THE EFFECTS OF LUMBER LENGTH ON PART YIELDS IN GANG-RIP-FIRST ROUGH MILLS

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ABSTRACT

The lumber processed in most rough mills typically arrives from vendors in packages of random width boards with lengths ranging from 8 to 16 feet. However, little attention has been given to analyzing how differences in board lengths affect rough mill yield given varying part-prioritization strategies and cutting bill scenarios. The objective of this study was to determine if the same clear part yield could be obtained from the same volume of lumber and grade mix of shorter boards (7 to 8 ft.), medium-length boards (11 to 12 ft.), and long boards (15 to 16 ft.). This study uses simulation (ROMI-RIP 2.0) and applies an experimental design that reflects actual gang-rip-first rough mill operations found in furniture, cabinet, and dimension industries. Two cutting bills representing "easy" and "hard" degrees of difficulty were used. Three part-prioritization strategies were applied to reflect both standard rough mill practices and an optimizing strategy. Five randomized replications from each length sort were run for both cutting bills and for each part-prioritization strategy. A total of 90 simulations were used in the analysis. Total part yield was the dependent variable in this study. Statistical analysis indicated that significant differences in part yields existed between the three lumber length sorts for both cutting bills and for all three part-prioritization strategies. Average part yields across part-prioritization strategies increased consistently, by more than 5 percent overall, for both cutting bills, as board length increased.

Lumber purchases are the greatest cost of operating a rough mill, comprising 50 percent of the cost of sales according to the 1999 Wood Component Manufacturer's Association "Cost of Doing Business Survey" (14). Therefore, it is critical that attention be given to optimal utilization of the wood resource with regard to the numerous variables that impact product recovery. Apart from the various personnel, machinery and process systems that are required to manufacture parts in a rough mill operation, the physical characteristics of the lumber resource significantly impact the manufacturing process. Optimal handling and processing of boards with different length, width, and grade distributions are essential to any rough mill operation. Board length, width, and grade characteristics interact with cutting bill requirements and part-prioritization strategies as mill operators attempt to extract as many usable dimension pieces (a.k.a. "rough parts" or "component parts") from the boards as possible (9). Lumber utilization, or yield (the surface measure of usable parts divided by the surface measure of rough lumber) is the statistic by which rough mill efficiency is measured.

Many studies have been conducted to investigate how the various attributes of lumber affect rough mill yield and productivity. Most recently, these investigations have explored the following: the effects of lumber grade on machine productivity (7), the effects of preprocessing lumber to minimize the effects of crook and other waste areas (3), the impact on yield by allowing character marks in furniture production (1), and an investigation into the potential of utilizing short lumber (boards less than 8 ft. long) in rough mill operations (12). These research studies have been conducted by means of both on site investigations and

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with the aid of computer programs designed to simulate rough mill processes and conditions.

Apart from a study conducted by Wiedenbeck (12) using a simulator that could not be set to mimic important aspects of rough mill processing, little attention has been given to analyzing how differences in board lengths affect rough mill yield given varying part-prioritization strategies and cutting bill scenarios. The lumber processed in most rough mills typically arrives from vendors in packages of random width boards with lengths ranging from 8 to 16 feet. This study investigates how differences in lumber lengths affect part yields in a gang-rip-first rough mill. This is important since any relationship between board length and yield would provide rough mill managers with valuable information to better determine optimal lumber throughput as it relates to required rough part output. Significant differences in part yields that are attributed to varying lumber lengths could impact rough mill management decisions regarding how to best apply the lumber resource to the capabilities of their operation and specific cutting orders. The feasibility of acquiring length sorting equipment and expanded dry storage may be indicated based on lumber length-based yield differences.

Because hardwood lumber has historically been widely available in lengths ranging from 8 to 16 feet, rough mill machinery, equipment, and processes are designed to accommodate these lengths (13). Therefore, 8- to 16-foot lengths are preferred in most rough mill operations today. The standard length distribution represents a considerable range from which to process parts that also can vary considerably with respect to length. This presents an important decision-making question: Is there greater likelihood of getting needed parts out of a given board footage of longer boards (12 to 16 ft.) or from the same board footage of shorter boards (8 to 12 ft.)? Clearly, the answer will depend on the size and number of parts that need to be produced, the quality of the boards used to do the job, and how rough mill management prioritizes the importance of particular parts in the cutting bill as boards are processed.

