VALIDATION OF THE ROMI-RIP ROUGH MILL SIMULATOR

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ABSTRACT

The USDA Forest Service's ROMI-RIP rough mill rip-first simulation program is a popular tool for analyzing rough mill conditions, determining more efficient rough mill practices, and finding optimal lumber board cut-up patterns. However, until now, the results generated by ROMI-RIP have not been rigorously compared to those of an actual rough mill. Validating the ROMI-RIP processing model involved comparing gang-rip, chopsaw, and overall yields to those obtained in an actual state-of-the-art rough mill. A 930-board-foot lumber sample was digitized by recording all defect locations, sizes, and types as well as board size and grade, allowing the rough mill and ROMI-RIP to process identical lumber samples. Results showed that the ROMI-RIP software accurately simulated the actual rough mill when the software exactly simulated the actual rough mill's settings.

Banks (2) defines simulation as "the imitation of the operation of a real-world process or system over time." Today, simulation models are most commonly developed and run on computer systems that allow an almost infinite number of variables and calculations to be processed. Simulation software is intended to allow users to simulate a real process on the computer without having to actually carry out the process in reality. This way, different scenarios can be analyzed and compared for problem-solving and decision-making purposes without the need to execute the actual process. However, since actual decisions are made based on simulation results, the software must be carefully tested for its validity (15).

Rough mill simulation software was one of the earliest applications of simulation technologies in the wood industry. Simulation is needed to solve the lumber cut-up problem due to a lack of generally applicable mathematical models for finding optimum cutting patterns. Before the advent of computing techniques, producers relied on traditional methods and their own experience to find good board cut-up patterns and estimate expected part yields. Today there are two basic types of simulation available for analyzing rough mills: flow and cut-up. Flow simulation examines the movement of materials through a rough mill as well as interactions with operators and equipment over time. Cut-up simulation is useful for investigating the production of parts from lumber. Often, flow-simulation models depend on cut-up simulators to provide processing information, such as operations performed and parts obtained. In this paper, simulation refers only to the cut-up type.

In the early 1960s, R.J. Thomas pioneered the use of computers to simulate lumber cut-up (20). Several other researchers later created more effective and applicable models. Today, Steele and Harding's RIP-X software (17) and Thomas' ROugh MIll RIP-first simulator (ROMI-RIP) (18) are the most widely used lumber cut-up simulation tools.

Numerous studies (4,5,7-9,13, among others) have relied on results generated by the ROMI-RIP simulation package. However, despite its widespread use, ROMI-RIP has never been validated. As Buehlmann et al. (4) pointed out, to allow the future use of ROMI-RIP in actual rough mills, verification and validation of the program are of crucial importance. Simulation model verification refers to verifying that the software code of the computerized model and its

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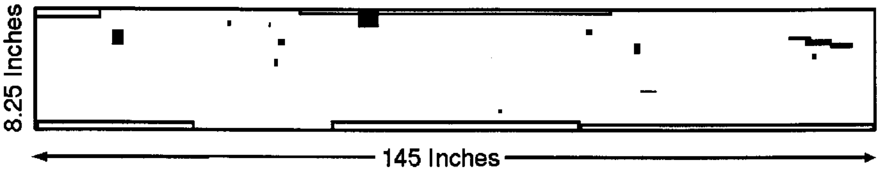

Figure 1. — Sample board showing digitized character marks.

TABLE 1. — Characteristics of the lumber sample as determined by UGRS.

Lumber grade	Board footage	Board count	Board footage as percent of total	Board count as percent of total
	(BF)[a]			
F1F	77	11	8.3	7.0
Selects	63	17	6.8	10.8
1 Common	480	77	51.6	48.7
2A Common	241	39	25.9	24.7
3A Common	69	14	7.4	8.8
Total	930	158	100	100

[a] BF = board feet.

implementation is correct (15). Validation, on the other hand, is defined as "*substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model* (16)." These two activities - verification and validation - often are intertwined activities in practice (12). Since ROMI-RIP was verified earlier, this study focuses on validation. There are several techniques for model validation (12,15). Since rough mills that optimize the cut-up of lumber for yield exist, ROMI-RIP could be validated using the Input-Output Transformation technique (2). However, because the optimization algorithms in rough mills are not the same as those used by ROMI-RIP, yield differences must be expected.

