character-mark area allowed	Diameter of circular defect	Restrictions applied
	(in.^{2})	(in.)	
1	0.0000	0.00	No char. marks allowed
2	0.0616	0.28	No void allowed
3	0.1963	0.50	No void allowed
4	0.4418	0.75	No void allowed
5	0.7854	1.00	No void allowed
6	1.7671	1.50	No void allowed
7	3.1416	2.00	No void allowed
8	All	All	No void allowed
9	All	All	All char. marks allowed

crosscut-first rough mill. The specific objectives that we addressed were to:

1. Find the effect of varying character-mark sizes allowed on yield.
2. Find the effect of other factors such as lumber grade mix, part quality, and cutting bill geometry on yield.
3. Compare the performance of ripfirst and crosscut-first systems and their relative response to character-mark inclusion in parts.

METHODS

The Forest Service's rough mill yield simulation program, ROMI-CROSS (16), was used to conduct t.1-lls research. The simulation set-up was identical to the rip-first simulations reported previously (2). Figure 1 shows the set-up of ROMI*CROSS* for one of the crosscut-first simulation tests performed for this study.

The main factors tested were: 1) character-mark size; 2) lumber grade mix; 3) part quality; and 4) cutting bills. Nine different character mark sizes, ranging from no character marks allowed in the parts to all character marks allowed, were examined. Except for void, which describes crook, taper, or differential shrinkage, no distinction as to the type of character mark allowed was made. Table 1 lists the limits of the character-mark sizes allowed in the dimension parts for the different tests.

Lumber from the 1992 data bank: for red oak lumber (7) was used as the "raw material" for this study. The lumber sample (size and composition) used in this part of the study was identical to the one used for the rip-first study (2). Two different grade mixes, one consisting of 1 Common lumber and the other consisting of 2A Common lumber, were investigated.

TABLE 2. - *Description of the cutting bill geometry for the seven cutting bills used in the simulation tests.*

	Distribution		Geometry								
			Length			Width			Area		
Cutting bill	No. of sizes in cutting bill	Total no. of parts in cutting bill	Minimum	Maximum	Average	Minimum	-Maximum	Average	Minimum	Maximum	Average
			(in.)						(in.^{2})		
A	77	*1,086*	*8.50*	78.75	34.60	1.00	5.75	3.17	18.50	334.69	106.23
B	13	1,200	5.75	77.25	26.53	1.00	6.00	3.13	15.81	240.00	80.12
C	45	1,515	12.00	63.00	26.55	1.00	6.75	3.44	17.50	330.75	98.44
D	36	1,362	18.50	81.25	29.69	1.50	325	2.18	31.50	203.13	75.41
E	42	1,220	12.25	68.75	23.07	1.25	6.75	3.04	16.88	364.50	74.40
F	47	1,648	17.75	73.00	30.99	1.50	3.25	2.19	30.38	164.25	68.56
G	- 12	2,000	14.50	75.50	27.19	2.00	3.50	2.73	36.00	188.75	73.52

Part quality, in this study, refers to the location of character marks in the parts. We use the code CM2F to indicate that character marks up to the specified size are allowed on both faces of the part. CMIF indicates character marks are allowed on one face only. Datamod (17), a C-routine that manipulates the red oak board files from the 1992 data bank for red oak lumber (7), was used to control the inclusion of character marks in the parts as specified by the experimental design. The Datamod routine deletes all the character marks in the original board file that fall within the specified allowable character-mark size (**Table 1**). Thus, when the ROMI-CROSS simulation program processes the modified boards, it, in effect, is generating parts that contain character marks up to the specified size limit

Seven part listings from four furniture manufacturers were employed as cutting bills. **Table 2** shows the geometric characteristics of the cutting bills. A more detailed description of the experimental design can be found in Buehlmann et al. (2).

The comparison of the two cut-up systems (crosscut-first vs. rip-first) combined all data points from this and from the earlier study (2). Table 3 shows the experimental design for the comparison of the two systems.

Yield increase, in this study, always refers to the absolute yield gain and not to the relative yield increase compared to the last observation. Thus, an increase in yield from 60 to 65 percent will be expressed as an absolute yield increase of 5 percent ([0.65 -0.60] X 100%) and not as a relative increase of 8.3 percent ([0.65 0.60] / 0.60 x 100%). All results presented are based on the average yield results for all seven cutting bills unless otherwise indicated.

RESULTS AND DISCUSSION FOR THE CROSSCUT-FIRST SYSTEM

Multiple ANOVA testing (α = 0.05) on the 1,260 data points from the crosscut - first simulation tests showed that all four variables (part quality, cutting bill, grade mix, and character-mark size) are significant determinants of yield. The specific effects for each of these variables will be discussed in the following sections.

