Potential for Yield Improvement in Combined Rip-First and Crosscut-First Rough Mill Processing

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Traditionally, lumber cutting systems in rough mills have either first ripped lumber into wide strips and then crosscut the resulting strips into component lengths (rip-first), or first crosscut the lumber into component lengths, then ripped the segments to the required widths (crosscut-first). Each method has its advantages and disadvantages. Crosscut-first typically works best for the production of wider components, while rip-first favors the production of narrower and longer components. Thus, whichever type of processing method is selected for a given rough mill usually depends on the characteristics of the cutting bills the mill expects to process. There is a third option, a dual-line mill that contains both rip-first and crosscut-first processing streams. To date, such mills have been rare for a variety of reasons, complexity and cost being among them. However, dual-line systems allow the mill to respond to varying cutting bill size demands as well as to board characteristics that favor one method (rip-first or crosscut-first) over the other. Using the Rough Mill Simulator (ROMI 4), this paper examines the yield improvement potential of dual-line processing over single-system processing (*i.e.*, rip-first or crosscut-first processing alone) for a variety of cutting bills and lumber grade mixes.

Keywords: Rough mill lumber yield; Cut-up systems; Rip-first; Crosscut-first; Performance

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INTRODUCTION

The cutting of kiln-dried hardwood lumber into components for the manufacture of solid wood products such as furniture, flooring, and kitchen cabinetry is of critical importance to manufacturers, as lumber costs may make up 40% to 60% of total product costs (Carino and Foronda 1990; West and Hansen 1996). As lumber is a heterogeneous material with large variances in geometric size, aesthetic look, and defect types, sizes, and locations, among other things, the cutting process is complicated and large cost savings are attainable if the best practices are employed to produce solid wood components (Wengert and Lamb 1994; Buehlmann 1998; Kline *et al*. 1998). Today, computer-controlled lumber cutting optimization systems employed in rough mills (processing facilities where a series of aligned equipment is used to cut components from kiln-dried lumber) strive to achieve maximum lumber yield. Lumber yield (the ratio of aggregate component surface area output to the aggregate lumber surface area input, according to Buehlmann 1998) is typically the most widely and closely watched key performance indicator (KPI) in rough mills, as it is directly correlated with rough mill costs.

In a rough mill, lumber can be converted into components in two ways: the lumber can be processed rip-first (the lumber sawn first along its length into narrower pieces) or crosscut-first (the lumber sawn first across its length into shorter pieces). In rip-first rough mills, the process starts by first ripping a board into strips that are of the same width as the rough dimension components needed. These long strips are then crosscut to the component lengths, whilst any unacceptable defects are cut out in the process. In crosscut-first rough mills, the process starts by crosscutting a board to component lengths while avoiding the larger, unacceptable defects (*i.e*., large, unacceptable defects, mostly the ones that extend over the entire board width or a large part of it, are cut out). Once the board segments are crosscut to length, they are then ripped to the width of the rough dimension components, while any remaining unacceptable defects are avoided. Each system offers advantages and disadvantages, and neither universally achieves a higher yield (Lucas and Araman 1975; Araman 1978; Pepke 1980; Hall *et al*. 1980; Gatchell 1987; Harding 1991). In general, rip-first processing favors the production of longer, narrower components, while crosscut-first processing favors the production of larger, wider components. It is no surprise, then, that the choice of a processing system is usually dictated by the demands of the cutting bill or list and schedule of dimension parts needed for a specific order Manalan *et al*. (1980, p. 40). Until the 1980s, crosscut-first systems dominated the cutting of lumber. Since then, rip-first systems have received more attention (Mullin 1990; BC Wood Specialties Group 1996) because rip-first systems produce higher yields of longer parts from lower grades of lumber (Gatchell 1987), require fewer and simpler operational decisions (Mullin 1990), and make it easier for operators to recognize and locate defects.

However, which one of the two systems results in a higher yield also depends on the cutting bill used for a given production run (Wengert and Lamb 1994; BC Wood Specialties Group 1996; Thomas 1997; Buehlmann *et al*. 2003, 2008a,b). Cutting bills inherently possess a distribution of component sizes given by the geometry of the components demanded. Often, some of these component sizes are better suited for rip-first processing, while other sizes are best cut using crosscut-first processing. Thus, the selection of the processing method (*i.e*., rip-first *vs*. crosscut-first) becomes a compromise for some cutting bills.

Also, the lumber grade (*i.e*., the lumber quality, NHLA 2011) used to cut components is of significance to the total component costs because of its influence on yield and mill productivity. Several authors have confirmed that lumber grade has an impact on yield (Thomas 1965; Gatchell 1985; Wengert and Lamb 1994; Gatchell and Thomas 1997; Buehlmann *et al*. 1998, 1999). Moreover, because high yield means that fewer boards have to be processed for a given amount of parts, the productivity of rough mills is also dependent on lumber quality (Pepke 1980; Perera 1994). In general, crosscut-first processing typically performs best with higher quality lumber (*i.e*., higher grades), while rip-first processing is advantageous with lower lumber grades. However, no rules exist to determine which cutting bill, lumber grade, or grade mix combination results in higher yields with any of the two processing systems. In fact, the type of processing used for any lumber cutting is most often determined by the type of processing system installed in a given rough mill. However, a number of mills have both systems, crosscut-first and rip-first. Combining these systems into an integrated dual-line system would provide the opportunity to obtain higher yields and consume less lumber than a crosscut or a rip-first only mill.