So far, little research has been done to validate rough-mill simulators. Kline et al. (13) found that ROMI-RIP produces higher yields than a state-of-the-art rough mill (69.1% versus 65.6%). However, ROMI-RIP was configured to generate optimum yield for a set of lumber. As a consequence, the results were inconclusive for validation purposes. RIP-X (17) was verified and validated in 1997 using Input-Output Transformation (10). There was good agreement in yield obtained by the actual mills observed and by simulation. In four tests in two mills, there were no significant differences in yield between actual and simulated operations. This is remarkable because each operation used a different set of boards.

Objectives

The goal of this research was to validate the use of ROMI-RIP version 2.00 (RR2) (18) for use in actual cut-up operations. We present yield comparisons between lumber processed in a rip-first rough mill and a simulated cut-up using RR2. The different operations: gang-ripping, crosscutting, and overall (gang-ripping and crosscutting combined) were analyzed separately. These comparisons allow the validation of RR2. For this study, we considered the following performance criteria:

Overall yield: the total yield resulting from strip-cutting and crosscutting strips to part lengths.

Strip yield: the yield obtained by the two systems when converting boards to strips.

Crosscut yield: the yield obtained by the two systems when chopping strips to part lengths.

The validation was defined as successful when no statistically significant yield differences at the 95 percent of significance level between actual and simulated overall average yields for the same test runs could be detected. Furthermore, if we did not detect significant yield differences at the 95 percent level for individual steps within the entire cut-up process (ripping and chopping), ROMI-RIP could also be claimed to be a true representation not only of the overall rough mill process but also of the individual steps involved in the cut-up of lumber.

Methods

Lumber sample

To compare actual rough mill operations to simulation results, a sample of 4/4-inch-thick, kiln-dried red oak lumber was obtained from a sawmill in the central Appalachian region. Red oak boards were selected randomly from the resorting-infeed station after kiln-drying at the sawmill. The boards (**Fig. 1**) were then digitized, recording for each board its dimensions, defect sizes, types, and locations using the methodology described in Anderson et al. (1). We then used the USDA Forest Service's Ultimate Grading and Remanufacturing System (UGRS) for a nonbiased determination of the lumber quality (14). The grade distribution of the lumber sample by board footage and count is shown in **Table 1**.

Cutting bill

The boards were ripped and chopped to the part sizes specified in the cutting bill (**Table 2**). This bill is from an actual rough mill and is typical of those processed in today's furniture rough mills. Quantities were adjusted to permit the cutting bill to be satisfied using the 930-board-foot sample available for this study. Parts were prioritized by the same assigned values in both simulation and at the chopsaw in the rough mill. These values were calculated using the L^2W formula (19) and scaling the values such that the maximum value was 1,000.

Rough mill

Processing began by gang-ripping the boards on a 24-inch Mereen-Johnson 424 gang ripsaw equipped with Barr-Mullin Compu-Rip gang-ripsaw optimizer software for finding optimum rip decisions. The optimizer did not consider the required quantity or area of parts by width required by the cutting bill. The saw spacings on the arbor were arranged using the GRADS program (6). The resulting saw spacing solution for the arbor, considering cutting bill width requirements and the width distribution of the lumber sample, is:

2.00 - 2.00 - 2.00 - 2.00 -
3.50 - 1.75 - 3.50 - 2.00

After ripping, the strip widths and sequence of the resulting strips were recorded for each board along with the occasional edging strip widths.