EFFECT OF CHARACTER-MARK SIZE ALLOWED IN DIMENSION PARTS ON YIELD

Columns 4 to 7 in Table 4 present the simulated yields and yield increases for the crosscut-first rough mill when character marks are allowed on both faces (CM1F) using 1 Common or 2A Common lumber. The results displayed are for the nine character-mark size scenarios shown in Table 1.

For CM2F part quality, an average 6.4 percent yield difference was found by including character marks up to 1 inch in diameter in parts when processing 2A Common lumber. A 2.8 percent yield increase was realized when using 1 Common lumber. Accepting character marks as large as 2 inches in diameter resulted in a 11.0 and 5.1 percent yield improvement for 2A Common lumber and 1 Common lumber, respectively. In running simulation test 9, our purpose was to establish the absolute upper bound on yield by permitting all types and sizes of character marks (including void). Simulation test 9 thus answers the question what these boards would yield if they were perfectly rectangular with no character marks and voids. For both the 1 Common and 2A Common grade mixes, this upper bound on yield was between 81 and 82 percent (**Table 4**).

Columns 8 to 11 in **Table 4** show the average crosscut-first yields and yield increases for the different charactermark increments and the two lumber grade mixes when character marks are only allowed on one board face (CMIF part quality). The 2A Common grade mix achieved a 3.7 percent higher yield when character marks up to 1 inch in diameter were allowed on one face. When the character-mark diameter was 2 inches, the yield increase observed was 5.5 percent. For 1 Common lumber, the yield increases were 1.4 and 2.2 percent, respectively.

The yield gains associated with the varying character-mark increments were tested using Duncan's Multiple-Range Test (α = 0.05). Yield differences were found to be significant for CM1F part quality when comparing 0-, 1-, and 2 inch character-mark increments. The same held true for CM1F part quality when processing 2A Common

TABLE 3. - *Overview of the experimental design for the comparison of the rip-first and the crosscut-first systems.*

Variable	No. of levels
Rip-first vs. crosscut-first	2
Part quality	2
Cutting bills	7
Grade mixes Character-	2
mark size Replications	9
Total	5
	2,520

TABLE 4. - *Average yield and yield increases for the seven cutting bills and the two grade mixes resulting from the inclusion of character marks on both faces (CM2F) and on one face (CM1F).*

	Part quality used		CM2F				CMIF			
Test no.	Character-mark area allowed	Diameter allowed	100% 1 Common	Cumulative yield increase	100%10 2A Common	Cumulative yield increase	100% 1 Common	Cumulative yield increase	100% 2A Common	Cumulative yield increase
	(in.)	(in.)	(%)							
1	0.0000	0,00	63,8		52.7		63.8		52.7	
2	0.0616	0.28	64.4	0.6	54.5	1.8	64.1	0.3	53.9	I.3
3	0.1963	0.50	64.8	1.0	55.7	3.1	64.3	0.5	54.7	2.0
4	0.4418	0.75	65.7	1.9	57.5	4.9	64.7	0.9	55.5	2.8
5	0.7854	1.00	66.6	2.8	59.1	6.4	65.2	1.4	*56A*	3.7
6	1.7671	1.50	67.7	3.9	61.7	9.0	65.6	1.8	57.5	4.9
7	3.1416	2.00	68.9	5.1	63.7	11.0	66.0	2.2	58.2	5.5
8	All, no voids		80.3	16.5	79.6	26.9	70.5	6.7	64.0	1 I.3
9	All		81.9	18.1	81.6	28.9	71.2	7.4	64.4	11.7

