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

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

ABSTRACT

The inclusion of character marks in furniture parts increases part yield at least as much as previously estimated by industrial practitioners and scientists specializing in yield efficiency. However, character-marked furniture is uncommon in the more popular North American furniture species and designs. Opportunities for extending the hardwood resource associated with using more of wood's natural character in secondary wood products can be more easily implemented today than a decade ago, given the advent of computer-supported sawing systems. In this study, the yield increases associated with including character marks on furniture parts were evaluated. We assessed gang-rip-first processing yields for seven furniture cutting bills using the USDA Forest Service's ROMI - RIP simulator. The yield increase associated with the inclusion of character marks in furniture parts depends on the size of the character allowed, the type of character, one-face versus both-face quality provisions, the lumber grade mix, and the cutting bill. Yield increases were highest when cutting 2 Common lumber into parts that allow character marks as large as 2 inches in diameter on both faces (13.8 percentage points higher yield than for clear parts). For a scenario that represents a less ambitious change from current practices, the yield obtained when cutting 2 Common lumber into parts that allow character marks as large as 1 inch on only one face was 3.9 percentage points higher than when cutting clear parts.

The furniture, component parts, and cabinet industries consume an estimated 28 percent of the hardwood lumber produced in the United States (6). Increasing public pressure to reduce timber harvesting and increasing raw material prices are forcing the wood industry to search for better ways to use the available resource. Each I percent increase in rough-mill yield will reduce hardwood timber demand by about 0.2 percent, assuming a typical sawmill recovery rate of 50 to 60 percent (14). For the industry, a more immediate impact of a small rough-mill yield increase is considerable raw material cost savings.

Today timber availability is constrained by forces not under the control of the wood industry. Also, alternate species are already heavily utilized, and the lumber supply from outside the United States (e.g., tropical lumber) is often restricted by environmental concerns. Therefore, yield improvements in the rough mill are the only remaining way for the component-parts industry to impact the availability of lumber. To produce the correct number of parts in the most economical way, the industry has developed and adopted advanced technologies and systems. However, the exclusion of character marks in dimension parts limits the achievable yield to below 75 percent for I Common or lower grade lumber.

A major reason for less than optimal yield when cutting dimension parts from lumber is the exclusion of character marks (commonly referred to as "defects") in the board area. Since "defects" are part of wood's natural variability, we prefer to use the term "character marks." Also, the definition of what constitutes a defect is highly variable from one company to the next, and the perception of what is or is not acceptable character varies widely between operators (3,4). With the average lumber size and quality of the available resource decreasing, the impact of character marks on yield becomes more important.

The authors are, respectively, Graduate Research Assistant, Dept. of Wood Sci. and Forest Prod., Virginia Tech, Blacksburg, VA 24061-0323; 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, V A 24061-0323. The authors would like to thank R.E. Thomas and B.S. Walker, USDA Forest Serv., Northeastern Forest Expt. Sta., Angela Neff and Greg Ligozio, Dept. of Statistics, Virginia Tech, and the four furniture manufacturers from Southwestern Virginia for their contributions to this project. Also, thanks to Phil Mitchell, Dept. of Wood and Paper Sci. at North Carolina State Univ. and an anonymous reviewer for their helpful suggestions. This research was supported by the National Research Initiative (NRI) Competitive Grants Program and the USDA Forest Service. This paper was received for publication in June 1997. Reprint No. 8681.
† Forest Products Society Member.
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Forest Prod. J. 48 (4):43-50.

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+ ------------------------------------------------- <ROMI-RIP Main> ------------------------------------------------- +
|    Run        Files          Output      Edit options          Cutting bill          Help      eXit          |
: ------------------------------------------------------------------------------------------------------------------ :

C Part lengths are SPECIFIED.

V Part lengths (max 30):
          8.50     17.50     22.75      30.50     42.75     60.50     78.75

V Primary part widths (max. 10):
          1.00      1.25      1.75       2.25      2.50      3.00      3.50      4.25

C Primary Operations AVOID ORPHAN PARTS.

C Arbor type is ALL-BLADES-MOVABLE
C Arbor has 15 spacings defined.
C Processing board from RIGHT edge of board to LEFT edge

C Boards will be edged 1/4-inch on both sides. C Boards will be trimmed
1/4-inch on both ends.