The strips were then processed by a Barr-Mullin Turbo Wondersaw crosscut saw. This saw read marks on the boards placed by operators to determine the location of defective and acceptable areas. The sawblade was removed from the chopsaw to preserve the strips and to allow multiple runs with the same lumber. Part counts and resulting yields were collected from the controlling computer. To simulate different qualities of lumber, four runs were made. For each run, the marker at the chopsaw was given a different set of character marks (defects) that were acceptable in the parts. Marks from the previous run were sanded away prior to the next run. First, no character marks were allowed in the parts, producing Clear-Two-Face (C2F) parts. Thereafter, character marks with an area described by a circle of 1/2 inch in diameter (i.e., an area of 0.1963 in.^{2}), then 1-inch diameter (0.7854-in.^{2}), and finally 2-inch diameter (3.1416-in.^{2}) were allowed on both sides of the parts. This methodology of incorporating character marks is the same as described by Buehlmann et al. (5). Since the inclusion of different sets of character marks in the boards creates different sets of clear areas to be optimized by the software for maximum yield, we treat each of these four runs as different, independent runs.

To support the marker, a special transparent plastic jig with allowable character mark sizes was prepared that showed the allowable character-mark area for a given run as a geometrical shape, such as circles, ellipses, squares, or rectangles (**Fig. 2**). The marker could place the jig on a character mark and assess if the area was within the allowable size. However, since we were aware that this measure would not assure 100 percent accuracy, we corrected inaccuracies of the marker by adapting the digitized boards used for the computer solution to precisely reflect the data set identified by the strip marker. For example, often the marker ignored small character marks less than 1/4 inch in diameter for the C2F parts run. These missed marks were then also excluded in the digitized lumber sample. This method ensured that the actual mill and the simulation processed exactly the same set of lumber with identical character marks.

TABLE 2. — Cutting bill part size and quantity requirements.

Part no.	Part width	Part length	Quantity	Part prioritization value
	----------- (in.) -----------			
1	3.50	67.00	12	1,000
2	3.50	57.00	6	724
3	3.50	43.50	6	422
4	3.50	33.50	12	250
5	3.50	31.25	30	218
6	3.50	29.50	12	194
7	3.50	27.50	6	168
8	3.50	25.50	12	145
9	3.50	20.50	18	94
10	3.50	18.25	62	74
11	2.00	65.25	18	542
12	2.00	59.00	36	443
13	2.00	49.50	33	312
14	2.00	43.50	18	241
15	2.00	35.75	55	163
16	2.00	31.25	49	124
17	2.00	29.50	18	111
18	2.00	27.50	90	96
19	2.00	25.50	130	83
20	2.00	23.00	113	67
21	2.00	20.50	204	54
22	2.00	18.25	36	42
23	1.75	65.25	30	474
24	1.75	43.50	30	211
25	1.75	27.50	30	84
26	1.75	25.50	30	72

The accuracy of the marks-scanner of a mark-sensing chopsaw is an important factor that can affect yield. Missed marks or cutting too far away from a mark decreases yield and increases part rejections. Before the validation study began, the chopsaw was calibrated to set its accuracy with respect to the marks. We also performed an experiment to determine the number of marks typically missed by the saw. Of 541 marks on 35 strips (total length 401 ft.), only 6 marks (1.11%) were missed. Thus, we believe that this low percentage of missed marks would not significantly affect the validation and did not adjust the results.

SIMULATION

A series of simulations was conducted using RR2 (18). Specifically, we looked at three different sets of yield results: overall, ripsaw, and chopsaw. Comparing only overall yield is not sufficient as yield differences between simulated and actual ripping and chopping might not be apparent. Ripping was simulated

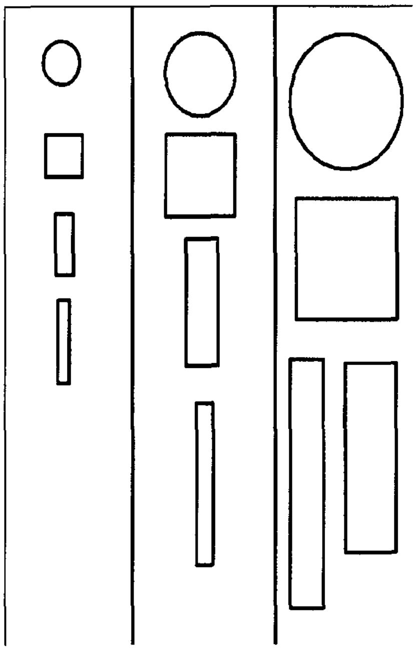

Figure 2.— Template used in rough mill to measure defect sizes for inclusion in parts.