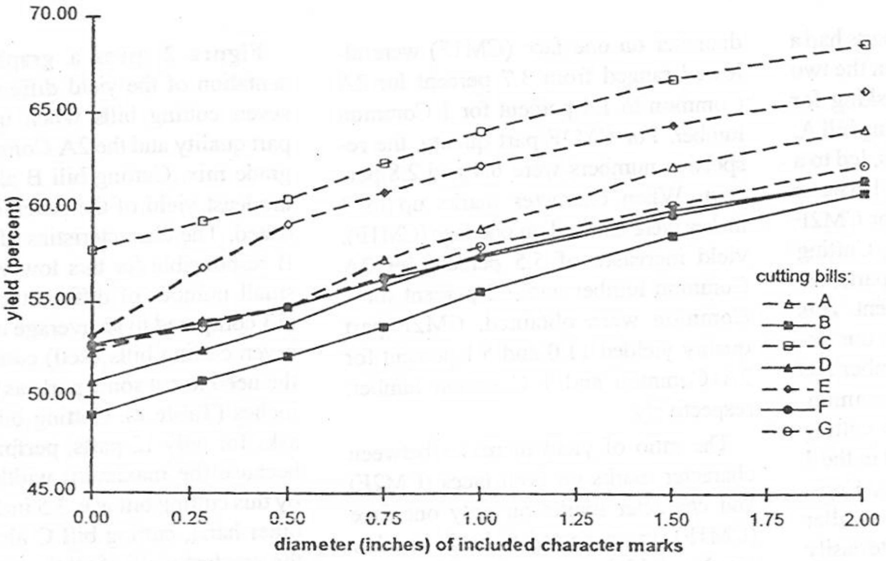


Figure 2. - Yield comparison for each of the seven cutting bills; part quality is CM2F; grade mix is 100 percent 2A Common.

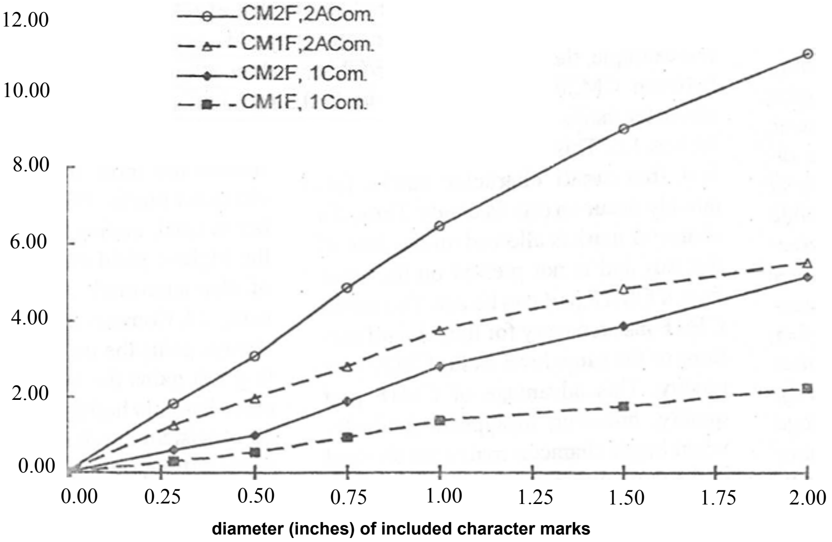


Figure 3. - Average yield increase for all seven cutting bills achieved by the crosscut-first system for 1 Common and for 2A Common lumber when allowing character marks on both faces (CM2F) or on one face (CM 1 F) only.

lumber. However, the 1 Common lumber failed to produce significant yield differences at the 95 percent significance level between 1- and 2-inch diameter increments when cutting CMIF parts. In this case, pooling the seven cutting bills introduced a large yield variability, thereby masking the relatively small main effects tested (character-mark size). Yield differences between 2-inch diameter and all character marks allowed were significant in all cases.

The coefficient of variation (COY) between individual cutting bills for the same test for 1 Common lumber ranged from a high of 4.8 percent to a low of 4.0 percent for CMIF part quality and from a high of 4.8 percent to a low of2.9 percent for CM2F part quality. For 2A Common lumber, the range was from 5.6 to 4.5 percent for CMIF part quality and from 4.3 to 2.9 percent for CM2F part quality. Inclusion of character marks on both faces (CM2F) led to slightly less variation in yield for the same test among the seven cutting bills than for the CMIF case. This is because between-board variability is reduced only on one face when cutting CM I F part quality versus two faces when cutting CM2F quality parts. Also, the average COY for 2A Common lumber is higher than the one found for 1 Common, which is due to the higher character mark density and variability in the lower lumber grade.

When we tested the effect of character-mark size on yield for individual cutting bills, we found the differences (ex = 0.05) between 0-, 1-, 2-, and all character marks increments to be significant in every case. As shown in Figure 2, different levels of yield were obtained for individual cutting bills. Moreover, the yield increased in different patterns for individual cutting bills. Some exhibited linear increases whereas others showed more curvilinear yield gains.

Character mark size was the primary factor affecting differences in yield. in this study. However, lumber grade mix, part quality, and cutting bill geometry also had a significant influence on yield.