The objective of this study was to determine if the same clear part yield can be obtained from the same board footage and grade mix of shorter boards (7 to 8 ft.), intermediate length boards (11 to 12 ft.), and long boards (15 to 16 ft.). The study will use simulation and apply an experimental design that reflects actual gang-rip-first rough mill operations typically found in the furniture, cabinet, and dimension industries. This information will provide gang-rip-first rough mill managers with useful board length decision-making criteria to promote more efficient, productive, and profitable lumber utilization. For a typical rough mill cutting 12,000 board feet (BF) of lumber daily, valued at $900 per thousand BF, a 1 percent increase in yield will save the mill approximately $58,000 per year in operating expenses (4).

Using the ROMI-RIP 2.0 rough mill computer simulation program (9,10) and the accompanying 1998 Data Bank for Kiln-Dried Red Oak Lumber (2) consisting of 3,487 boards, the effects of differing lumber lengths on part yields can be manipulated and analyzed. Because ROMI-RIP was designed to accommodate a variety of process control strategies, the often-complicated interactions between arbor designs and setups, as well as large cutting bills with up to 300 part sizes, this package has the unique ability to isolate individual factors that affect rough mill performance. To take on similar on-site investigations would be cumbersome, expensive, and time consuming (9).

The ROMI-RIP 2.0 simulation program has been validated for the fixed-blade ripsaw operating mode (11). This mode simulates the most common gang ripsaw in use today. The validation study indicated that ROMI-RIP 2.0 closely simulates yield on the chopsaw and closely simulates overall rough mill yields when cutting very large cutting bills. ROMI-RIP 2.0 consistently gives higher yields than actual mill yields when cutting smaller cutting bills in which part priorities shift during processing; ROMI-RIP 2.0 optimizes to produce yields that are approximately 5 percent higher than in the mill. Simulation results are a valid means of testing for yield differences. Processing, lumber input, and product sizes are varied even if the actual yields and simulation yields are not the same. The change in yields that results from changes in an operating variable will give a good prediction of how the change can be expected to affect yield in actual operations.

PROCEDURE

LUMBER

For this study, three sets of length-sorted files (five files per set) were created from the 1998 Data Bank for Kiln-Dried Red Oak Lumber (2) using the *Makefile* component in ROMI-RIP (10). This program allows the user to select specific board foot volumes of lumber by choosing boards based on percentages of grades, widths, and lengths desired in the lumber mix.

In *Makefile*, each file in each of the three length sorts was programmed to contain 2,000 BF of random width lumber (ranging from 4 to 13 in.) from a grade mix comprised of 80 percent 1 Common, 12 percent 2A Common, and 8 percent First and Seconds (FAS). For the first group of five board data files, the short lumber sort, the lumber files were programmed to select boards ranging from 80 to 100 inches in length for an approximate 7- to 8-foot category. The five files in the intermediate board length sort were set up to contain boards ranging from 130 to 150 inches for an approximate 11- to 12-foot category. The five long board length files were programmed to select boards ranging from 175 to 195 inches for an approximate 15- to 16-foot category.

Prior studies using analysis of variance (ANOVA) and Duncan's multiple-range tests to determine how many boards are required in a file to get an accurate estimation of rough mill yield have identified that predicted yields do not change significantly when more than 150 boards are included in the sample file ($\alpha = 0.05$) (1). Therefore, our board files were set up so that at least 150 boards were contained in all data files. The board footage requirement established for each of the three sets of length-sorted lumber files was 2,000 BF. For the long-length lumber group, 2,000 BF was enough to accommodate the 150-board requirement. The total number of boards for each of these short, intermediate, and long length-based lumber data files averaged 425, 280, and 187, respectively.

