Performance review of the ROMI-RIP rough mill simulator

Edward Thomas
Urs Buehlmann*

Abstract

The USDA Forest Service's ROMI-RIP version 2.0 (RR2) rough mill rip-first simulation program was validated in a recent study. The validation study found that when RR2 was set to search for optimum yield without considering actual rough mill strip solutions, it produced yields that were as much as 7 percent higher (71.1% versus 64.0%) than the actual rough mill. However, since rough mills are starting to use lower lumber grades for dimension part production, the benefits of overall optimization, as used in RR2, could be higher. This study focuses on the potential of the RR2 software to achieve better yields than actual mills. Knowing the yield improvement possible when using computerized lumber cut-up decision making will enable rough mill managers to assess the economic feasibility of spending hundreds of thousands of dollars for vision systems and related equipment for the rough mill of the future. A significant potential exists for saving lumber and decreasing production cost by using modern, computerized yield optimization software.

Thomas and Buehlmann (8) showed that ROMI-RIP 2.0 (RR2) (9), the USDA Forest Service's rip-first rough mill simulation software, is a valid representation of actual rip-first rough mills when the software is forced to adhere closely to actual rip-first rough mill ripsaw performance. This study also indicated that RR2 potentially offers significant yield improvement over today's state-of-the-art rip-first rough mill systems. This paper verifies and quantifies this observation using the same materials and technologies as in the validation study (8). This study and discussion are specific to rip-first rough mills and do not consider crosscut-first mills.

Theoretically, there is a vast potential for improving the utilization of wood for dimension-part producers. On average, about one-sixteenth (6.25 percent) of the original tree is converted into solid wood parts (5). Also, less than 25 percent of a log is utilized for parts, assuming 50 percent conversion rates in both the rough mill and the sawmill (11). The rest is either processed into other wood products or wasted. To produce the correct number of parts in the most economical way, the secondary wood products industry has developed and adopted different technologies and systems. Some examples of these innovations (12) include: gang-rip first rough mills, computer-based optimization of cuttings, changes in product specifications, and better use of lower quality lumber. Today, research is being done on improved computer-based yield maximization algorithms, vision systems, cutting techniques that reduce sawkerf width, cutting bill design, part prioritization systems, and other innovative ideas.

Maximum yield is defined by board area minus the area covered with unusable character marks (defects) and the loss due to sawkerfs. In Wiedenbeck et al. (13), the percentage of total board area covered by defects was determined. For FAS, Selects, 1 Common, and 2A Common lumber, an average of 1.2, 2.3, 6.8, and 9.8 percent of each board contains defects, respectively.

Approximately 3 to 8 percent of each board's area is lost to sawkerfs during processing. Small clear areas often can-

The authors are, respectively, Research Scientist, USDA Forest Serv., Forestry Sciences Laboratory, 241 Mercer Springs Road, Princeton, WV 24740; and Assistant Professor and Extension Specialist, Dept. of Wood and Paper Science, North Carolina State Univ., Raleigh, NC 27695. The authors thank the Wood Education and Resource Center in Princeton, WV, for allowing us to use its rough mill and associated facilities. We also thank Neal Bennett, Debbie Butler, and Kris Bush for their early efforts in this research. Robert L. Govett, Univ. of Wisconsin-Stevens Point, and an anonymous reviewer contributed to this paper with their helpful comments. This research was supported by the USDA Forest Serv., Northeastern Res. Sta., Newtown Square, PA. This paper was received for publication in November 2001. Article No. 9403.
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Table 1. Char acteristics 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)	(no.)		
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

Table 2. Cutting bill par t size and quantity requirements.

Part number	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

not be used due to the lack of part requirements capable of fitting in them. Because of all of these factors, yield obtained in actual rough mills is significantly lower than what is theoretically achievable. Nonetheless, there are indications that current state-of-the-art technologies and best practices in rough mills lead to inferior yield because of the way cut-up decisions are made. With the exception of the most advanced vision-based systems, all current systems optimize clear board areas in a two-step process: 1) the board's width is optimized to obtain as much strip area as possible; and 2) the strips are optimized to obtain as many (long) parts from the available clear strip area as possible. Achieving the global optimum solution is not guaranteed using a two-step approach that has two local optimum solutions. To make matters worse, the first optimization step at the ripsaw often does not take into account unusable areas (character marks) within the board, nor cutting-bill requirements.