EFFECT OF LUMBER GRADE MIX AND CHARACTERMARK SIZE ON YIELD

As expected, 2A Common lumber consistently achieved the higher yield increase due to the inclusion of character marks than did 1 Common lumber. The yield increase for 2A Common lumber was always significantly (ex = 0.05) higher than for *I* Common lumber. Lower quality lumber grades contain more character marks per board area and thus have smaller clear areas available for cuttings. Therefore, allowing character marks in parts trees up more area in lower grades. Nonetheless, the yield differential between 2A Common and 1 Common lumber was smaller than expected. When accepting no character marks on either face (i.e., clear-two-face parts), the yield difference between the two lumber grades was 11.1 percent for the seven pooled cutting bills. However, since the difference in clear cutting area between 1 and 2A Common lumber according to the NHLA rules is at least 17 percent (13), we expected this yield difference to be higher.

Cutting bills requiring large parts had a higher yield differential between the two grades than did cutting bills asking for smaller parts. For example, cutting bill A, which required many large parts, led to a yield difference of 13.1 percent between I Common and 2A Common for CM2F part quality. On the other hand, Cutting bill F, which asked for smaller parts, resulted in a difference of 9.2 percent. This observation was consistent with our expectations, since I Common lumber has larger clear areas than 2A Common. Thus, the large parts required by cutting bill A were more easily obtained in the 1 Common lumber than in the 2A Common lumber. Cutting bill F's smaller parts, on the other hand, were quite easily obtainable in the smaller clear areas found in 2A Common lumber.

Given this finding and the existing price differential between the two grades, there appeal's to be a yield advantage to using 2A Common lumber. Still, there is some concern that not enough long pieces for clear dimension parts can be obtained (6). However, 2 Common lumber should provide enough long lengths, at least up to 60 inches (5,10). Moreover, the inclusion of character marks in dimension parts promotes the recovery of larger parts. This is because the usable board areas become larger when objectionable character marks become fewer and further between. However, the economic viability of using different lumber grades depends not only on the lumber price differentials and yield potentials. Other factors like productivity, salvage operations, drying capacity, 'or lumber availability have to be considered as well.

When allowing all character marks on both faces of parts, the usable area for cuttings is the entire board. Using these boards, the average yield difference between the two lumber grades shrank to 0.4 percent (no significant difference at a; = 0.05). As expected, the larger the character marks that are accepted in parts, the more alike the yield obtained by the two lumber grades becomes.

EFFECT OF ALLOWING CHARACTER MARKS ON ONE OR BOTH FACES ON YIELD

Part quality, which refers to whether character marks are allowed on one (CMIF) or on both faces (CM2F), influenced yield significantly. Figure 3 compares the yield increases achieved for these two quality classes. Yield increases when character marks up to 1 inch in diameter on one face (CM1F) were allowed ranged from 3.7 percent for 2A Common to 1.4 percent for 1 Common lumber. For CM2F part quality, the respective numbers were 6.4 and 2.8 percent. When character marks up to 2 inches were allowed on one face (CMIF), yield increases of 5.5 percent for 2A Common lumber and 2.2 percent for 1 Common were obtained. CM2F part quality yielded 11.0 and 5.1 percent for 2A Common and 1 Common lumber, respectively.

The ratio of yield increases between character marks on both faces (CM2F) and character marks on only one face (CM 1 F) was expected to be 2. In other words, yield increases for CM2F part quality should be twice as high as for CM1F part quality. However, we found that this assumption only holds when using 1 Common lumber. For 2A Common lumber, when small character marks were allowed, CMIF part quality led to a yield increase closer to that of CM2F. For example, the ratio for yield increases between CM2F/CMIF when allowing character marks up to 0.5 inch in diameter was 1.5. This can be explained by the fact that small character marks frequently occur on one face only. Thus, if a character mark is allowed on one face of the part and is not present on the other face, a CM1F part can be cut. This raises CM 1 F part recovery for these board sections to the same level as for CM2F part quality. This advantage of CM1F part quality, however, disappears gradually when larger character marks are allowed in the parts. When 2-inch-diameter character marks are allowed, the ratio CM2F / CM1F was 2.0 for 2A Common lumber.

EFFECT OF CUTTING BILL GEOMETRY AND CHARACTERMARK SIZE ON YIELD

Cutting bill geometry is a main determinant of yield (2). All other variables held constant, the largest yield difference between two cutting bills in this study was 9.0 percent. This yield variance was found between cutting bill B (59.8% yield) and cutting bill C (68.8% yield) for 100 percent 1 Common lumber and no character marks allowed in the parts. The smallest yield difference was 0 percent between cutting bill B (54.8% yield) and cutting bill F (54.8% yield) when character marks were allowed up to 0.5 inch in diameter on both faces (CM2F) using 2A Common lumber.