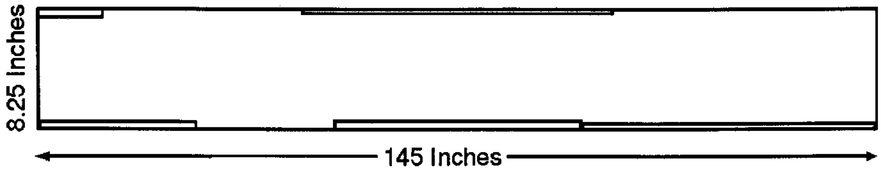

Figure 3.—Sample board from Figure 1 with only edge character marks included.

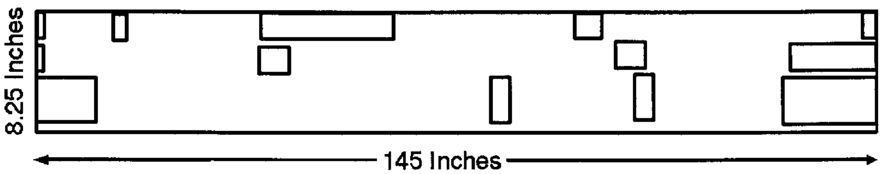

Figure 4. — Sample board from Figure 1 showing character marks as marked at chopsaw.

so that it matched as closely as possible the rough mill's ripsaw settings. In the mill, the ripping operation optimized the conversion rate of boards to strips based on maximizing strip area only, without consideration of character marks or cutting bill requirements. The only character marks considered by the mill's ripping operation were those located along the edge of the board. These were indicated by the ripsaw operator setting laser beams inside the board edges due to significant edge character marks, such as wane. Further, no consideration of the required part quantities or strip area by part width was used other than the arrangement of the saw spacing widths on the arbor, as calculated by the GRADS software (6). To simulate actual ripsaw operations, we used RR2s Fixed-Blade-Best-Feed arbor type with the same saw spacings as the mill's ripsaw. This arbor selection best reproduces the arbor controls and optimizer used in the rough mill. These choices allowed RR2 to gang-rip all the sample boards into strips using the same optimization goals as the rough mill.

The board data set used for the simulation had to be adapted to reflect the real system. A data sample, *Edge-Only*, was generated that included only character marks located along the edges, such as wane. **Figure 3** shows the *Edge-Only* version of the board shown in **Figure 1**. By presenting only character marks along the edges to the program, the optimization was done based only on part yield from clear area. To complete the comparison, a special cutting bill was created that specified a quantity of 10,000 for each part and thus prioritized parts based on area alone. This ensured that no part requirements could be met with the boards available and that all arbor positions were considered for each board. This way, RR2 was prevented from using one of its powerful features, namely its ability to de-emphasize ripping certain widths to avoid the production of orphan parts as part requirements for a given part are met (an orphan part is a primary part that has been cut, but for which there is no longer a need.) This feature reduces strip yield, producing only strips required by the cutting bill, but increases both overall yield and processing capacity. However, this de-emphasizing feature did not correspond to the rough mill in the study and therefore these other measures were taken so that the two gang-ripping procedures would be more comparable.

In the next step, we compared the two chopsaws. Since the ripping of the boards was performed physically on the mill's ripsaw, the simulation chopsaw had to be evaluated using the same strip solution as produced by the mill's ripsaw. A special version of RR2 was developed that referenced a file containing the strip widths and sequences of the strips sawn in the mill. This allowed the simulation software to exactly reproduce the mill's strips, permitting direct comparison of RR2's and the mill's chopsaw performance.