There is a considerable potential for improving the utilization of wood for producers of dimension components. On average, only about one-sixteenth (6.25%) of the original tree is converted into solid wood parts (Khan and Mukherjee 1991), and less than 25% of a log is utilized for parts, assuming 50% conversion rates in rough mills and in the sawmill (Wiedenbeck and Buehlmann 1995). Also, for individual mills, improving yield is paramount to remaining competitive in global markets, with lumber costs accounting for up to half of the product costs (Weidhaas 1969; Anonymous 1984; West and Hansen 1996). Thus, reducing drying times, labor and/or energy expenditures usually have little effect on lowering overall operating costs (Wengert and Lamb 1994). Saving 1% of the raw material (*i.e.*, increasing yield by 1%) would potentially save 2% of total production costs, thus increasing the potential revenue (Wengert and Lamb 1994; Kline *et al*. 1998). Improving rough mill yield not only saves raw material, thus lowering costs, but also increases the production capacity of the operation because less lumber is processed for the same output (Buehlmann 1998).

In an earlier paper, a small sample of cutting bills and processing methods for dual-line processing were examined (Thomas *et al*. 2014a). In that study, only a fixed-blade-best-feed arbor configuration (Thomas and Weiss 2006) was considered, as that is the most common rip-first arbor configuration used in industry. This research revealed that as the quality of the lumber grade mix decreased, the advantage of using a dual-line process increased over the advantages of using either rip-first or crosscut-first processing alone. That is, when using FAS or high-quality lumber (*e.g*., FAS and Selects, NHLA 2011), the yields of all three possible processing set-ups (rip-first, crosscut-first, and dual-line processing) were similar. However, when employing lower grades (*i.e*., 2A common and 3A common, NHLA 2011), it was more difficult for either system to produce components, and dual-line processing had a distinct advantage. However, questions remained as to how dual-line processing would perform given a wider range of cutting bill demands. In addition, it was unknown how dual-line processing would perform compared to the more efficient all-blades-movable (ABM) arbor system, which is becoming more commonly used in the industry today.

EXPERIMENTAL

To investigate the influence of 11 different cutting bills, five different lumber grades or grade mixes, and three different processing strategies (rip-first, crosscut-first, and dual-line), simulation techniques were used (Banks 1998; Buehlmann and Thomas 2001). ROMI 4 (Grueneberg *et al*. 2012; Thomas *et al*. 2014b), the U. S. Forest Service's rough mill simulator, which was designed to simulate a wide range of rough mill processes using digitized board data of various grades (Gatchell *et al*. 1998) and using custom-created cutting bills that can consist of as many as 300 solid, panel, or random-length components, was employed. The settings for all the simulation runs used in this manuscript were as follows:

- All-blades-movable or fixed-blade-best-feed arbor type
- Salvage cut to primary length and width
- Total yield used; consists of primary and salvage yield (*i.e*., no excess salvage yield)
- Complex dynamic exponential part prioritization (Thomas 1996)

- No random width or random length parts
- Continuous update of part counts
- No end or side trim

A set of 11 cutting bills was used for the rough-mill lumber cutting simulation runs executed for this research. Table 1 displays a summary of the demand specifications of the components of these 11 cutting bills. Note that the cutting bills in Table 1 are listed in order from easiest to hardest from top to bottom with respect to component demands and the ease of obtaining these components from a variety of lumber grades. All these cutting bills were used in prior studies (Thomas 1996), and cutting bills 1 through 10 were originally used to develop the component prioritization methods of ROMI-RIP (Thomas 1996). Cutting bills 2, 4, 5, 9, and 10 are copies of actual industry cutting bills from furniture and case goods rough mills. Cutting bills 2 and 4 are for cabinets, 9 and 10 are large case goods, and 5 is for bedroom suite dimension components. The remaining cutting bills were developed by researchers to test various aspects of rough mill component production. Cutting bill B is a hypothetical cutting bill developed by Buehlmann (1998) to test for the maximum yield possible given various rip-first rough mill configurations and lumber grade mix specifications.

Table 1. Description and Rankings of Cutting Bills Used

Cutting bill (Easiest)	Widths	Lengths	Comments
1	4[a]	9[a]	Mostly short and narrow.
	1.5 to 2.75[b]	12 to 48[b]	
2	7	14	Most parts are narrow. Wider parts are short.
	1.75 to 5.25	10 to 31.5	
3	3	5	Most parts are in wider widths.
	2 to 2.75	16 to 32	
4	4	7	Long, wide and short, narrow parts with good distribution in between.
	2 to 4.75	11 to 53	
5	7	12	Wide cuttings are short. Good distribution of lengths and widths.
	1.5 to 4.25	19.5 to 87.75	
6	2	6	Mostly short (41 in. and under) and narrow parts.
	2 and 3.25	15 to 97	
7	2	8	Large gap between short and long lengths; 3 in. width requires twice as many parts in longest lengths as a single short length.
	1.5 and 3	18 to 72	
B	4	5	Mix of long and short parts. Most parts demands are for narrower widths and medium lengths. However, rather large need for long and wide parts.
	1.5 to 4.25	10 to 72.5	
8	4	10	Most parts are long and wide with very few short and wide parts.
	2 to 4.25	15 to 72	
9	5	5	Widest parts are short. Equal numbers of short and long parts.
	2 to 4.5	16 to 84	
10	5	3	Only one short and two very long lengths. More long, wide parts than short ones.
	4 to 6	29 to 84	
(Hardest)			

[a] Number of sizes
[b] Range (inches)

ROMI simulates a dual-line rough mill by determining the optimal yields for each board from rip-first and crosscut-first processing at the time each board is processed (*i.e*., as the boards are processed and the components are obtained, the demand for a given component listed in a cutting bill may change between two boards). The method that gave the highest primary component yield was used to process the board. ROMI 4 tracks the count, grade, and footage of the boards processed such that yield is reported by processing method, by lumber grade, and overall. Two different dual-line rough mill setups were simulated: one using a fixed-blade-best-feed (FBBF) arbor and one using an all-blades-movable (ABM) arbor. Three single-line rough mill configurations were simulated: FBBF rip-first, ABM rip-first, and a crosscut-first setup. The optimal fixed-blade arbor spacing configurations were determined using the arbor optimization feature of ROMI 4 (Zuo 2003). The optimizer determines the best fixed-blade spacing sequence based on cutting bill component sizes, component quantities, and lumber width distribution. The ABM arbor consists of a series of movable blades that are optimally spaced to accommodate the features of each board, given the component widths called for by the cutting bill (Thomas *et al*. 2014b.). A single blade ripsaw was simulated in the crosscut-first scenarios.