Figure 2 gives a graphical representation of the yield differences of the seven cutting bills when using CM2F part quality and the 2A Common lumber grade mix. Cutting bill B always led to the least yield of the seven cutting bills tested. The characteristics of cutting bill B responsible for this low yield are the small number of different cutting sizes (13 compared to an average of 39 for the seven cutting bins used) combined with the need to cut some parts as wide as 6.0 inches (Table 2). Cutting bill G, which asks for only 12 parts, performed better because the maximum width asked for by this cutting bill was 3.5 inches. On the other hand, cutting bill C always led to the greatest yield of all the seven cutting bills tested. Cutting bill C requires a large number of different cutting sizes to be cut (45 different parts, Table 2), making it possible to find parts that fit well into the clear areas available in the boards. Thus, different characteristics of a cutting bill (part sizes, number of different parts to. be cut, number of parts to be cut of each size) in combination are responsible for the yield differences observed.

The same cutting bill does not always benefit the most from the inclusion of character marks. When 1 Common lumber is used, cutting bill B always shows the highest yield increases for all levels of character-mark sizes allowed. When using 2A Common lumber, cutting bill E always gains the most yield. Which cutting bill gains the smallest yield, on the other hand, is highly erratic. There were no consistent trends observed among the seven cutting bills as to which gained the least yield from the inclusion of different levels of character-mark sizes.

According to our initial reasoning, allowing large character marks would reduce yield differences between all the cutting bills. This was true when considering the impact of character-mark size on yields from 1 Common versus 2A Common lumber. However, Figure 2 shows that the differences in yield obtained for the seven cutting bills remain relatively constant for all character-mark size levels within the same lumber grade mix. The range in yield between cutting bills when processing 2A Common lumber with no character marks in the parts was 8.7fversus 7.9 percent when character marks up to 2 inches in diameter were allowed on both faces. From this observation we conclude that the interaction of cutting bill geometry and the geometric size of the lumber is an important factor in determining yield, too.

Yield and yield increases are dependent on cutting bill characteristics. This points to the opportunity to compose cutting bills with selected parts to obtain increased yield. However, more research is needed to understand the complex interrelationships of cutting hill characteristics that determine yield.

COMPARISON OF THE PERFORMANCE OF RIP-FIRST AND CROSSCUT-FIRST SYSTEMS

This section compares the results presented in Buehlmann et al. (2) of yields from a rip-first system with the results of a crosscut-first system shown in the previous section.

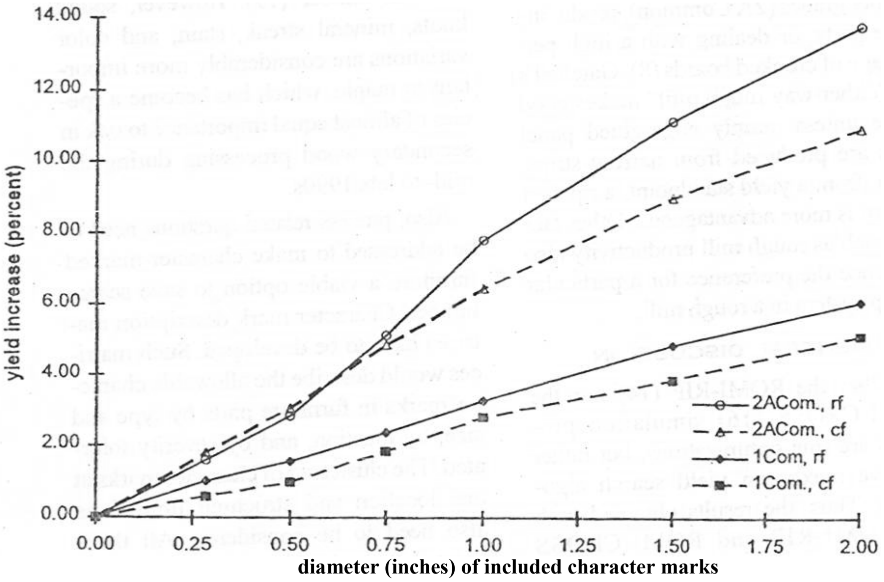


Figure 4. -Average yield increases for all seven cutting bills achieved by the rip-first (rf) and the crosscut-first (cf) systems for 1 Common and 2A Common lumber; part quality is CM2F.