RR2 (9) avoids the shortcomings of actual rough mill systems. The software examines every possible board cut-up solution, keeping the rip and chop solution that results in the greatest combined value of rough dimension parts. Thus, RR2 optimizes ripping and chopping operations together, not independently of one another. During the optimization process, RR2 considers character marks and cutting bill requirements when making rip and crosscut decisions. Due to this more powerful decision-making procedure, RR2 achieves higher yields than current rough mill systems. But for RR2 to help the industry increase its lumber yields, board data needs to be available in digitized form, such that a computer can search for near optimum or optimum solutions. This requires rough mills to install vision systems that cost hundreds of thousands of dollars. For the industry to assess the economic feasibility of such an investment, reliable information about realistic yield improvements is crucial.

Objectives

This study identifies potential yield improvement opportunities using the USDA Forest Service's RR2 rough mill simulator (9) for lumber cut-up in gang-rip first rough mills. The different operations (gang-ripping, crosscutting, and overall [gang-ripping and crosscutting combined]) were analyzed separately. The following performance criteria were examined:

1. Maximum unconstrained overall RR2 yield: overall yield possible when RR2 is not constrained to adhere to existing rough mill limitations.

2. Strip yield: obtained by the simulator and in the rough mill when converting boards to strips.

3. Crosscut yield: obtained by the simulator and rough mill when chopping strips from their respective rip-operation to part lengths.

For operations in which RR2 is not constrained by solutions produced by the actual ripsaw in the rough mill, the model is expected to obtain near optimal yield because of its exhaustive, iterative optimum yield search algorithms. Only if RR2 achieves the same or higher yield than the actual operation can it be assumed that the simulator's yield is closer to the optimum solution than is the rough mill. Due to the difficulties in creating mathematical cut-up optimization

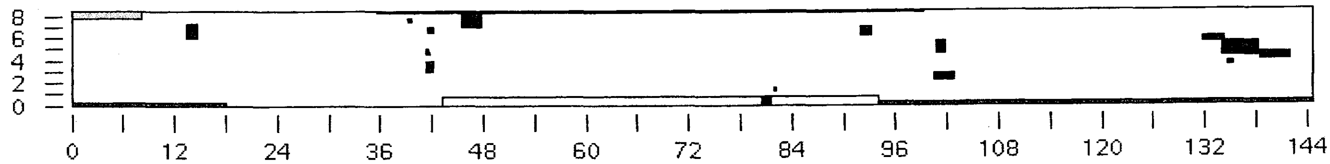

Figure 1. Sample board showing digitized character marks.

systems, the true optimum cut-up solution is not known.

Methods

The methods and materials used for this study are identical to the ones used for an earlier study, the validation of RR2 (8). Therefore, this section contains only an abbreviated summary of those methods and materials used. Please refer to the original study (8) for complete details.

Lumber sample

One-hundred and fifty-eight 4/4-inch-thick, kiln-dried red oak boards obtained from the resorting-infeed station of a central Appalachian sawmill were digitized according to the method described by Anderson et al. (1). **Figure 1** shows a sample board as recorded by the digitization process. Grades were established using the USDA Forest Service's Ultimate Grading and Remanufacturing System (UGRS) (7). More information about the lumber sample is in **Table 1**.

Cutting bill

Table 2 shows the cutting bill used for this study. We believe this cutting bill is a good representation of cutting bills currently used in rough mills. Quantities were set so the cutting-bill requirements could be satisfied using the 930 board foot lumber sample. The L^2W formula (10) was used for part prioritization and the maximum value was set at 1,000.

Rough mill

This study was conducted at the Wood Education and Resource Center's (WERC) rough mill in Princeton, West Virginia. This mill features a 24-inch Mereen-Johnson 424 gang ripsaw with Barr-Mullin Compu-Rip gang-ripsaw optimizer software. The fixed-blade arbor setup was determined using the Gang Ripsaw Arbor Design System (GRADS) (4). The following arbor spacing set-up, in inches, was used:

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

After ripping, the strip solution for every board was recorded.