C Salvage uses primary widths.

C Salvage uses primary lengths.
+ ------------------------------------------------------------------------------------------------------------------ +
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Figure 1. - Set-up of ROMI-RIP 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.

Allowing character marks in dimension parts promises the biggest untapped opportunity to increase yield since it effectively increases the usable area of the board. However, the complexity of detecting, classifying, and deciding which character to include can be overwhelming for an operator in a manual sawing system when a normal level of throughput must be maintained (4). With the advent of vision systems with automatic yield maximization, more intelligent inclusion of character marks in parts becomes possible. The cutting of more parts that have character marks on only one face or in hidden locations can be readily accomplished on these new saws utilizing grade-mark readers. These new sawing systems also allow the cutting of different part qualities because operators no longer have to make cutting length decisions. Yet, many companies have been slow to implement mixed-quality specifications in cutting bills. This study points to the magnitude of the opportunity costs these companies are incurring, i.e., yield benefits associated with adopting clear one-face specifications on parts can be a primary benefit of these new optimizing saws.

Market acceptance of charactermarked furniture is the crucial determinant of the economic viability of including characters in furniture parts. For many designs, the inclusion of character marks on one face, the obscure face, is acceptable. The inclusion of character marks on both faces is currently acceptable for only a few designs in the most popular species (oak, maple, ash, cherry). However, if design team members from operations can substantiate the material loss and costs associated with clear, color-matched designs, then perhaps furniture designers will work harder to contrive alternate designs that utilize wood's character more intelligently.

A stronger influence weighing in on designers comes from recent marketing research results. Ozanne and Vlosky (9) found that 62 percent of U.S. homeowners with incomes of at least $30,000 expressed a willingness to pay a premium for environmentally certified furniture. This significant consumer segment holds an attitude that can be tapped into in design, marketing, and promotion efforts for character-marked furniture. A second phase of this study that is also supported by the USDA Competitive Grants Program will focus on the market acceptance of character-marked furniture. This marketing study will measure how information on the yields associated with various character-mark inclusion levels might affect buying behavior for various consumer and retail buyer segments.

With regard to operations, knowing the potential yield gain is a critical piece of information in finding an economic balance among lumber cost, system cost, character mark repair cost, and acceptable product quality (3). This study investigates potential yield gains associated with different character mark size limits when processing red oak lumber in a gang-rip-first rough mill system. The gang-rip-first system is usually more highly automated than the crosscut-first system and has become the preferred processing system in recent years. In gang-rip-first cutting operations, character and quality decisions are made on strips rather than full-width boards so operators (markers) can more easily distinguish between marginal character marks. Thus, gang-rip-first rough mill yields in cutting character-marked parts for furniture merit primary treatment in our research.

OBJECTIVES

The overall objective of this study was to assess the potential for improved utilization (yield) of the red oak resource by acceptance of character marks in furniture component parts. This paper will focus on potential yield increases resulting from the inclusion of character marks when using a gang-rip-first rough mill system.

To study the overall objective, the following sub-objectives were addressed: 1) effect of character-mark size allowed in dimension parts on yield; 2) effect of the interaction between lumber grade mix and character-mark size on yield; 3) effect of allowing character marks on one or both faces on yield; and 4) effect of the interaction between cutting bills and character-mark size on yield.

METHODS

The experimental procedures in this study involved the simulation of rip-first rough mill lumber cut-up operations for different sizes of character marks allowed in the cuttings. The simulations were performed using the ROMI-RIP (10,11) rough mill simulation program (Version 1.10).

RIP-FIRST ROUGH MILL YIELD SIMULATION

The ROMI-RIP (Rough Mill RIP-first simulator) rough mill yield simulation program (10,11) offers many user-specified set-up options. In this study, we simulated maximum possible yield using the most advanced cut-up technique available today. This system included an all-blades-movable arbor, dynamic exponential cutting bill part prioritization, and smart salvage operation. The ROMI-RIP set-up used in these rip-first simulation tests is shown in Figure 1.