The accuracy of the marker greatly influences rough mill yield (3). Poor marking, such as marking too far away from character marks or missing character marks entirely, results in poor yield and rejected parts. However, for this study, the performance of the marker was of no importance since we adjusted all digital board data according to the marker's character-mark classifications. Thus, only character marks recognized and marked by the marker were included in the boards and strips that were processed by the simulation software. Mark locations were recorded for every strip of each board processed to ensure that the board data for simulation corresponded exactly to the marks processed in the mill.

Two forms of the board data were generated: *digitized* data and *marked-CM* data. **Figure 1** shows a board from the actual lumber data sample showing all character marks located and identified on a board during digitization. Board data from this sample are referred to as *digitized*. The character marks as identified by the marker on the strips from the ripsawing operation for the same board are shown in **Figure 4**. Note that the marked areas correspond to the strips on which the marks were made because the marker always marked the entire strip widths. Board data from this sample are referred to as *marked*. The *marked* data were used by RR2 to produce chopsaw results that can be compared with the rough mill's chopping operation. Results based on this configuration are shown under the "Simulated yield marked runs with rough mill strips" column in **Table 3**.

To obtain statistical data about the variability of the results when using RR2, the board data were randomly sequenced four times. This ensured that the samples processed were representative of usual operations and that no chance sequences of high or low quality boards would falsify the results. For the statistical tests we used regular, two-tailed t-tests at the 95 percent significance level unless otherwise noted.

RESULTS

STRIP YIELD COMPARISON

The strip yield achieved when not considering part quantities and character mark locations by the rough mill's ripsaw was 84.12 percent versus 91.52 percent for the simulated strip yield us-

TABLE 3. — Actual and simulated rough mill yield data (all numbers in percent.)

Character mark size	Board data file	Simulated yield marked runs with rough mill strips			Actual rough mill yields		
		Strip yield	Chopsaw yield	Overall yield	Strip yield	Chopsaw yield	Overall yield
		(%)					
Clear	a	83.68	74.24	62.12			
	b	85.45	74.86	63.97			
	c	85.33	73.84	63.01			
	d	85.54	74.13	62.93			
	Mean/actual	85.00	74.27	63.01	84.12	76.06	63.98
	Difference	0.88	-1.79[a]	-0.97			
	SD[b]	0.884	0.430	0.757			
0.5	a	85.63	81.93	70.16			
	b	85.73	81.94	70.25			
	c	85.14	81.62	69.49			
	d	84.07	81.60	68.60			
	Mean/actual	85.14	81.77	69.63	84.12	81.24	68.34
	Difference	1.02	0.53	1.29			
	SD	0.760	0.188	0.763			
1.0	a	84.52	85.16	71.98			
	b	84.97	85.52	72.67			
	c	85.09	84.91	72.25			
	d	85.81	85.02	72.95			
	Mean/actual	85.10	85.15	72.46	84.12	85.57	71.98
	Difference	0.98	-0.42	0.48			
	SD	0.535	0.266	0.432			
2.0	a	84.09	86.60	72.82			
	b	83.49	87.19	72.79			
	c	84.24	86.74	73.07			
	d	84.22	86.81	73.11			
	Mean/actual	84.01	86.84	72.95	84.12	86.65	72.89
	Difference	-0.11	0.18	0.06			
	SD	0.353	0.252	0.166			
Average	Mean/actual	84.81	82.01	69.51	84.12	82.38	69.30
	Difference	0.69	-0.37	0.21			
	SD	0.77	4.99	4.13	0.00	4.82	4.05

[a] Significantly different at 95 percent level.
[b] SD = standard deviation.

ing the *Edge-Only* board data (**Table 4**). This difference of 7.40 percent was highly significant at the 99 percent level. All four repetitions generated a strip yield of 91.52 percent because of the high part quantity requirements of the cutting bill used in the simulation. This prevented RR2 from meeting the part requirements of any strip width and thus prevented the removal of any width from the range of optimization choices. Thus each board, no matter what sequence it may be processed in, was ripped the same way for each of the four repetitions. This setup was necessary to mimic the actual ripsaw operation, which never removes strip widths from its optimization choices.