The same specifications (width, length, and grade mix) for the five board data files in each set were used; *Makefile* randomly selected and shuf-

ALL part measurements are in INCHES!
Panel specifications: Min. part width = 1.00; Max. part width = 4.50
Random width edging strips acceptable for use in panel production
Rough mill central controller priorities updated continuously
Primary operations avoid orphan parts
Board placement with respect to arbor optimized in 2/16-inch steps
2/16-inch ripsaw kerf
2/16-inch chopsaw kerf
Left edger set to edge 0.2500 inch
Right edger set to edge 0.2500 inch
Boards will be trimmed 16/16-inch on both ends.
Salvage specific widths (max 15): 1.0000, 1.3750, 2.0000
Salvage specific lengths (max. 15): 12.0000, 20.0000, 30.0000

Figure 1. — ROMI-RIP 2.0 gang-rip-first rough mill simulation set-up parameters that were held constant for all 90 simulations.

fled the boards from the 1998 Data Bank (2) to create these files. Using the five files in the study allowed replication of the simulation, i.e., ROMI-RIP could run five replications for each length sort, part-prioritization strategy, and cutting bill to ensure statistical precision and accountability in the results.

CUTTING BILLS

To effectively simulate actual rough mill conditions, two cutting bills that represent a feasible range of processing difficulty (relatively easy and relatively hard) were used. These cutting bills have been designated "easy" and "hard." Although cutting bills are an essential component of any rough mill, they are not the primary focus in this study. Rather, these two cutting bills are incorporated to determine if differences in cutting bills will change how length affects part yield.

The easy and hard cutting bills, with arbor sequences, used for this study were selected from a study published in the *Forest Products Journal* (3). It should be noted that the type of arbor used in this study was changed to a fixed-blade, best-feed arbor, instead of the all blades movable type used in that study. The use of fixed-blade arbors is quite common in the furniture, cabinet, and dimension industries. Once the size and number of arbor spacings have been designed to best accommodate a specific cutting bill, the blades cannot be moved. The ripsaw operator uses his judgment to feed the boards through the arbor to maximize part widths (yield) using the available saw spacings to optimize board surface area.

An easy cutting bill can best be described as having many short and narrow parts, including a variety of panels that can accommodate most of the extra parts (3). It is "easy" because it includes a greater variety of rough part sizes that can be readily obtained from most lumber grade and size mixes. The easy cutting bill in this study had 15 part lengths, 5 part widths, and 5 panel parts. Average part width and length for this cutting bill were 2.94 inches and 30.36 inches, respectively (weighted based on need). Nine part lengths were shorter than 40 inches (72 percent of all parts), four part widths were narrower than 2 inches (69 percent of all parts), and four of the panels could absorb extra parts. Total width for the easy cutting bill saw spacing set-up was 27.63 inches. This spacing would fit on a standard 31-inch arbor.

A hard cutting bill has a higher percentage of parts that are wider and longer, with fewer panels to accommodate the extra parts (3). It is "hard" because there is less variety in part sizes relative to usable cutting space in the dimensions of the mix of boards. The hard cutting bill in this study had 12 part lengths, 6 part widths and only 2 panel sizes. Average part width and length for this cutting bill were 4.96 inches and 40.36 inches, respectively (weighted based on need). Nine part lengths were shorter than 40 inches (61% of all parts), none were narrower than 2 inches, and only one panel part could absorb extra parts. Total width for the hard cutting bill saw spacing set-up was 29 inches. Again, this fits on a standard 31-inch arbor.

PART-PRIORITIZATION STRATEGIES

Three part-prioritization strategies have been incorporated into this experimental design; two that best reflect what is commonly applied in industry practice and one to suggest the optimal. As with cutting bills, it is important to determine whether differences in part-prioritization strategies will affect the present board-length/part-yield analysis. The part-prioritization strategies include the following:

1. The static strategy for emphasizing longer length parts, but without regard for quantity (8):

$$Priority = L^2 \times W$$

where L = length; W = width.

2. The basic dynamic strategy that incorporates quantity based on "need" (8):

$$Priority = L^2 \times W \times N$$

where N = need, which is the quantity of a specific part size required at a particular moment in time.