TABLE 1. - *Description of the cutting bill geometry for the seven cutting bills used in the simulation tests.*

Cuttmg bill	No. of sizes in cutting bill	Total no. of parts in cutting bill	Length			Width			Area		
			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	3.25	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

LUMBER

Red oak lumber was used in this research. Red oak lumber accounts for 27 percent (7) of the wood used for furniture manufacturing in the United States and is thus the most important species used. The lumber was attained from the USDA Forest Service 1992 Data Bank for Red Oak Lumber (1).

Choosing the lumber sample size was an important consideration for this study. The amount of lumber demanded to fulfill a cutting bill influences the yield obtained. For example, a small cutting bill asking for a few parts only needs 32 boards and gives a yield of 61.1 percent. The same cutting bill, but with a proportionally increased number of parts required, consumes 894 boards to satisfy the demand, and gives a yield of 66.3 percent. This increased yield for larger cutting bills is due to the possibility of better matching the board area available to the parts demanded when more boards are processed.

Iterative testing of different cutting order sizes on yield revealed that yield changed only insignificantly when at least 150 boards were required to obtain all the parts demanded. ANOVA and Duncan's multiple-range test showed that the difference in yields for 150 boards and larger quantities of boards are not statistically significant (ex = 0.05). Therefore, all seven cutting orders were set such that at least 150 boards were used in each simulation test.

CUTTING BILLS

Before starting the simulation tests, seven cutting bills were obtained from four furniture manufacturers in southwestern Virginia. These cutting bills were for bedroom and entertainment suites. Because the 1992 Data Bank for Red Oak Lumber (I) contains only 4 by 4 red oak lumber, predominantly parts with a thickness of 4 by 4 and a very small percentage of smaller thicknesses were used. Additionally, no cutting widths greater than 6.75 inches were used; such parts typically come from glued-up boards. Some of the actual cutting bills included too many different length and width groups for the simulation to handle; ROMI-RIP's cutting bill matrix is limited to 30 different part lengths and 10 different part widths (10, 11). If the number of lengths in the bill exceeded 30, the number of lengths was reduced by clustering the lengths that were closest to each other, and the longest length was used to represent this group in ROMIRIP. For example, if a cutting bill demanded 25 parts of length 17.5 inches and 10 parts of length 18.0 inches, the cutting bill entered into the simulation would ask for 35 parts (25 + 10) of length18.0 inches. This way, all the parts required by the cutting bill can ultimately be obtained in their exact size. Similarly, we clustered widths when required to limit the total number of different widths in the cutting bill to 10. Table 1 gives an overview of the characteristics of the cutting bills used.

TABLE 2. - *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

Since the objective was to find out the yield gains achievable for primary parts asked for in the cutting bill, yield cuttings or quantity cuttings, i.e., cuttings that are not part of the specific order but will go into inventory, were not allowed in the simulation. Edge-glued panels, finger jointing, and other techniques used to increase yield also were excluded from consideration.

CHARACTER MARKS

In the furniture, kitchen cabinet, and dimension manufacturing industries, the allowable character-mark size is often described as a circular area (3), thus the allowable character-mark area for this study was determined accordingly. An often-heard measure in the companies visited, for example, was "not to exceed the size of a quarter" (14), that is about 1 inch in diameter. Table 2 shows the limits of the character-mark size allowed in the dimension parts and the restrictions for the character-mark types. Note that tests 8 and 9 were used to quantify the amount of yield possible if all non-void character-marks (test 8) and all character-marks including

void (test 9) were allowed. These tests were used to establish the theoretical upper bound on yield when considering character marks. Each grade mix and face treatment simulation (character marks allowed on both or only on one face) was submitted to these nine character-mark size treatments.

According to the research objective to estimate maximum possible yield gains associated with allowing character marks in dimension parts, the type of character mark allowed in the parts was not restricted. The sole restrictive determinant was the area of the character marks allowed. Only void, which describes crook, taper, or differential shrinkage, was excluded as usable area for eight of the nine character-mark setups used. Wane, a character mark identifying an area less than full board thickness, was not excluded as usable area and thus allowed in dimension parts according to the size restrictions imposed for each test. Wane is usually a large character mark. The average size of wane as found in the 1992 Data Bank for Red Oak Lumber (1) was 16.1 in.2 for 1 Common lumber and 16.6 in.2 for 2A Common lumber. This is well above our maximum allowable character mark area of 3.2 in?