Chopsaw yield comparison

Actual rough mill yields for ripping, chopping, and overall for the four runs processed are shown in **Table 3**. As discussed in the Methods section, the same set of strips obtained from the ripsaw were processed four times at the chopsaw with different marking specifications each time. The yields achieved by the chopsaw were 76.06, 81.24, 85.57, and 86.65 percent for clear parts (C2F) and parts with character-marks of 0.5, 1.0, and 2.0 inches in diameter, respectively.

To compare simulated and actual chopsaw yields, any potential yield variations due to differences in strip yield had to be removed. As discussed earlier, this was achieved by referencing a special version of RR2 to a set of board data containing the mill's ripsaw solutions. The mill's chopsaw results are shown in **Table 3** under the column "Actual rough mill yields" and the equivalent simulation results are shown under the column "Simulated yield marked runs with rough mill strips." You may note that "Strip yield" in these columns differs in yield up to 1 percent compared to the actual rough mill strip yield. However, this

TABLE 4. — *Actual and simulated rough mill ripsaw yield data (all numbers in percent.)*

	Board data file	Simulated yield edge-only runs			Actual ripsaw yield		
		Strip yield	Chopsaw yield	Overall yield	Strip yield	Chopsaw yield	Overall yield
		(%)					
All area	a	91.52	NA	NA			
	b	91.52	NA	NA			
	c	91.52	NA	NA			
	d	91.52	NA	NA			
	Mean	91.52	NA	NA	84.12	NA	NA
	Difference	7.40[a]	NA	NA			
	SD[b]	0.00	NA	NA			

[a] Significantly different at 99 percent level.
[b] SD = standard deviation.

difference is due to differences in the algorithms calculating yield and was not significantly different at the 95 percent level. In the rough mill, all the boards were processed into strips before any chopping began and strip yield was calculated for the entire board population. However, RR2 operates by ripping and chopping each board in turn. Thus, RR2 calculates a strip yield for only those boards processed, not all boards in the board sample. Since we used the same cutting bill as in the rough mill for this study, but RR2 achieved a higher chopsaw yield, the program did not process all the boards (only 95% to 99% of total, depending on the test). Thus, a small yield deviation between the actual test and the simulation was created. The rough mill's chopsaw yield was found to be 76.06, 81.24, 85.57, and 86.65 percent for clear parts, 0.5-, 1.0-, and 2.0-inch-diameter character mark runs, respectively (**Table 3**). RR2's chopsaw yield for the same runs was 74.27, 81.77, 85.15, and 86.84 percent (**Table 3**). With the exception of the clear part runs, these results were not significantly different at the 95 percent level using double sided t-tests.

Overall yield comparison

Overall yield (e.g., ripping and crosscutting) for the actual mill was 63.98, 68.34, 71.98, and 72.89 percent for clear parts, and parts with 0.5-, 1.0-, and 2.0-inch-diameter character marks allowed in the parts, respectively. The simulated overall yields using the rough mill's gang-rip strip solutions were found to be 63.01, 69.63, 72.46, and 72.95 percent for clear parts, 0.5-, 1.0-, and 2.0-inch-diameter character marks allowed in the parts, respectively. These results are shown in **Table 3** in the column "Simulated yield marked runs with rough mill strips" under the heading "Overall yield." None of these results between actual mill and simulation was significantly different at the 95 percent level.

Average yield comparison

The average yield over all runs (i.e., clear parts, 0.5-, 1.0-, and 2.0-in.-diameter character marks allowed) confirm the observations stated so far. Observed average mill yields were 84.12, 82.38, and 69.30 percent for strip, chopsaw, and overall yields, respectively (**Table 3**). The simulated yields using the mill's strip solutions were 84.81, 82.01, and 69.51 percent as shown in the column "Simulated yield marked runs with rough mill strips" (**Table 3**). These results were not significantly different at the 95 percent level from the ones observed in the mill. It can be concluded that RR2 is a valid representation of an actual rough mill.