3. The complex dynamic exponent strategy (CDE) uses an exponential weighting factor (WF) based on quantity requirements but with an emphasis on increasing the priority of parts having low initial quantities. This allows those parts to be obtained at earlier, more opportunistic times. CDE not only puts emphasis on longer parts, but also prefers wider parts to narrower parts of the same length and quantity (8).

$$Priority = L^{WF\ length} \times W^{WF\ width}$$

As previously mentioned, the CDE strategy was included because it best represents the optimal-part quantities and needs are updated continuously. However, it is unlikely that many rough mills can or do update parts consistent with this high level of control.

ROMI-RIP SET-UP

Aside from three primary variables in this study (board lengths, cutting bills, and part-prioritization strategies), the remaining parameters that have been included in the ROMI-RIP set-up are presented in **Figure 1**. These parameters were held constant for all simulations. A

TABLE 1. — Yield results from ROMI-RIP simulations of two furniture/cabinet cutting bills showing the effect of lumber length on yield.[a]

		% Part yield: "easy" cutting bill			% Part yield: "hard" cutting bill		
Part prioritization	Reps.	7 to 8 ft.	11 to 12 ft.	15 to 16 ft.	7 to 8 ft.	11 to 12 ft.	15 to 16 ft.
$L^2 \times W$	1	59.7	63.0	66.0	52.5	55.5	58.6
	2	59.4	63.6	65.7	52.9	55.7	58.1
	3	59.7	63.4	66.0	52.1	54.9	59.1
	4	59.5	63.1	66.5	52.5	55.5	59.0
	5	59.5	63.8	65.6	52.1	56.0	59.1
	Average	59.6	63.4	66.0	52.4	55.5	58.7
	SD	0.1	0.3	0.3	0.3	0.4	0.4
$L^2 \times W \times N$	1	60.9	63.5	66.0	53.8	56.0	60.0
	2	59.9	62.9	65.2	54.2	55.7	59.6
	3	60.3	63.7	66.8	54.6	57.5	59.7
	4	60.2	63.3	65.5	54.0	56.5	59.0
	5	60.8	63.5	66.0	54.4	56.3	59.5
	Average	60.4	63.4	65.9	54.2	56.4	59.6
	SD	0.4	0.3	0.6	0.3	0.7	0.4
CDE	1	67.8	69.3	71.6	58.2	59.8	63.6
	2	67.7	69.0	71.6	58.1	59.4	63.2
	3	67.6	68.8	71.3	58.4	59.7	63.8
	4	67.6	69.2	71.2	57.9	59.6	63.5
	5	67.7	69.1	71.3	57.9	60.0	64.0
	Average	67.6	69.1	71.4	58.1	59.7	63.6
	SD	0.1	0.2	0.2	0.2	0.2	0.3

[a] SD = standard deviation; CDE = complex dynamic exponent strategy.

TABLE 2. — Yield increases associated with processing three different lumber lengths to fill two furniture/cabinet cutting bills.[a]

	% Part yield for "easy" cutting bill			% Part yield for "hard" cutting bill		
Part prioritization	(7 to 8 ft.) to (11 to 12 ft.)	(11 to 12 ft.) to (15 to 16 ft.)	(7 to 8 ft.) to (15 to 16 ft.)	(7 to 8 ft.) to (11 to 12 ft.)	(11 to 12 ft.) to (15 to 16 ft.)	(7 to 8 ft.) to (15 to 16 ft.)
$L^2 \times W$	3.8	2.6	6.4	3.1	3.2	6.3
$L^2 \times W \times N$	3.0	2.5	5.5	2.2	3.2	5.4
CDE	1.4	2.3	3.8	1.6	3.9	5.5
Average	2.7	2.5	5.2	2.3	3.4	5.7

[a]CDE = complex dynamic exponent strategy.

total of 90 simulations were conducted and analyzed: 3 length groups × 2 cutting bills × 3 part prioritizations × 5 repetitions = 90 simulation runs.