TABLE 3. - *Overview of the experimental design for the rip-first simulation.*

Variable	No. of levels
Part quality	2
Cutting bills	7
Grade mixes	2
Character-mark sizes	9
Replications	5
Total	1,260

Therefore, wane was included only if its size was very small and void therefore unlikely to be present.

Since the ROMI-RIP simulation program does not allow specification of character-mark size in the detail needed, a C-routine was written to manipulate the red oak board files from the 1992 Data Bank for Red Oak Lumber (1). The program, called Datamod (12), allows the specification of 1) the allowable size of the character marks; 2) the face on which the character marks are allowed (both faces, face one, or face two); and 3) the type of character marks accepted in the dimension parts. The Datamod routine creates a new board file where all the character marks listed in the original board file that fall within the specified allowable range are deleted. Thus, when the rough mill simulation program processes the newly created board file, the deleted character marks are no longer listed and the area is considered clear area.

Two different character-mark quality specifications were used. First, the case when all character marks up to the specified size (tests 1 through 9) are allowed on both faces of the dimension parts was researched. Second, only character marks up to the specified size on one face were allowed, having the other face 100 percent free of character marks (clear-one-face parts). In the second case, Datamod adjusted the worse face of the board. Note that clear-one-face cuttings were based on this simplistic approach rather than exhaustive board flipping. Therefore, one might expect slightly higher yield results for the one face clear quality parts when board flipping is performed.

GRADE MIX

We used two different lumber grades in our investigations. The most important grades used in the furniture industry today are 1 Common and 2A Common lumber; therefore these two grade mixes were chosen.

SUMMARY OF VARIABLES

Table 3 summarizes all of the simulation experiments presented in this paper. To assure statistically valid results, each simulation test was repeated five times with another set of boards randomly selected from the 1992 Data Bank for Red Oak Lumber (1).

A note on the technology used in this paper is necessary here. Yield, in this publication, refers to the relative surface area of the parts recovered from the original surface available (shrinkage not included). Yield increase always refers to the absolute yield increase (the difference) as observed by running the simulation and not to the relative increase in yield as compared to the former observation. For example, if the yield in the first simulation test was 60 percent and in the second test 65 percent, the yield increase will be expressed as an absolute increase of 5 percent (0.65 - 0.60) and not as a relative increase of8.3 percent ([1.0 / 0.6 x 0.65] - 1.0).

Also, the following notation is introduced for the remainder of the paper: CM2F refers to character marks allowed on both faces, CMIF refers to character marks allowed on one face often referred to as clear-one-face (CIF). However, the clear one face (CIF) terminology is used without referring to the size of the character marks on the non-clear face. Therefore, the term CM 1 F is used in

TABLE 4. - *Average yield and yield increases from the inclusion of character marks for 1 Common and 2A Common lumber for the seven cutting bill-f, with character marks allowed on both faces (CM2F) and on one face only (CMIF).*

			CM2F				CMIF			
Test no.	Character-mark area allowed	Diameter allowed	100% 1 Common	Cumulative yield increase	100% 2A Common	Cumulative yield increase	100% 1 Common	Cumulative yield increase	100% 2A Common	Cumulative yield increase
	(in.^{2})	(in.)	(%)							
1	0.0000	0.00	65.2		50.9		65.2		50.9	
2	0.0616	0.28	66.3	1.0	52.5	1.6	66.0	0.8	51. 9	1.0
3	0.1963	0.50	66.8	1.6	53.8	2.8	66.2	1.0	52.8	2.0
4	0.4418	0.75	67.6	2.4	56.1	5.1	66.8	1.5	53.6	2.7
5	0.7854	1.00	68.5	3.3	58.8	7.8	67.2	1.9	54.7	3.9
6	1.7671	1.50	70.1	4.8	62.1	11.2	67.7	2.5	56.3	5.4
7	3.1416	2.00	71.3	6.1	64.7	13.8	68.4	3.2	57.4	6.5
8	All, no voids		82.8	17.6	82.2	31.2	75.1	9.8	66.5	15.6
9	All		84.5	19.3	84.4	33.5	76.8	11.5	68.5	17.6

this paper to indicate that the character marks on the non-clear face are restricted in size according to the set-up of the particular simulation test.