The strips were then processed by a Barr-Mullin Turbo Wondersaw chopsaw. The blade was removed from the chopsaw to allow repetitive use of the strips, i.e., to allow multiple runs with the same lumber. For every run, part counts and resulting yields were collected from the controlling computer. Also, the marking solutions made by the marker for each board on every run were recorded. By recording this information and thereafter adjusting the digital boards, the cut-up of the exact same boards as were processed in the actual rough mill could be simulated. Also, every effort was made to assure that the simulation used exactly the same set-up (arbor set-up, end cuts, part prioritization, etc.) as did the actual rough mill. This way, existing differences in performance can be attributed to the optimization algorithms employed.

To simulate different lumber grades, four runs with the same lumber were made using a different set of acceptable character marks. This procedure simulated the use of different lumber grades by decreasing the effective number of defects and increasing the size of the clear cutting areas. Marks were sanded away between the runs, thus creating "fresh" strips for every run. To simulate different lumber grades, four separate runs were made. Run 1 allowed no character marks and produced Clear-Two-Face (C2F) parts. Run 2 allowed character marks with an area of 0.196 $in.^2$ (a circle with a diameter of 1/2 in.). Run 3 allowed 0.785 $in.^2$ area character marks (1-in. diameter). Run 4 allowed character marks with an area of 3.142 $in.^2$ (2-in. diameter) on both faces. Buehlmann et al. (2) describes the methods in more detail. By incorporating different sized character marks into the parts, different lumber grades were simulated for the optimization programs in both the actual rough mill and the simulation. Each one of these four scenarios was treated as an independent run for this study.

The answer to the question "Which character marks are acceptable and which aren't, based on area?" was difficult for the marker, considering the rate of work at marking stations. For this reason, a special transparent jig was prepared, helping the marker make decisions based on character-mark size. This idea is explained in more detail in the validation paper (8). Knowing that complete accuracy cannot be expected from the marker, the digitized boards were adjusted to the marker's solutions for each individual run such that the only defects present were those that were indicated by the marker. This way, the actual rough mill and the simulation processed exactly the same set of character marks.

Prior to the tests, the chopsaw mark reader was calibrated. Tests showed that the error from false readings was 1.11 percent. We decided that this low error rate would not influence our results significantly and thus did not adjust the results.

Simulation

Unlike the simulations performed in the validation paper (8), the simulations in the study did not adhere to the actual mill's gang ripsaw strip solution. Once the boards were adjusted for marker inaccuracies, RR2 performed an iterative optimum yield search. **Figure 2** shows the actual character marks that were located within the marker's areas (character marks that were marked correctly) as well as the marks along the edges (character marks that were in the edging strips from the ripsaw operation) for the C2F part run. The sizes of these character marks were obtained from the digitized board data rather than from the marks drawn by the marker. As a result, we were able to examine yields using the same character marks encountered by

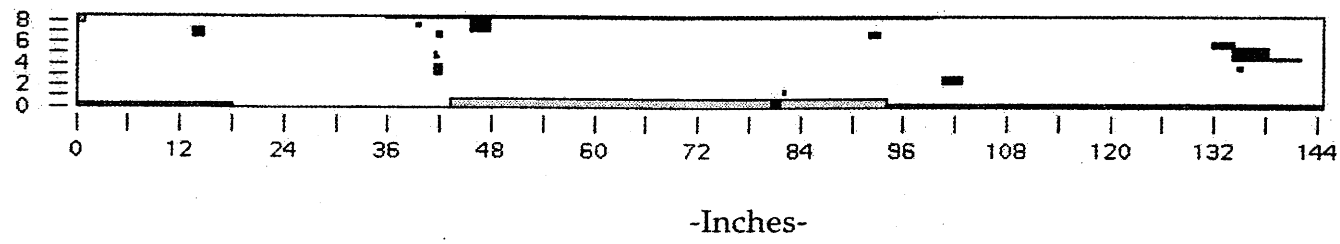

Figure 2. *Sample board from Figure 1 showing only character marks included in marked areas and along edges.*