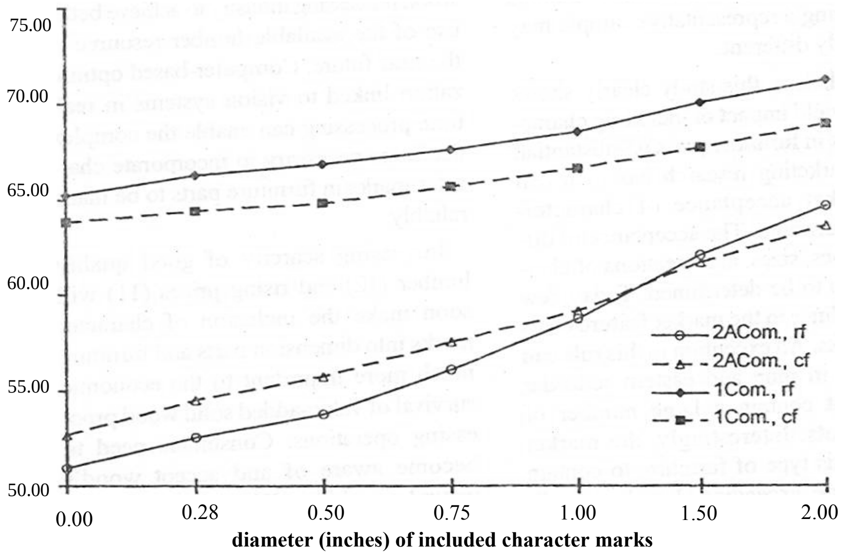


Figure 5. - Average total yield for all seven cutting bills achieved by the rip-first (rt) and the crosscut-first (cf) systems for 1 Common and 2A Common lumber; part quality is CM2F.

When looking at overall yield trends, the crosscut-first system achieved smaller yield increases from the inclusion of character marks than the rip-first system. However, when lower quality lumber (i.e., 2A Common) was used and the allowable character mark size was small (less than 0.75 in. in diameter), then crosscut-first achieved slightly higher yield than rip-first. Figure 4 shows the average, cumulative yield gains for 1 Common and 2A Common lumber for both cut-up systems when cutting CM2F parts.

According to Figure 4, the rip-first system generally derives greater benefit from the inclusion of character marks in dimension parts. However, one needs to be aware that individual cutting bills may lead to contradictory results. For example, four of the seven cutting bills performed better using a crosscut-first system than when using a rip-first system processing 2A Common lumber into CM2F parts and allowing character marks up to 1.5 inches. Therefore, the statistical variability among individual cutting bills needs to be studied to determine if the overall trend differences observed in Figure 4 are truly significant.

No statistically significant difference (a = 0.05) in the level of yield gained between the two rough mill systems was found for 2A Common lumber. Likewise, no significant differences (a = 0.05) were found between the rip-first and the crosscut-first systems for I Common lumber when the allowable character-mark sizes were greater than 0.75 inch. The main reason that we failed to detect significant differences was due to the large variability in yield for individual. cutting bills produced by the rip-first system. For character-mark sizes equal or below 0.75 inch, however, the yield increase differences between the two systems were statistically significant, with rip-first having greater yield increases than crosscut-first (a=0.05).

Figure 5 shows the average total yield obtained for 1 Common and 2A Common lumber for the two cut-up systems for CM2F part quality. Using 1 Common lumber and producing CM2F part quality in a rip-first rough mill was the solution that achieved highest total yield. For the seven cutting bills, when no character marks were allowed, the average yield was 65.2 percent compared to 63.8 for the crosscut-first system. When character marks up to 2 inches in diameter were allowed, results were 71.3 versus 68.9 percent, respectively. All these results were highly significant using two-tailed t-tests *(a* == 0.05).

When 2A Common lumber was used for CM2F part quality, however, crosscut-first usually performed better than rip-first, on average for the seven cutting bills. Crosscut-first achieved 52.7 percent yield when no character marks were allowed, versus 50.9 percent for the ripfirst system. The crosscut-first system showed higher yield than the rip-first system for character-mark sizes of up to 1 inch in diameter. Thereafter, the ripfirst system resulted in higher yield. However, these differences for charactermark sizes greater than 1 inch were not significant (a. = 0.05). Comparing individual results revealed that these observations do not apply to all cutting bills.

The rip-first system's higher yield over the crosscut-first system when using 1 Common lumber was more consistent than the crosscut-first system's higher yield over the rip-first system when using 2A Common lumber. Only one cutting bill achieved higher yield using the crosscut-first system and 1 Common lumber; all the other six cutting bills achieved higher yield using the rip-first system. For 2A Common lumber, three of the seven cutting bills performed better using the rip-first system; four did better with the crosscut-first system. These inconsistencies as to which system performs better were mainly due to the interaction of lumber quality and cutting bill geometry. The wider the widest part required in a cutting bill, the more likely crosscut-first will outperform rip-first using 2A Common lumber. This becomes evident by the fact that all four cutting bills that did better with the crosscut-first system using 2A Common lumber have parts equal to or wider than 5.75 inches. The maximum width required for the three cutting bills (D, F, and G) that performed better using ripfirst and 2A Common lumber was 3.50 inches (fable 2).