RESULTS AND DISCUSSION

Multiple ANOVA testing(a=0.05) on the 1,260 data points obtained from the simulation tests revealed that all four variables (part quality, cutting bill, grade mix, and character mark sizes) are significant determinants of yield.

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

Character marks allowed on both faces (CM2F). - In the case of a rip-first rough mill where character marks are allowed on both faces (CM2F), columns 4 to 7 in **Table 4** show the yield increases for different sizes of allowable character marks using 1 Common and 2A Common lumber grades. These yield results are based on an average when all seven cutting bills are pooled.

As expected, the lower grade mix used (2A Common) shows the most significant increase in yield when allowing character marks on both faces. A 7.8 percent increase in yield can be expected if character marks up to 1 inch diameter are allowed, while a 13.8 percent yield increase can be expected when character marks up to 2 inches diameter are allowed. The yield increase for the better grade mix (1 Common) was found to be 3.3 percent for character marks up to 1 inch diameter and 6.1 percent for character marks up to 2 inches diameter. Note that for both lumber grades, if all boards were perfectly rectangular with no defects (as simulated in test 9), the upper bound on yield is approximately 84 percent.

The variance in yield between cutting bills as measured by the coefficient of variation (COY) within each charactermark increment and grade mix ranged from 1.7 percent to 12.0 percent. The highest COY occurred when cutting clear two face parts (test 1) from the lowest grade mix (2A Common). A higher COY makes it harder to detect significant differences between character-mark increments. Also, from a practical standpoint, having a high COY indicates that the expected yield for a particular cutting bill may deviate significantly from the result shown. Generally, a lower COY occurs between cutting bills when the allowable character-mark size increases, when a better grade mix is used, or when both are combined.

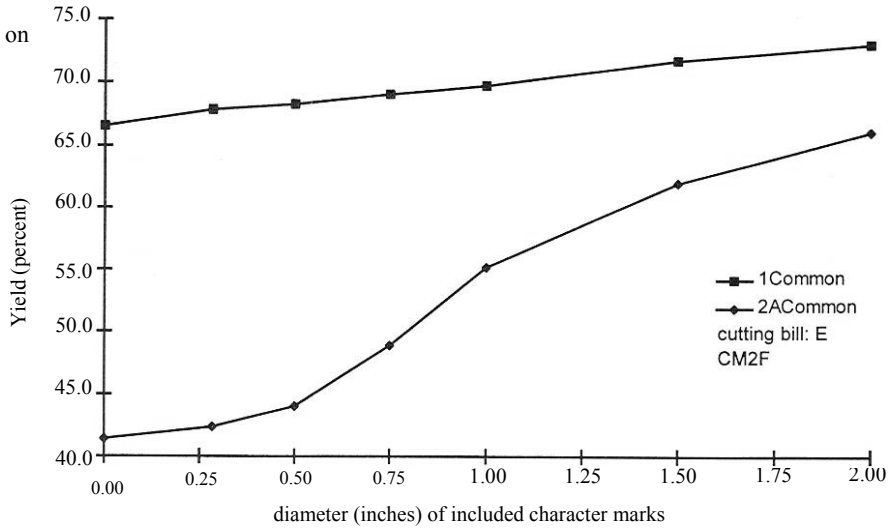

Figure 2. - Yield comparison for cutting bill E when using 1 Common or 2A Common lumber; part quality CM2F.

Using Duncan's multiple-range test at the 95 percent level, significant differences between yields for different character-mark increments can be detected when 0-, 1-, and 2-inch diameter, and all character marks are allowed in the parts. However, for smaller size character-mark increments, significant differences depend upon grade mix and cutting bill. In the best grade mix used (1 Common), it is most difficult to detect significant differences between smaller character-mark increments since the corresponding yield increase is smallest.

The change in yield for different character-mark sizes allowed is not always proportional to the increase in allowable character-mark size. The change depends on cutting bill and grade mix. **Figure 2** shows the yield increase for cutting bill E when using 1 Common and 2A Common lumber. The yield increase for the 1 Common grade mix is steady and approximately proportional to the increase in allowable character-mark size. This behavior is typical for most of the results obtained. However, for the case of 2A Common grade mix, the increase in yield is not proportional to the increase in allowable character-mark size. Although cutting bill E demonstrates an extreme case, other cutting bills show inconsistent yield increases when processing 2A Common lumber as well.