STATISTICAL ANALYSIS OF RESULTS

Multiway ANOVA was conducted on the data using SAS® statistical software (6) with a level of significance of $\alpha = 0.05$. The model tested was a three-way ANOVA with equal replication (5 yield measurements per cell). All pairwise comparisons were of interest. For multiple comparisons of mean yields, the Tukey Studentized Range (HSD) Test (6) was chosen over other methods because it is less likely to detect borderline significance between factors that may, in fact, not be significant. A retrospective power analysis was conducted using the SAS *Power Macro* (6) after the ANOVA was run to assess the power of the performed test. To investigate the possibility that board width might influence yield, requiring the need for covariate analysis, ANOVA was run to test for the significance of this effect as well. Average board widths for the 15 lumber files (3 length groups × 5 files in each group) created in *Makefile* were calculated and used in this analysis.

RESULTS AND DISCUSSION

ROMI-RIP 2.0 output summary reports give part yield data for each completed simulation both by grade and for the entire lumber mix combined. These results are presented in **Tables 1** and **2** and **Figures 2** and **3** for interpretive analysis and discussion. **Table 1** summarizes data from this study by organizing the part yields for all lumber grades and for each simulation. Means and standard deviations have been calculated and recorded for each set of five repetitions for each length sort, part-prioritization strategy, and for each cutting bill. **Figures 2** and **3** show average part yields for the three board length sorts for both cutting bills. It should be noted that the investigation into whether board width affected yield resulted in a nonsignificant *p*-value. Therefore, the null hypothesis, which is that there is no effect of lumber width on mean part yield, is not rejected for this study. This finding eliminates the need for covariate analysis.

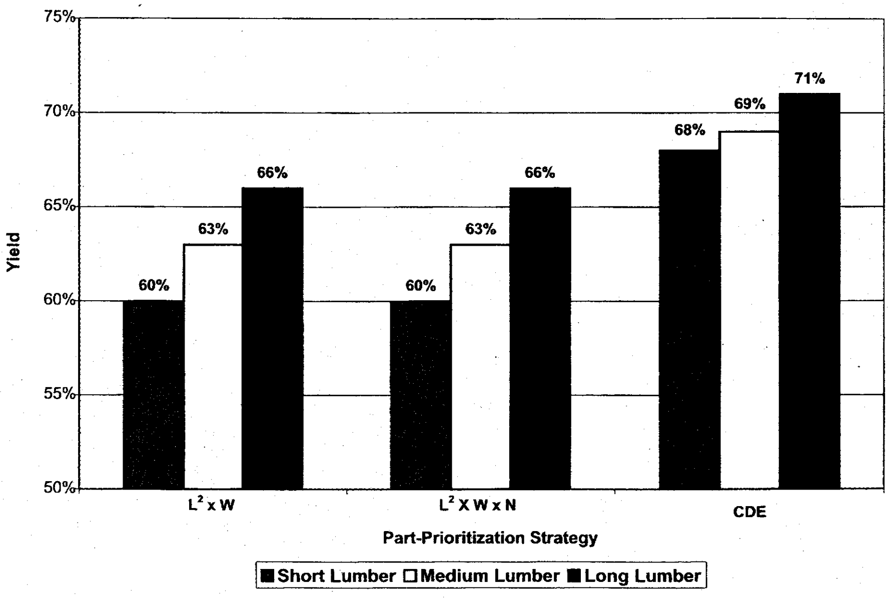

Figure 2. — The impact of lumber length on yield for the "easy" cutting bill.