Discussion

This study allowed a true validation of the RR2 software since, as Kleijnen (11) states, "*true validation requires that data on the real system be available.*" Based on the findings of this study, RR2 was fully validated as a "correct" representation of the actual rough mill used as a "real world model." Since the Mereen-Johnson and Barr-Mullin rough mill combination employed for this study is widely used in the American wood industry, many rough mill managers can now access a verified and validated lumber cut-up simulation model for their mill. For users of different systems, RR2 still should be a good representation, since these systems tend to work on similar principles and achieve similar results.

Ripping was the area with the largest yield difference between the actual rough mill and the simulation model. When RR2 was fed with lumber boards without character marks except the ones on the edges (**Fig. 3**), the yield from the simulation was 7.40 percent higher (highly significantly different at the 99% level, **Table 4**) compared to the one achieved in the rough mill. Clearly, RR2 isn't a valid representation of the ripsaw solution in the mill used.

This large yield difference was a surprising, since the optimization problem at hand (to optimize a given usable board width with any combination of 1,75-, 2.00-, and 3.50-wide strips) seems quite straightforward. Reasons for this problem could be either mechanical (board positioning) or software related (optimization algorithm). However, the problem doesn't appear to be manufacturer specific, since rip-yields around 85 percent can be observed with other systems as well. This observation points out an area for improvement for ripsaw manufacturers.

To be able to validate the chopsaw and the overall cut-up operation, RR2 was instructed to adhere closely to the strip solution produced by the actual ripsaw. Once these modifications were in place, no significant yield differences between the actual and simulated ripsaw were found. Unfortunately, this required some software manipulations that are not easily repeated by the average user. However, future versions of RR2 may include a way to force the program to adhere more closely to the inferior strip solution produced by today's ripsaws.

Using this modification, the average chopsaw yield turned out to be similar for the two systems. For the average of the four tests, no significant yield difference was found. For the individual tests, only the one when producing clear parts was found to be significantly different at the 95 percent level. We explain this observation by the difficulty the simulation had processing the mill's sub-optimal strip solution. Although RR2 and the rough mill prioritized parts in the same manner, the underlying optimization systems are likely different. Since RR2 had to work with a solution created by the actual rough mill software, no optimum solution was achieved by the program.

Overall yield between actual rough mill and RR2 for all individual tests as well as on average of all tests was found to be not significantly different at the 95 percent level. When using the same processing configuration and board data for the actual and simulated runs, the average overall actual yield difference between the real rough mill and the simulation was only 0.21 percent. Based on the criterion for successful validation described in the Objectives section, RR2 clearly was validated to be a true representation of a real rough mill system. RR2, although a valid model of real systems, also offers the potential to assess the potential yield improvements in real rough mills. Since RR2 has some advanced optimization features and does not suffer from human error, the program is able to pinpoint the achievable performance of rough mills of the future. This potential will be shown and discussed in a future paper.

SUMMARY

RR2 is a rough mill simulator that generates optimum primary yield or the maximum prioritized value of parts. The intended use of the simulator is to determine potential yield and cutting operations for user-specified cutting bills, processing options, and lumber grade mixes. This allows users to determine more efficient and cost-effective processing strategies and optimum cutting patterns for lumber boards, thus reducing waste. Since the simulation software is widely used for academic and non-academic work, careful validation was needed.

For the validation of RR2, the simulation program was compared to an actual state-of-the-art rough mill. Every effort was made to make the systems comparable. RR2 outperformed the actual ripsaw system by more than 7 percent, despite the fact that the lumber material processed by both systems was exactly the same. However, once RR2 was forced to adhere to the strip solution produced by the actual ripsaw, no significant yield difference between the actual rough mill and the simulation model could be found for the chopsaw and for the overall system. This study clearly demonstrated that RR2 satisfactorily simulates the real world system and can confidently be used for analytical purposes.

The RR2 simulation software is available free of charge from the USDA Forest Service, Forestry Sciences Laboratory, 241 Mercer Springs Road, Princeton, WV 24740; 304-431-2700; ethomas@fs.fed.us

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