Character-marks on one face (CMIF). - Columns 8 to 11 in Table 4 show the rip-first yields and yield increases for the different character-mark increments and the two lumber grade mixes where character marks are only allowed on one board face (CMIF). These yield results are based on an average when all seven cutting bills are pooled.

For the 2A Common grade mix, a 3.9 percent higher yield is achieved when character marks up to 1 inch diameter are allowed on one face of the parts (CMIF). For character marks up to 2 inches diameter, a 6.5 percent yield increase is achieved for CMIF, compared to 13.8 percent for CM2F. For 1 Common lumber and CMIF, the yield increase is 1.9 percent and 3.2 percent, respectively, when character marks up to 1 inch and 2 inches diameter are allowed. Except for one case, Duncan's multiple-range test at the 95 percent level shows that all yields for 0-, 1-, 2-inch, and all character-mark inclusion increments are significantly different.

Variation of the yield between individual cutting bills within a particular character-mark size was somewhat higher for CMIF than for the CM2F case. The COY for the seven different cutting bills ranged from 2.1 percent to 12.1 percent (compared to 1.7 to 12.0% COY for CM2F), This tendency makes sense since allowing character marks on both

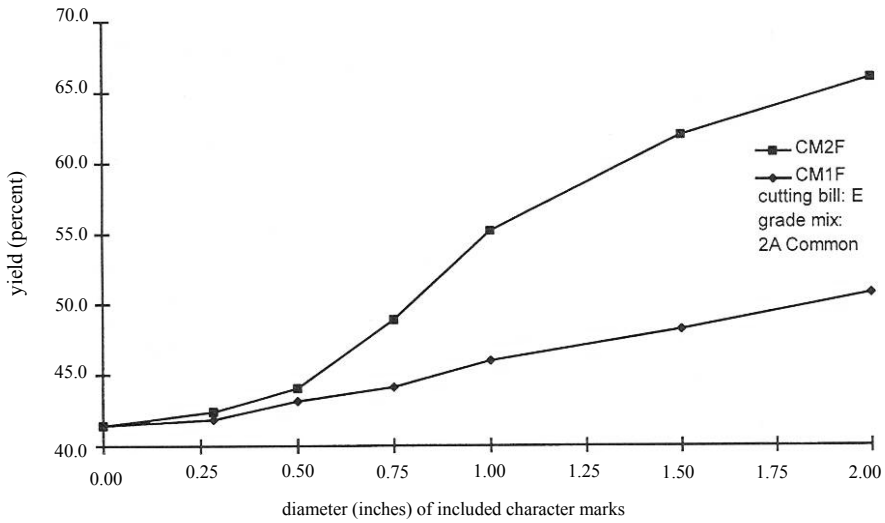

Figure 3. - Yield comparison for cutting bill E; 2A Common lumber; part qualities CM2F and CM 1 F.

faces will always reduce variability between boards more compared to allowing character marks on one face only.

EFFECT OF THE INTERACTION BETWEEN LUMBER GRADE MIX AND CHARACTER-MARK SIZE ON YIELD

Lumber grade mix is a strong determinant of the potential yield increase due to the inclusion of character marks in dimension parts. Using a one-tailed t-test with unequal variances (a. = 0.05), 2A Common yield increases were found to be significantly higher than 1 Common when I-inch, 2-inch, and all character marks were allowed in the parts. This applies for CM2F as well as for CMIF part quality. **Table 4** shows the average cumulative yield increases for the different allowable character-mark increments for 1 Common and 2A Common lumber and both part qualities.

As a rough rule, yield increases due to the inclusion of character marks were twice as big when using 2A Common lumber compared to I Common lumber. However, the difference between the 2A Common and 1 Common yield increases attributable to the inclusion of larger character marks was smaller when character marks were only allowed on one face (CMIF). For the CMIF case, the potential for yield increase due to the inclusion of character marks is restricted because one board face always retains all character marks as unusable board area.

Table 4 also shows that the yield differences between different grade mixes largely disappeared when larger character marks were allowed in the dimension parts. When all character marks were allowed on both faces (test 9), meaning that the boards were viewed by the ROMIRIP program as clear rectangles although character marks were present (for the CM2F-case), the difference in yield obtained between I Common and 2A Common shrank to an insignificant 0.1 percent.