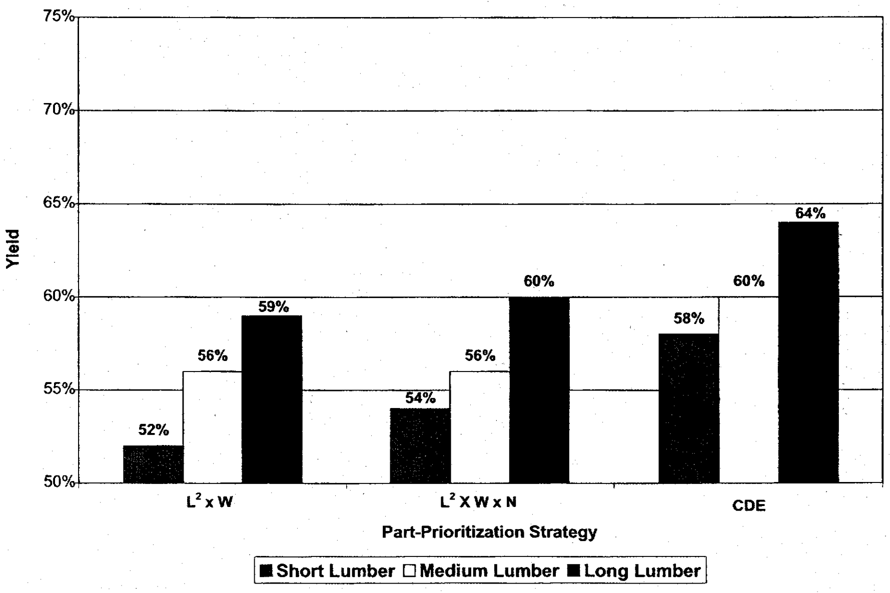

Figure 3. — The impact of lumber length on yield for the "hard" cutting bill.

The retrospective power analysis indicated that the power of the performed test was effectively 1, i.e., the sample size was more than adequate for detecting differences between main effects at a significance level of $\alpha = 0.05$.

Statistical analysis was conducted on the raw part yield data, contained in **Table 1**, using ANOVA. The basic parametric statistical results indicate that all main effects for board length sorts, part-prioritization strategies, cutting bills, and all interactions were statistically significant ($\alpha = 0.05$). The r^2 for the full ANOVA model that includes all main effect and interaction terms is 0.99 with a p-value < 0.0001. The r^2 for the model that includes main effects only is 0.97.

The contribution of the interaction terms toward explaining the total variance of the model is very small; the cutting bill*part prioritization strategy is the most important interaction effect as it accounts for 0.9 percent of the total sum of squares. Part priority*length, cutting bill*length, and cutting bill*part priority*length account for only 0.5, 0.1, and 0.1 percent of the total model sum of squares, respectively. In total, the four interaction effects account for only 1.6 percent of the model sum of squares. Thus, the main effects account for 98.4 percent of the model sum of squares.

To further assess the importance of the interaction effects, treatment mean plots were prepared and examined. Plots were constructed for each pair of main effects and these were plotted against all levels of the remaining effect. The plots were examined for parallelism, which would indicate a lack of meaningful interaction among main effects. With a couple minor exceptions (which were not large enough to cause intersection of the plotted yield curves), pronounced parallelism of the yield curves was evident. In combination, the low contribution of the interaction terms to the sums of squares and the parallelism of the interaction plots leads to the determination that the addition of the interaction terms to the reduced (main effects) model is unimportant; for a discussion of technique see Neter et al. (5).

The Tukey multiple comparison test was used to conduct pairwise comparisons of the factor levels (i.e., short vs. medium vs. long lumber length groups, easy vs. hard cutting bill, and $L^2 \times W$ vs. $L^2 \times W \times N$ vs. CDE prioritization strategies) for all significant main effects. The Tukey comparisons indicated that within each main effect no factor levels were similar ($\alpha = 0.05$).

Without exception, rough mill yields increased with increasing board length for both cutting bills and for all three part-prioritization strategies. **Table 2** summarizes the yield increases due to length as a function of part-prioritization strategy for both easy and hard cutting bills. Also, the average length-based yield difference for all three part-prioritization strategies is given. For the easy cutting bill, average part yield was 2.8 percent higher for 11- to 12-foot lumber than for 7- to 8-foot lumber. It was 2.5 percent higher for 15- to 16-foot lumber than for 11- to 12-foot lumber. Yield for the 15- to 16-foot lumber was 5.2 percent higher than for the 7- to 8-foot lumber.