In summary; the rough mill system that produced higher. part yield was determined by the lumber grade used and two factors inherent in the cutting bill: 1) most importantly, the geometric size of the parts; and 2) the number of parts required by the cutting bill and their distribution over the whole range of geometric sizes. Yet, the exact correlation between yield, cutting bill geometry, and preferred cut-up system cannot be fully understood from this study.

Even though rip-first systems get the most attention today, crosscut-first technology is beneficial when processing low lumber grades (2A Common), producing wide parts, or dealing with a high percentage of crooked boards (8). Gatchell's (4) "either-way rough mill" makes good sense unless mainly edge-glued panel parts are produced from narrow strips. Then, from a yield standpoint, a rip-first system is more advantageous. Other factors such as rough mill productivity also influence the preference for a particular cut-up system in a rough mill.

GENERAL DISCUSSION

Neither the ROMI-RIP (14) nor the ROMI-CROSS (16) simulation programs are true optimizations, but rather iterative maximum yield search algorithms. Thus, the results obtained with the ROMI-RIP and ROMI-CROSS simulations for boards containing character marks are near optimal (15). To be able to incorporate the use of these programs into tomorrow's automated rough mill, these programs have to be validated. Also, the 1992 data bank for red oak (7) is not a statistically representative sample of the Appalachian red oak lumber on the market today (19). Results obtained when using a representative sample may be slightly different.

Nonetheless, this study clearly shows that the yield impact of including character marks in furniture parts is substantial. Now, marketing research has to reveal the market acceptance of charactermarked furniture.. The acceptance of different types, sizes, and locations of characters has to be determined. Today, few furniture lines in the market feature character marks. An exception to this rule can be found in pine and eastern redcedar suites that contain a large number of sound knots. Interestingly, the market expects this type of furniture to contain knots, some exceeding 2 inches in diameter (18). Also, veneer and, more importantly, high-pressure laminate overlaid furniture often exhibit built-in character-mark patterns as an aesthetic characteristic. For solid hardwood furniture, however, the use of character marks is largely limited to Early American, Western, and Shaker style

Western, and Shaker style furniture. Sound knots, small holes, small pitch/ gum pockets, mineral streak, slight stain, sapstain, or grain and color variations (18) are the types of character marks accepted in these furniture lines. Unfortunately, these character marks do not make up the bulk of character marks in red oak lumber (19), However, sound knots, mineral streak, stain, and color variations are considerably more important in maple, which has become a species of almost equal importance to oak in secondary wood processing during the mid- to late 1990s.

Also, process-related questions need to be addressed to make character-marked furniture a viable option to save scarce lumber. Character mark description matrices have to be developed. Such matrices would describe the allowable character marks in furniture parts by type and size, by location, and by severity tolerated. The clustering of character marks at one location and structural limitations also need to be considered. All these points have to be incorporated into a future, true yield maximization algorithm.

The ability to reliably detect and describe character marks in boards with vision systems (3) is becoming a reality. This knowledge, combined with specific information about the acceptance of character marks, will allow the secondary wood processing industry to achieve better use of the available lumber resource in the near future. Computer-based optimization linked to vision systems in realtime processing can enable the complex decisions necessary to incorporate character marks in furniture parts to be made reliably.

Increasing scarcity of good quality lumber (12) and rising prices (11) will soon make the inclusion of character marks into dimension parts and furniture much more important to the economic survival of value-added solid wood processing operations. Consumers need to become aware of and accept wood's natural variability. We are hopeful that market segmentation and promotion can transform consumer perceptions of wood defects so that many character marks come to be valued as marks of wood's uniqueness .and beauty and market acceptance of character-marked furniture can be achieved.

CONCLUSIONS

Accepting character marks in furniture parts increased yield significantly in a crosscut-first rough mill. Allowing character marks up to 2 inches in diameter on both faces of parts increased yield by 11 percent (52.7% to 63.7%) using 2A Common lumber. Yield increased 5.1 percent (63.8% to 68.9%) for 1 Common lumber. Respective yield gains were 6.4 percent (52.7% to 59.1%) and 2.8 percent (63.8% to 66.6%) when the allowable character-mark size was no larger than 1 inch in diameter. When accepting character marks up to 2 inches in diameter on one part face only, yield increases were 5.5 percent (52.7% to 58.2%) for 2A Common lumber and 2.2 percent (63.8% to 66.0%) for 1 Common lumber. With a reduced character-mark size to no larger than 1 inch, yield was up by 3.7 percent (52.7% to 56.4%) and 1.4 percent (63.8% to 65.2%), for 2A Common and 1 Common lumber, respectively.