Gatchell (2) states that according to the National Hardwood Lumber Association's (NHLA) rules (8), the theoretical minimum potential yield increase between I Common and 2 Common lumber is 17 percent. From a clear-face cutting area perspective, yield differences smaller than 17 percent indicate that 2A Common uses the boards better relative to the NHLA grade rules (8). On average for the seven pooled cutting bills, the largest yield difference measured between I Common and 2A Common in this study was 14.3 percent when no character marks were allowed (test I). This result indicates that the 2A Common lumber grade performs better than expected according to the grading rules.

However, there are cutting bills that favor the use of I Common lumber. For example, when no character marks are allowed on either face (test I), the yield difference between I Common and 2A Common ranged from 25.1 to 9.3 percent for different cutting bills. Most importantly, the larger the size of character-marks accepted in the parts, the more economically feasible it is to utilize 2A Common lumber to produce dimension parts.

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

CM2F does not always, as one may assume, lead to twice the yield increase compared to CMIF. The ratio varies according to character-mark size and grade mix. As a rough rule, the yield increase when allowing small character marks (diameter 0.5 in. or less) averaged approximately 1.5 times higher for CM2F compared to CMIF. When the character-mark diameter was above 0.5 inch, the yield increases for the CM2F part quality were approximately two times the ones for CMIF part quality.

Most small character marks are more likely to be present only on one face, so allowing them on either one or both faces of the parts has a different impact on yield. Wane is another character mark that predominantly occurs on one face and can affect the CM2F/CMIF rule-of thumb just stated. In general though, the larger the character mark, the more likely it will be present on both faces. Thus, allowing larger character marks on either one or both faces leads to greater yield gains for CM2F compared to CMIF parts. **Figure 3** illustrates the CM2FCMIF character-marked cutting yield relationships.

EFFECT OF THE INTERACTION BETWEEN CUTTING BILLS AND CHARACTER-MARK SIZE ON YIELD

The geometric characteristics of individual cutting bills are a main determinant of the resulting yield when cutting up lumber. Geometric characteristics include not only part sizes and number of parts, but also the distribution of part sizes. **Table 1** shows that the geometric characteristics of the cutting bills used in this study were very different. Therefore, we were not surprised to find large variations in yield obtained. The maximum yield variation between any two of the seven cutting bills was 16.4 percent for cutting bills E (41.8% yield) and F (58.2% yield) when processing 2A Common lumber and including character marks up to 0.28 inch in diameter on one face (CMIF). The minimum yield difference between the seven cutting bills was found for 1 Common lumber when character marks up to 1.5 inches were allowed on both faces (CM2F). The yield difference in

this case was 4.0 percent between cutting bill B (67.8% yield) and cutting bill E (71.8% yield).

Figure 4 shows the yields for each of the seven cutting bills when 0- up to 2-inch diameter character marks were allowed on both faces of the parts (CM2F) using 2A Common lumber. Duncan's multiple-range test at the 95 percent significance level revealed that the difference between the lowest yielding and the highest yielding cutting bill is significant in every case. In fact, with only a few exceptions, the yield results for the different cutting bills for each grade-mix/part-quality set-up were found to be significant.

The geometric parameters of a cutting bill influence the potential for yield increases and, therefore, a given cutting bill does not always produce the maximum or minimum yield. However, when considering the results of allowing either 0-, 1-, or 2-inch diameter character marks, three cutting bills (B, C, and E) result in minimum yields and three cutting bills (D, E, and F) result in maximum yields depending on grade mix and part quality (CM2F vs. CMIF). In fact, sometimes a cutting bill can result in minimum and maximum yield for the same set-up with the only change being the character-mark sizes allowed in the parts (cutting bill E, Fig. 4).