Looking at the easy cutting bill results (**Table 2** and **Fig. 2**), with focus on individual part-prioritization strategies, the increase in yield associated with increased lumber length was greatest when employing the static ($L^2 \times W$) and basic dynamic strategies ($L^2 \times W \times N$). These were 6.4 and 5.5 percent, respectively compared to 3.8 percent for the CDE strategy. For this case, lumber length has less impact when using the CDE strategy because of the inherent ease of cutting parts that is associated with the easy cutting bill and the optimal performance (parts updated continuously) of the CDE. Here, the part yields were already quite high to begin with, such that increases in lumber length did less to improve yields. Where parts cannot be updated continuously, using longer boards will allow more opportunity for yield improvements. These results indicate the length factor is more important for mills that have less sophisticated process control.

For the hard cutting bill (**Table 2** and **Fig. 3**), average yield was 2.3 percent higher for 11- to 12-foot lumber than for 7- to 8-foot lumber. It was 3.5 percent higher for 15- to 16-foot lumber than for 11- to 12-foot lumber. Yield for the 15- to 16-foot lumber was 5.8 percent higher than for 7- to 8-foot lumber. The length-based yield differences are larger for the hard cutting bill than for the easy cutting bill. This is likely due to the difficulty in obtaining the longer parts from short lumber. However, these results, in general, indicate that similar and substantial yield improvements from using longer length lumber can be achieved regardless of the difficulty inherent in the cutting bill. The fact that yield improvements were better for longer lumber using the hard cutting bill represents a best-case scenario for part yield improvement when it comes to making decisions regarding efficiency.

Also, with respect to the hard cutting bill, the yield differences between the part-prioritization strategies were not as variable for the different lumber length sorts (**Table 2**). However, an increase of almost 4 percent was recorded for the CDE strategy when lengths increased from 11- to 12-foot lumber to 15- to 16-foot lumber. This indicates that when cutting difficulty increases, there is more opportunity for increases in lumber length to improve yields than there is for easier cutting bills, even when parts are updated continuously. The ability to update parts continuously using the CDE strategy allows the rough mill to better realize the yield improvements that longer boards can achieve. This result, combined with the observation that the other two prioritization strategies ($L^2 \times W$ and $L^2 \times W \times N$) also increased yield more over this length range, indicates that potential yield improvements when processing the hard cutting bill, are greatest when lumber length is increased from intermediate (11 to 12 ft.) to long (15 to 16 ft.). However, they still fall short of optimal gains (average yields are still lower than for CDE) due to lack of perfection in updating part requirements. These results indicate the length factor is more important for mills that have less sophisticated process control and more difficult cutting orders.

CONCLUSIONS

Most rough mills today are designed to accommodate and process lumber material with lengths ranging from 8 to 16 feet. Yet, little attention has been given to the significance with which board length impacts yield, and ultimately, how this affects productivity and profitability. In this study, ROMI-RIP computer simulations were used to determine if the part yield obtained from different length lumber of the same grade mix would differ. Simulation results were compared for shorter boards (7 to 8 ft.), intermediate length boards (11 to 12 ft.), and long boards (15 to 16 ft.) using two cutting bills and three part-prioritization strategies. The results of this study indicate that, in a gang-rip-first rough mill, lumber yield improves when longer boards are processed. Overall, average part yields increased by more than 5 percent when using long boards compared to the shorter boards. Furthermore, these increases are only minimally affected by differences in part-prioritization strategies or cutting bill scenarios, less than 1 percent in most cases, and only slightly more for scenarios using the CDE strategy. Subsequent statistical analysis supported these findings with the conclusion that statistically significant differences in part yields exist between the three lumber length sorts for both cutting bills and for all three part-prioritization strategies.

Yield increases of 2.5 to 5.8 percent associated with 4-foot increases in lumber length are large and meaningful. Given lumber costs, which typically are 50 percent of the cost of sales in rough mill operations, a large investment in mill equipment to enable the rough mill to improve its lumber sorting and dry storage control strategies can be justified. This investment should greatly improve the process of matching lumber lengths with cutting bill requirements.

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