Seven different lumber grade mixed samples were created. Because of its importance to the industry (Espinoza *et al*. 2011) and the availability of a large data bank of digitized boards, red oak, *Quercus rubra*, was used for this study (Gatchell *et al*. 1998). Listed in order from highest to lowest grade quality (NHLA 2011), the grades or the grade mixes used were: 1) 100% FAS; 2) 50% FAS/50% 1 common; 3) 100% 1 common; 4) 25% FAS/25% 1 common/50% 2A common; 5) 50% 1 common/50% 2 common; 6) 100% 2A common; and 7) 67% 1 common/33% 3A common. Each grade mixed sample was replicated 10 times, with each being a random sample from the entire kiln-dried red oak data bank (Gatchell *et al*. 1998; Buehlmann and Zuo 2008). Each cutting bill was processed once using each processing method (rip-first, crosscut-first, and dual-line), and each of the 10 random digital lumber samples for each lumber grade mix for each cutting bill. Thus, a total of 3,850 simulations were performed (11 cutting bills x 5 processing methods x 7 grade mixes x 10 replicates). The usable yield for each simulation (Thomas *et al*. 2014b) was recorded and averaged within each cutting bill, grade mix, and processing method group. Usable yield is the sum of the primary component yield and the salvage yield that was cut to required primary component sizes, *i.e*., no orphan or excess component yields (primary components cuts for which there was no longer a requirement) were included in the usable yield percentage (Thomas *et al*. 2014b).

RESULTS AND DISCUSSION

The usable component yield from each cutting bill, grade mix sample, and processing method are presented in Tables 2, 3, 4, 5, 6, 7, and 8. In each of these tables, yields from the ABM dual-line and FBBF dual-line were compared to those of the ABM rip-first, FBBF rip-first, and crosscut-first, respectively. In Tables 2 through 8, the rightmost columns (columns 7 through 11) show the average yield differences between the different processing methods. In addition, the average yields by processing method are presented at the bottom of the left-most columns (columns 2 to 6), while at the bottom of columns 7 through 11, the average differences in yield between the two processing methods over all cutting bills are shown. Figure 1 shows the overall average differences in yield between the different processing methods for the 11 cutting bills tested over the seven different grades or grade mixes tested (*i.e.*, the overall average yield over all 11 cutting bills, columns 7 through 11, bottom row).

Higher-Quality Grade Mixes

The 100% FAS and the 50% FAS/50% 1 common lumber samples represent the highest and the second highest quality lumber samples used in this study. The results for these two samples are presented in Tables 2 and 3. With the 100% FAS lumber sample, with one exception, the ABM dual-line consistently obtained higher yields than did the ABM rip-first or crosscut-first only methods. In five instances (cutting bills 2, 5, B, 9, and 10), the yield difference between the ABM dual-line and the ABM rip-first was less than 1.0% (Table 2, column 8), showing that high-grade lumber and ABM rip-first are achieving decent yields without the option of crosscutting-first. However, the advantages of crosscutting-first became apparent with cutting bills 1 and 4, where yield differences between the ABM dual-line and ABM rip-first were, on the average of the 10 replicates, 5.7 and 6.1%, respectively. Thus, the ability to crosscut-first specific boards provided the opportunity to come up with better cutting solutions (*i.e.*, higher yielding solutions) for cutting bills that called for components that were either mostly short and narrow (cutting bill 1, Table 1) or components that were long and wide and short and narrow with good distribution in between (cutting bill 4, Table 1). Of the two bills under discussion, cutting bill 4 was better suited to crosscut-first processing with a large proportion of longer and wider components. For cutting bill 4, the 100% FAS lumber sample, and ABM dual-line processing, 11.4% of the boards were crosscut-first, compared to 0.3% for cutting bill 5.

Table 2. Usable Yield for FAS Lumber Sample

Cutting bill	ABM dual-line	ABM rip-first	FBBF dual-line	FBBF rip-first	Cross cut first	ABM dual-line *vs.* FBBF dual-line	ABM dual-line *vs.* ABM rip-first	ABM dual-line *vs.* Cross cut first	FBBF dual-line *vs.* FBBF rip-first	FBBF dual-line *vs.* Cross cut first
1	80.6	74.9	77.8	77.8	72.9	2.8	5.7	7.7	0.1	4.9
2	84.1	83.6	77.1	77.1	75.7	7.0	0.5	8.4	0.0	1.4
3	78.3	77.1	65.4	61.5	70.5	12.9	1.2	7.8	3.9	-5.1
4	78.8	72.7	68.4	64.7	74.3	10.5	6.1	4.5	3.6	-5.9
5	80.8	80.0	75.0	74.5	70.3	5.8	0.9	10.6	0.5	4.8
6	74.7	73.0	75.6	72.1	70.1	-0.9	1.7	4.6	3.5	5.5
7	77.9	76.3	76.7	76.2	69.7	1.2	1.6	8.2	0.5	7.0
B	81.9	81.7	78.0	77.8	78.4	3.8	0.1	3.4	0.3	-0.4
8	80.1	78.3	78.8	77.4	76.5	1.3	1.8	3.6	1.4	2.3
9	75.8	75.6	69.5	68.1	69.5	6.3	0.1	6.2	1.4	0.0
10	67.7	68.1	63.4	63.7	62.6	4.3	-0.4	5.1	-0.3	0.9
Average	78.2	76.5	73.2	71.9	71.8	5.0	1.8	6.4	1.4	1.4