Yield gains from the inclusion of character marks were related to the size of the character marks. Overall yield, though, was also dependent on cutting bill geometry, lumber grade-mix, and cut-up technology (crosscut-first or rip-first). The influence of character-mark types on yield was not part of this study.

Yield trends for the crosscut-first system were usually lower than those for rip-first systems when including character marks. Overall yield, however, was not always less when using a crosscutfirst system. Crosscut-first yield trends were slightly higher when low-quality lumber (lA Common) was used and only small character marks (less than 0.75 in. in diameter) were allowed in the furniture parts. Using statistical comparison procedures, however, observed yield trends were only found to be significantly higher in the case of rip-first when allowing character mark sizes of less than I inch in diameter for 1 Common lumber.

LITERATURE CITED

1. Brunner, C.C., DA. Butler, A.G. Maristany, and D. Vanleeuwen. 1990. Optimal clear-area sawing patterns for furniture and millwork blanks. Forest Prod. J. 40(3): 51-56.
2. Buehlmann, U., J.K. Wiedenbeck, and D.E. Kline. 1997. Character-marked furniture: Potential for lumber yield increase in rip first rough mills. ForestProd. J. 48(4):43-50.
3. Conners, R. W., D.E. Kline, PA Araman, andT.H.Drayer.I997.Machinevisiontechnology for the forest products industry. IEEE Computer Innovative Technology for Computer Professionals 30(7): 43-48.
4. Gatchell,C.J.1987.Rethinking the design of the furniture rough mill. Forest Prod. I 37(3):8-14.
5. ________1989. Recognizing interac tions among lumber grading rules, gang-ripping technology, and industry needs could increase the use of No. 2 Common lumber. Forest Prod. J. 39(2):33-37.
6. ________, R.B. Anderson, and P.A. Araman. 1983. Effect of gang-ripping width on CIF yields from No.2 Common oak lumber. Forest Prod. J. 33(6):43-48.
7. ________, J.K. Wiedenbeck, and E.S. Walker. 1992. Forest Service 1992 databank for red oak lumber. Res. Pap. NE-669. USDA Forest Serv., Northeastern Forest Expt Sm., Radnor, Pa. 47 pp.
8. __________, _______,and_________.1996. The effects of crosscutting before gang-ripping on dimension part yields from No. 1 and 2A Common red oak lumber. Forest Prod. J. 46(2): 61-66.
9. Lamb, F.M. 1994. Rough mill optimization: The reasons why. Wood Digest. August 1994:28-31.
10. Lucas, E.L. 1973. Long length cuttings from No.2 Common hardwood lumber. Res. Pap. NE-248. USDA Forest Serv., Northeastern Forest Expt Sm., Broomall, Pa.
11. Luppold, W.G. and J.E. Baumgras. 1995. Price trends and relationships for red oak and yellow-poplar stumpage, sawlogs, and lumberin Ohio: 1975-1993.NorthernJ. ofAppl. Forestry 12(4):168-173.
12. _____________and G.P. Dempsey. 1996. Is eastern hardwood sawtimber becoming scarcer? Northern J. of Appl. Forestry 13(1):46-49.
13. National Hardwood Lumber Association. 1998. Rules for the measurement and inspection of hardwood and cypress. NHLA, Memphis, Tenn.
14. Thomas,R.E.1995.ROMl-RIP: Rough mill rip-first simulator user's guide. Gen. Tech. Rept. GTR-NE-206. USDA Forest Serv., Northeastern Forest Expt Sta., Radnor, Pa. 72pp.
15. __________.1996. Personal interview. USDA Forest Serv., Northeastern Forest Expt Sta., Princeton, W. Va.
16. ___________. 1997. ROMl-CROSS:Rough mill crosscut-first simulator. Gen. Tech. Rept GTR-NE-229. USDA Forest Serv., Northeastem Forest Expt. Sta., Radnor, Pa.
17. Walker, B., U. Buehlmann, and J. Wiedenbeck. 1995. Datamod: A program to manipulate the 1992 red oak data bank files. Unpublished program. USDA Forest Serv., Northeastern Forest Expt. Sta., Princeton, W.Va.
18. Wiedenbeck, J. and U. Buehlmann. 1995. Character-marked furniture: The yield picture. *In:* Proc. of the 23rd Ann. Hardwood Symp. National Hardwood Lumber Assoc., Memphis, Tenn. pp. 85-90.
19. _________, C.J. Gatcl1ell, and E.S. Walker. 1995. Quality characteristics of Appalachian red oak lumber. Forest Prod. J. 45(3):45-50.