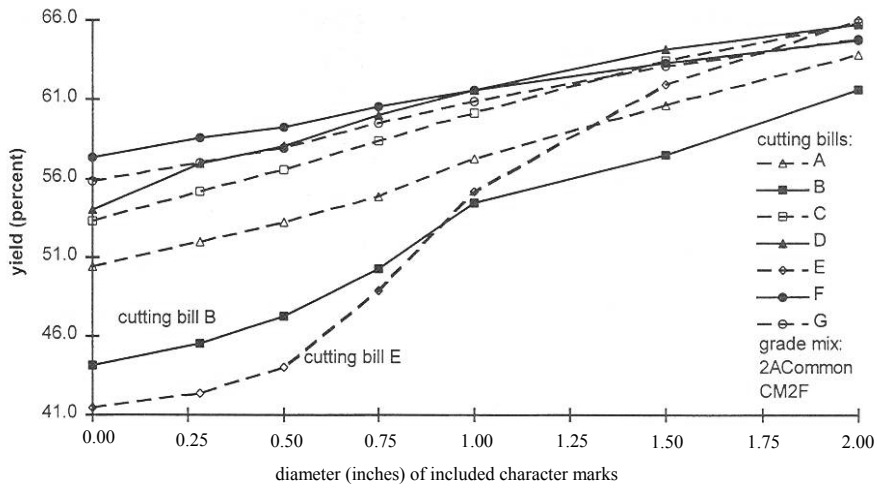

Figure 4. - Yield comparison for each of the seven cutting bills; 2A Common grade mix; part quality CM2F.

GENERAL DISCUSSION

West and Hansen (13) predict a growing segment of consumers that will favor wood due to its natural beauty, but most of them are also increasingly concerned about environmental issues. Thus, the inclusion of character marks in furniture is viewed as an opportunity to create unique products *"which can be marketed for their natural beauty and distinctiveness"* (13). The character marks allowed in furniture parts today are sound knots (some with small holes or pits), small holes (for example worm holes), small pitch/gum pockets, mineral streak, slight stain, sapstain, or grain and color variation (5,13,14). Unfortunately, these are not the ones making up the majority of character marks in red oak lumber. For the lumber in the 1992 Data Bank for Red Oak Lumber (1), unsound knots, bark pockets, wane, and split are the most common character marks. Unsound character marks in the boards contained in the 1992 Data Bank for Red Oak Lumber take up 88 percent of the total character mark area in I Common boards. For 2A Common boards the number is 87 percent (15). To capture the large yield gains found in this study, unsound knots, bark pockets, wane, and split should be examined for incorporation into parts.

Rough mill systems with the capability of positioning the character marks in dimension parts are becoming a reality. With such systems, character marks can be positioned with little or no visibility in areas with profiles, on the downward side, or on blind spots. This way, the widespread use of character marks may become feasible. Highly computerized and automated rough mills will be necessary, because humans are not able to perform these complex tasks fast enough or reliably enough (4).

This research showed that cutting bill geometry, grade mix, and character-mark size and location (CMIF or CM2F) are interrelated and can, combined or as individual parameters, have a positive or a negative effect on yield. Understanding these variables and being able to monitor them in the rough mill is a source for yield improvement. In particular, the influence of cutting bill geometry on yield when using different grade mixes or allowing different character-mark sizes seems to be highly erratic.

The continuation of the research presented in this paper will focus on the influence of the inclusion of character marks when using a crosscut-first system. That research will be presented in a second paper, which will also compare the two systems (rip-first and crosscut first) to identify which one results in higher yield when including character marks in dimension parts.

CONCLUSIONS

Allowing character marks in furniture dimension parts increases yield significantly. When allowing character marks up to 2 inches in diameter on both faces (CM2F) of dimension parts, a 13.8 percent yield increase is achieved for 2A Common lumber and a 6.1 percent yield increase is achieved for 1 Common lumber. If character marks are only allowed on one face (CMIF) while maintaining the other face entirely clear, the yield increase is 6.5 percent for 2A Common lumber and 3.2 percent for I Common lumber. If character marks are limited to I-inch diameter and allowed on both faces (CM2F), the yield increase for 2A Common is 7.8 percent and 3.3 percent for I Common. In the case when character marks are allowed on one face only (CMIF), the yield increases are 3.9 for 2A Common and 1.9 percent for I Common.

The size of the character marks allowed in the dimension parts is an important determinant of the yield increase achieved. In addition, the lumber grade mix used, the faces on which character marks are allowed (on one face or on both faces, i.e. CMIF or CM2F), and the cutting bill geometry are also important determinants of the character-marked part yield. As this study showed, allowing character-marked parts in furniture and other value-added products offers real and significant yield gain potential.

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