Table 3. Usable Yield for 50% FAS/50% 1 Common Grade Mix

Cutting bill	ABM dual line	ABM rip-first	FBBF dual line	FBBF rip-first	Cross cut first	ABM dual-line *vs.* FBBF dual-line	ABM dual-line *vs.* ABM rip-first	ABM dual-line *vs.* Cross cut first	FBBF dual-line *vs.* FBBF rip-first	FBBF dual-line *vs.* Cross cut first
1	74.7	67.2	71.1	69.8	65.7	3.6	7.5	9.0	1.3	5.4
2	77.4	77.1	71.8	71.6	68.0	5.6	0.3	9.4	0.2	3.8
3	70.5	70.6	59.8	56.6	63.2	10.7	-0.1	7.3	3.2	-3.4
4	69.9	61.5	61.5	56.6	64.0	8.4	8.4	5.9	4.8	-2.5
5	73.0	71.9	67.6	67.6	60.0	5.4	1.2	13.0	0.0	7.6
6	65.6	65.4	66.6	65.2	60.6	-1.0	0.2	5.0	1.5	6.1
7	71.1	70.2	70.0	69.2	62.2	1.1	0.9	8.9	0.8	7.8
B	74.2	73.7	71.1	69.6	71.8	3.1	0.5	2.5	1.5	-0.7
8	71.6	68.9	70.5	66.8	65.1	1.1	2.7	6.5	3.7	5.4
9	65.0	61.6	58.6	55.6	57.4	6.4	3.4	7.6	3.0	1.2
10	47.1	47.0	44.8	44.4	43.9	2.3	0.0	3.2	0.5	0.9
Average	69.1	66.8	64.9	63.0	62.0	4.2	2.3	7.1	1.9	2.9

Comparing the all-blades movable dual-line (ABM) with the fixed blade, best feed (FBBF) dual-line, the ABM dual-line obtained higher yields on 10 of the 11 cutting bills compared to the FBBF dual-line. Yield differences of 5% or more (with a maximum yield difference of 12.9% for cutting bill 3) were observed in five instances, with an average yield difference over the 10 cutting bills of 5.0% (Table 2). In one instance, that of cutting bill 6, the FBBF dual-line achieved a yield 0.9% higher, requiring 106 bdft less to obtain all the required components. This atypical observation can be explained by the fact that cutting bill 6 had only two component widths, 1.5 and 4.25 inches, while most components demand a width of 1.5 inches. The limited widths and high percentage of narrow width components negated some of the optimization advantages of the ABM arbor for this bill.

For the FAS grade mix, the crosscut-first obtained higher yields than did the FBBF dual-line on three cutting bills: 3, 4, and B (column 11, Table 2). However, the yield difference on cutting bill B was low (0.4%), or a difference of 16 board feet only. Yet, for cutting bills 3 and 4, the crosscut-first processing bested the FBBF-dual line by yields of 5.1 and 5.9%, respectively. These unexpected anomalies were due to the way that components are prioritized within the simulator and do not necessarily indicate superior performance of a given processing methodology. For a given board, while the crosscut-first algorithm was optimized for the production of single large components on some boards, the rip-first component achieved a higher total of prioritized component values by fitting a greater number of smaller components into some of the boards processed. Thus, the rip-first component missed opportunities to cut larger, harder-to-obtain component sizes early in the processing sequence, resulting in a need to process more lumber to cut the larger component sizes.

Yield results from the 50% FAS/50% 1 common lumber sample (Table 3) closely mirrored those of the 100% FAS sample. As before, on cutting bill 6, the FBBF dual-line returned 1.0% higher yields than did the ABM dual-line. Crosscut-first processed bested the FBBF dual-line processing on three cutting bills: 3, 4, and B (column 11, Table 3). The yield difference for cutting bill B was slightly higher (0.7%) than that with FAS alone (0.4%, Table 2). However, for cutting bills 3 and 4, the crosscut-first system achieved yields (3.4 and 2.5%, respectively, Table 3) that were still better than the yields obtained for the FBBF-dual line, yet less so than those obtained for the 100% FAS grade (yields of 5.1 and 5.9%, respectively, Table 2).

The results from the simulation of the cutting of high-quality lumber samples (*i.e.*, 100% FAS and 50% FAS/50% 1 common) confirmed the old adage that crosscut-first systems do best with high-quality lumber combined with cutting bills that have a relatively high demand for short and/or wide components. However, only 3 out of 11 cutting bills performed better with crosscut-first as opposed to the FBBF dual-line, and no cutting bill performed better with crosscut-first as opposed to the ABM dual-line (Tables 2 and 3). This showed the strength of the dual-line concept, especially when rip-first processing line used an all-blades movable ripsaw arbor. For the 100% FAS simulations, the ABM dual-line achieved, on average, 6.4% higher yield as compared to the crosscut-first line, with cutting bill 5 yielding a 10.6% higher yield using the dual-line (column 9, Table 2). For the 50% FAS/50% 1 common simulations, the respective numbers were 7.1%, averaged over the 11 cutting bills tested, and 13% for cutting bill 5 (column 9, Table 3).

Medium-Quality Grade Mixes

The medium quality grade mixes used in this study are comprised of the 25% FAS/25% 1 common/50% 2A common lumber samples, and the 100% 1 common lumber samples. The results for these grade mixes are shown in Tables 4 and 5.

Table 4. Usable Yield for 25% FAS/25% 1 common/50% 2A Common Lumber Grade Mix

Cutting bill	ABM dual-line	ABM rip-first	FBBF dual-line	FBBF rip-first	Cross cut first	ABM dual-line *vs* FBBF dual-line	ABM dual-line *vs* ABM rip-first	ABM dual-line *vs* Cross cut first	FBBF dual-line *vs* FBBF rip-first	FBBF dual-line *vs* Cross cut first
1	66.2	58.0	62.2	59.7	54.8	4.0	8.2	11.4	2.5	7.4
2	68.7	68.5	64.1	63.8	58.6	4.6	0.2	10.1	0.3	5.5
3	61.2	61.2	53.4	51.3	53.2	7.8	0.0	8.0	2.1	0.2
4	53.6	45.9	50.2	43.3	48.9	3.5	7.8	4.8	6.8	1.3
5	61.6	59.5	56.7	56.3	46.3	4.9	2.1	15.3	0.4	10.4
6	55.1	52.3	55.4	53.8	48.2	-0.3	2.8	6.9	1.6	7.2
7	60.6	60.7	61.1	59.1	49.4	-0.4	-0.1	11.3	2.0	11.7
B	62.9	63.0	60.3	60.1	55.2	2.6	-0.1	7.7	0.2	5.1
8	57.7	53.6	56.4	53.2	48.7	1.3	4.2	9.0	3.2	7.7
9	48.7	43.6	43.4	39.9	35.2	5.3	5.1	13.5	3.5	8.2
10	26.4	26.3	25.6	25.2	24.5	0.9	0.1	1.9	0.4	1.1
Average	56.6	53.9	53.5	51.4	47.5	3.1	2.7	9.1	2.1	6.0

Table 5. Usable Yield for 1 Common Lumber Sample

Cutting bill	ABM dual-line	ABM rip-first	FBBF dual-line	FBBF rip-first	Cross cut first	ABM dual-line *vs* FBBF dual-line	ABM dual-line *vs* ABM rip-first	ABM dual-line *vs* Cross cut first	FBBF dual-line *vs* FBBF rip-first	FBBF dual-line *vs* Cross cut first
1	68.7	59.7	64.8	62.2	57.6	3.9	9.0	11.1	2.6	7.2
2	70.0	70.0	66.2	65.4	60.4	3.8	0.0	9.6	0.8	5.8
3	63.7	63.2	55.0	52.7	55.5	8.7	0.6	8.2	2.3	-0.5
4	56.7	49.0	54.1	45.1	52.9	2.6	7.8	3.9	9.0	1.2
5	64.9	62.5	59.3	59.0	48.9	5.6	2.4	16.0	0.3	10.4
6	58.4	55.6	58.0	57.3	51.2	0.4	2.8	7.2	0.7	6.8
7	63.8	62.8	64.0	61.5	51.3	-0.2	0.9	12.5	2.5	12.7
B	66.5	65.4	64.2	63.3	58.2	2.3	1.1	8.3	0.9	6.0
8	60.8	58.0	59.4	55.7	50.5	1.4	2.7	10.3	3.7	8.9
9	50.0	46.1	45.4	42.3	37.1	4.6	3.9	13.0	3.1	8.3
10	26.7	26.4	26.3	25.7	24.7	0.3	0.2	1.9	0.6	1.6
Average	59.1	56.2	56.1	53.7	49.8	3.0	2.9	9.3	2.4	6.2

On average, the dual-line processing methods outperformed the rip-first only and crosscut-first only methods by 2.1 to 9.3% depending on processing method (Tables 4 and 5).

The ABM dual-line outperformed the crosscut-first processing on both grade mixes, with an average yield improvement of 9.1% using the FAS/1 common/2 common sample and an average yield improvement of 9.3% with the 100% 1 common sample (Tables 4 and 5). Similarly, yield differences were observed in the results for the FBBF dual-line process. The FBBF dual-line achieved an average yield 6.0% higher than that of the crosscut-first processing with the FAS/1 common/2 common samples. With the 100% 1 common lumber sample, the FBBF dual-line performed better in all but one instance (cutting bill 3) compared to the crosscut-first processing, with an average improvement in yield by 6.2%. Crosscut-first performed better on cutting bill 3, a cutting bill whose part demands favor crosscut-first processing, as discussed previously.

On average, the ABM dual-line performed better than the ABM rip-first only processing, with average yield differences of 2.7% with the FAS/1 common/2A common samples and 2.9% with the 100% 1 common sample (Tables 4 and 5). However, when using cutting bills 7 and B, the ABM rip-first only line achieved slightly higher yield (0.1%) than did the ABM dual-line. A 0.1% difference in yield represents 1 extra board processed. For the FBBF simulations, dual-line *vs*. rip-first only, the FBBF dual-line returned yield improvements on average of 2.1% for the FAS/1 common/2A common samples and 2.4% for the 1 common samples.

In most instances, the ABM dual-line outperformed the FBBF dual-line, exhibiting an average yield improvement of 3.1% when applied to the FAS/1 common/2A common samples (Table 4) and 3.0% for the 1 common samples (Table 5), respectively. For the FAS/1 common/2A common samples, the FBBF dual-line obtained slightly better yields on cutting bills 6 and 7 (Table 4). With the 1 common sample, the FBBF dual-line obtained a slightly better yield only with cutting bill 7 (0.2% better, Table 5). Cutting bills 6 and 7 were characterized by having only two widths, the widest being 3.25 inches. The absence of numerous widths decreased the optimization advantages of the ABM arbor, thus setting the ABM solution on par with the FBBF solution. All other cutting bills had more than two widths, and thus the ABM solution outperformed the FBBF solution.

With the exception of cutting bill 3 and the 100% 1 common lumber sample and the comparison between the FBBF dual-line and the crosscut-first, no surprises were found among the medium quality grade mix tests (*i.e.*, the FAS/1 common/2A common and all the 1 common samples, Tables 4 and 5). Even the results from cutting bill 3 and the 100% 1 common lumber sample revealed a relatively weak (0.5%) yield advantage for the crosscut-first line (Table 5). Thus, as was indicated previously, crosscut-first does best with high-quality lumber and is less advantageous when applied to lower-quality grades. This is a major reason why few crosscut-first systems are installed in modern rough mills, as industry users predominantly employ lower-quality lumber grade mixes for cost savings and other reasons

Lower-Quality Grade Mixes

No widely used definitions of what constitutes "lower-quality grade mixes" exist. However, most practitioners would consider any grade mix containing more than 25% 2A common or other lower grade material a "lower-quality grade mix." Thus, for this part of the study, the following grade mixes were simulated: (1) 50% 1 common/50% 2A common, (2) 100% 2A common, and (3) 67% 1 common/33% 3A common. The results are shown in Tables 6, 7, and 8, respectively.

Table 6. Usable Yield for 50% 1 Common/50% 2A Common Lumber Grade Mix

Cutting bill	ABM dual-line	ABM rip-first	FBBF dual-line	FBBF rip-first	Cross cut-first	ABM dual-line *vs.* FBBF dual-line	ABM dual-line *vs.* ABM rip-first	ABM dual-line *vs.* Cross cut-first	FBBF dual-line *vs.* FBBF rip-first	FBBF dual-line *vs.* Cross cut-first
1	62.1	54.1	57.6	55.5	48.1	4.5	8.0	14.0	2.2	9.5
2	65.0	64.1	60.9	58.8	54.0	4.1	0.9	11.0	2.1	6.9
3	57.1	56.2	50.5	48.4	48.1	6.6	0.9	9.1	2.1	2.5
4	43.9	37.7	43.9	36.4	41.4	0.0	6.2	2.5	7.5	2.5
5	56.9	53.2	51.7	51.1	39.4	5.2	3.7	17.5	0.6	12.3
6	51.6	47.2	51.6	48.5	43.2	0.0	4.4	8.4	3.1	8.4
7	57.2	56.6	57.7	55.5	41.1	-0.5	0.6	16.1	2.2	16.6
B	57.8	57.6	56.1	55.3	47.2	1.7	0.3	10.6	0.8	8.9
8	51.7	49.1	50.2	47.5	40.5	1.5	2.6	11.2	2.7	9.8
9	37.5	32.5	34.5	30.4	22.3	3.0	5.0	15.2	4.1	12.2
10	15.9	15.5	15.9	15.2	14.2	0.0	0.4	1.7	0.6	1.7
Average	50.6	47.6	48.2	45.7	39.9	2.4	3.0	10.7	2.6	8.3

Table 7. Usable Yield for 2A Common Lumber Sample

Cutting bill	ABM dual-line	ABM rip-first	FBBF dual-line	FBBF rip-first	Cross cut-first	ABM dual-line *vs.* FBBF dual-line	ABM dual-line *vs.* ABM rip-first	ABM dual-line *vs.* Cross cut-first	FBBF dual-line *vs.* FBBF rip-first	FBBF dual-line *vs.* Cross cut-first
1	54.3	47.1	50.4	48.03	37.29	3.9	7.2	17.0	2.3	13.1
2	59.4	56.9	54.4	51.8	47.2	5.0	2.5	12.2	2.6	7.2
3	51.0	49.5	46.8	45.4	41.4	4.3	1.5	9.6	1.3	5.4
4	29.0	24.5	30.3	25.8	25.8	-1.3	4.5	3.2	4.4	4.5
5	46.7	40.3	40.4	39.6	28.7	6.3	6.4	18.0	0.8	11.7
6	41.5	38.1	42.8	39.0	34.2	-1.3	3.4	7.3	3.8	8.6
7	48.0	46.5	47.8	45.9	29.7	0.2	1.5	18.3	1.9	18.1
B	45.1	44.9	44.0	39.5	33.6	1.1	0.2	11.6	4.5	10.4
8	40.9	37.1	39.8	36.5	29.4	1.1	3.8	11.5	3.3	10.4
9	14.5	13.2	14.9	13.2	7.8	-0.4	1.3	6.7	1.7	7.1
10	6.8	6.7	7.0	6.7	6.1	-0.1	0.2	0.8	0.3	0.9
Average	39.7	36.8	38.0	35.6	29.2	1.7	2.9	10.6	2.4	8.9

Table 8. Usable Yield for 67% 1 Common/33% 3A Common Lumber Grade Mix

Cutting bill	ABM dual-line	ABM rip-first	FBBF dual-line	FBBF rip-first	Cross cut first	ABM dual-line *vs.* FBBF dual-line	ABM dual-line *vs.* ABM rip-first	ABM dual-line *vs.* Cross cut first	FBBF dual-line *vs.* FBBF rip-first	FBBF dual-line *vs.* Cross cut first
1	58.7	50.1	53.7	51.2	45.8	5.0	8.6	12.9	2.5	7.9
2	61.7	60.9	57.9	56.2	51.1	3.8	0.8	10.6	1.7	6.8
3	53.1	52.5	47.8	46.9	46.0	5.3	0.6	7.1	0.9	1.8
4	40.5	34.4	39.4	32.7	37.8	1.1	6.1	2.7	6.7	1.6
5	52.6	48.2	47.1	46.3	36.0	5.5	4.4	16.6	0.8	11.1
6	48.5	47.4	46.7	47.5	40.1	1.8	1.1	8.4	-0.8	6.6
7	52.9	52.5	53.4	51.5	38.2	-0.5	0.4	14.7	1.9	15.2
B	53.4	53.5	51.7	51.8	43.9	1.7	-0.1	9.5	-0.1	7.8
8	46.1	44.0	45.1	42.7	37.1	1.0	2.1	9.0	2.4	8.0
9	34.8	31.2	32.1	28.7	22.9	2.7	3.6	11.9	3.4	9.2
10	16.7	16.4	16.5	16.1	14.9	0.2	0.3	1.8	0.4	1.6
Average	47.2	44.6	44.7	42.9	37.6	2.5	2.5	9.6	1.8	7.1

On average over all 11 cutting bills, the dual-line processing methods outperformed the rip-first or crosscut-first only methods by at least 1.8% (FBBF dual-line *vs*. FBBF rip-first line, 67% 1 common/33% 3A common grade mix, Table 8) and at most 10.7% (ABM dual-line *vs*. crosscut-first line, 50% 1 common/50% 2A common lumber grade mix, Table 6).

The ABM dual-line process outperformed the crosscut-first process on all cutting bills and grade mixes. On average, the ABM dual-line achieved yields that were 10.7%, 10.6%, and 9.6% higher than did the crosscut-first only line for the 50% 1 common/50% 2A common, 100% 2A common, and 67% 1 common/33% 3A common grade mixes, respectively (Tables 6, 7, and 8). The FBBF dual-line achieved yields that were 8.3%, 8.9%, and 7.1% higher in comparison to the crosscut-first line, averaged over all 11 cutting bills, for the 50% 1 common/50% 2A common, 100% 2A common, and 67% 1 common/33% 3A common grade mixes, respectively (Tables 6, 7, and 8). As discussed above, these results demonstrated the challenges of crosscut-first processing lines when cutting lower-quality lumber.

However, the dual-line concept also performed well when compared to rip-first only lines. When averaged over all cutting bills, the ABM dual-line achieved 3.0%, 2.9%, and 2.5% higher yields compared to the ABM rip-first line for the 50% 1 common/50% 2A common, 100% 2A common, and 67% 1 common/33% 3A common grade mixes, respectively (Tables 6, 7, and 8). For the FBBF dual-line, the yield improvements found were 2.6%, 2.4%, and 1.8%, respectively. However, when the 67% 1 common/33% 3A common grade mix was processed with cutting bills 6, B, and 10, the FBBF rip-first only line achieved more favorable yield results (by 0.8%, 0.1%, and 0.4% for the 50% 1 common/50% 2A common, 100% 2A common, and 67% 1 common/33% 3A common grade mixes, respectively, Tables 6, 7, and 8) compared to the FBBF dual-line processing line.

The ABM dual-line process outperformed the FBBF dual-line, on average over all cutting bills, by 2.4%, 1.7%, and 2.5% for the 50% 1 common/50% 2A common, 100% 2A common, and 67% 1 common/33% 3A common grade mixes, respectively (Tables 6, 7, and 8). Cutting bill 7 achieved a 0.5% higher yield when using the FBBF dual-line as opposed to the ABM dual-line when processing the 50% 1 common/50% 2A common and when processing the 67% 1 common/33% 3A common grade mixes (Tables 6 and 8). Cutting bills 4, 6, 9, and 10 achieved yields 1.3%, 1.3%, 0.4%, and 0.1% higher, respectively, for the 100% 2A common grade mix when using the FBBF line (Table 7). As discussed previously, cutting bill 6 called for two widths, thereby decreasing the optimization paths that would allow an ABM saw to achieve higher yields over the FBBF saw, which could explain the results presented here.

Cutting bills 4 and 10 were characterized by their need for long and wide pieces, while cutting bill 10 required short and wide pieces (Table 1). Here, the sum of the yields for the combined systems was the key. Approximately 10 to 38% of the lumber that was processed used the crosscut-first system, depending on grade-mix, cutting bill, and the specific dual-line system used. In addition, the yields for the dual-line FBBF and dual-line ABM for some mixes were nearly the same. For example, processing cutting bill 4 using the 50% 1 common/50% 2A common mix resulted in a yield of 43.9% for both dual-line systems. But how each system obtained the same yield was very different. The FBBF dual-line system processed 38% of the lumber using crosscut-first processing, while the ABM dual-line processed only 19% of the lumber by the crosscut-first method. Still, on average the total lumber required by each dual-line system differed by only 3 bdft. The preference for crosscut-first processing in these analyses was dictated by degree of the demand for long, wide parts in the cutting bill and by the sizes of the specific board to be processed at any given moment. The preference for crosscut-first was highest with cutting bill 4, the second highest with cutting bill 10, and the third highest with cutting bill 9. In these cases, the optimization algorithm for crosscut-first processing was better at optimizing the cutting of those parts while still obtaining other in-demand parts from a large portion of the board. When lower grades were processed using the rip-first method, to obtain long, wide parts from a board, either end of the board could fail to yield a part depending on the presence of kerfs and defect characteristics. However, with crosscut-first processing, the board segments were available for processing in its entirety and thus, an extra part, wider than possible with rip-first, could potentially be available leading to increased yield.

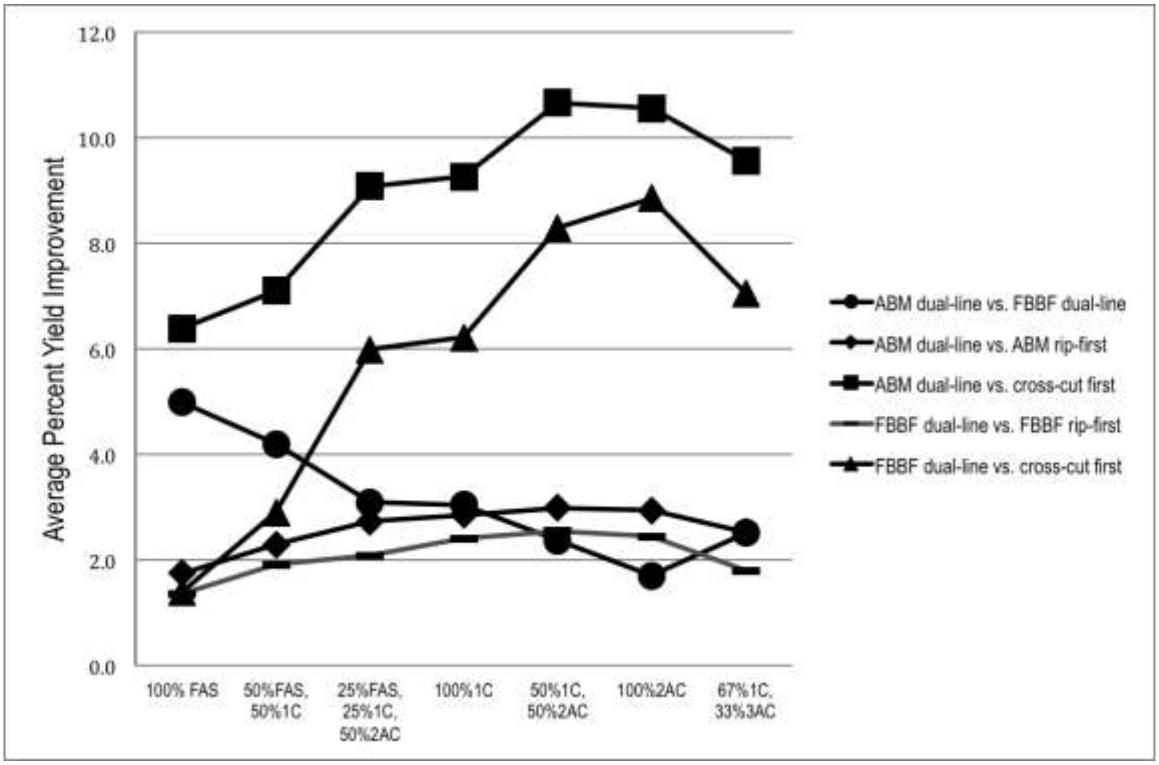

Fig. 1. Average yield improvement by dual-line *versus* selected others for seven different grades or grade mixes

Generally, for most cutting bills, when lower lumber grades or lumber grade mixes are used, rip-first systems achieve higher yields than do crosscut-first systems, a fact confirmed by this study. However, this study also showed that a dual-line system often achieved higher yields than a rip-first system. In the dual-line system, the yield is improved because each board is processed by either a rip-first or by a crosscut-first process, depending on which produces best results given each board's characteristics and the cutting bill's specific requirements. When using an ABM dual-line system, the yields were, on average over the 11 cutting bills used in this study, 1.8%, 2.3%, 2.7%, 2.9%, 3.0%, 2.9%, and 2.5% higher in comparison to the ABM rip-first system and 6.4%, 7.1%, 9.1%, 9.3%, 10.7%, 10.6%, and 9.6% higher when compared to the crosscut system for the 100% FAS, 50% FAS/50% 1 common, 25% FAS/25% 1 common/50% 2A common, 100% 1 common, 50% 1 common/50% 2A common, 100% 2A common, and 67% 1 common/33% 3A common, respectively.

On average across all cutting bills tested, the rip-first systems with all-blades-movable ripsaw arbors consistently outperformed fixed-blade-best-feed arbor configurations. The fixed-blade-best-feed system bested the all-blades-movable system only in rare cases, and mostly for cutting bills with a limited demand for components with varying widths. The minimum yield advantage across all 11 cutting bills was 1.2% (100% 2A common, Table 7), while the maximum difference was 4.6% (100% FAS, Table 2), and the average yield advantage for the all-blades-movable system was 2.6%.

CONCLUSIONS

1. Using simulation software (ROMI 4), this study investigated the potential benefits of dual-line (rip-first and crosscut-first) mill processing on lumber yield. Such a system required that the processing of every board be optimized for highest yield using either rip-first or crosscut-first systems depending on the cutting bill requirements. After the highest-yield process was determined for each board, the board was processed, and the next board was analyzed using the updated cutting bill requirements. While such a system proved easily configurable in simulation software, it will require real-time scanning and an analysis of its capabilities in a real world system.
2. Such a dual-line system offers considerably higher yields in most cases. When processing higher quality lumber (100% FAS or 50% FAS/50% 1 common) and using an all-blades-movable arbor (ABM) on the ripsaw, yield improvements of between 1.8% and 7.1% over single-line processing (*i.e.*, either rip-first or crosscut-first) were recorded.
3. When processing medium quality lumber (100% 1 common or 25% FAS/25% 1 common/50% 2A common), yield improvements of between 2.7% and 9.3% were observed.
4. When processing low-quality grade mixes (50% 1 common/50% 2 common, 100% 2A common, or 67% 1 common/33% 3A common), yield improvements ranging from 2.9% to 10.7% over the single-line were found.
5. Thus, dual-line rough mill systems were able to achieve higher yields for most cutting bills than the single-line systems. However, total lumber cost is not only dependent on yield, but also on the purchasing costs of the lumber. This problem, commonly referred to as the least-cost grade-mix problem, has the potential to offset some of the benefits uncovered in this study.

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