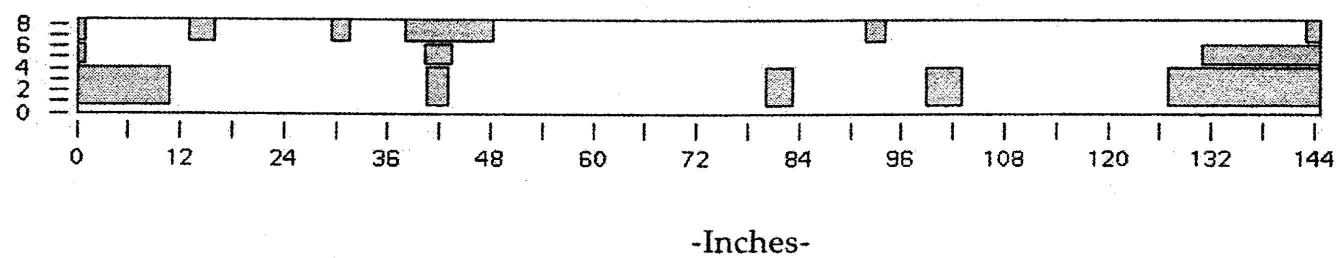

Figure 3. *Sample board from Figure 1 showing character marks as marked by human marker at chopsaw.*

the marker but without the error created by inaccuracies in the marking process (**Fig. 3**). This corrected set of data was used to create new ripping and chopping solutions to assess RR2's overall performance. Boards from this data sample are referred to as *Marked-CMs* (where CMs stands for character marks) and results based on this configuration are shown in the *Simulated yield* column in **Table 3**.

Table 3 displays the yields obtained for gang ripping (strip yield), for chopsawing (chopsaw yield), and the overall yield (gang ripping and chopsawing combined). RR2 simulation, unlike the actual mill, took into account non-allowable character marks and cutting-bill part requirements when searching for the optimum strip solution, whereas the actual rough mill performs ripping without considering character marks or cutting-bill requirements. Yield differences between these two systems, therefore, are to be expected.

The digitized, modified board data were randomly sequenced four times to assure representative samples and to obtain a measure of variability due to board sequence. For the statistical tests, a two-tailed t-test at the 95 percent significance level was used unless otherwise noted. All yield results and yield differences are reported as absolute differences in percent, as explained in Buehlmann et al. (2).

Results and discussion

Strip yield comparison

Simulated strip yield was 87.5, 87.6, 87.7, and 87.1 percent for clear, 0.5-, 1.0-, and 2.0-inch diameter character marked parts, respectively (**Table 3**). These strip yields were between 3.0 and 3.6 percent greater than the observed yields from the actual ripsaw, which was 84.1 percent. Thus, overall average strip yield from the simulated runs was higher than the mill's ripsaw (87.5% vs. 84.1%). This difference is highly significant at the 99 percent level. The simulated strip yields for the performance analysis are shown in the *Simulated yield* column in **Table 3**. These yields were generated with respect to the total number/area of parts required for each strip width. This resulted in a lower strip yield, but higher overall yield since the strips yielded more usable parts at the chopsaw.

The lower strip yield of the actual rough mill (84.1%) compared to the simulated strip yield (87.5% on average of four repetitions) is surprising. Whereas the actual rough mill's strip saw only optimizes for maximum yield, the simulation optimizes for maximum yield and also incorporates the final part dimensions, character marks, and quantity requirements into its optimization process. Thus, one would expect a lower strip yield from the simulation that would then translate into higher chopsaw and overall yields. This finding also underlines the importance of doing everything possible to ensure that the laser or scanning systems in actual rough mills accurately record the width of the boards and that the best arbor feed position is chosen when ripping to ensure high yield.

Chopsaw yield comparison

Simulated chopsaw yield was 81.3, 84.0, 86.3, and 87.3 percent for clear, 0.5-, 1.0-, and 2.0-inch diameter character marked parts, respectively. The actual chopsaw yield was found to be 76.1, 81.2, 85.6, and 86.7 percent for clear, 0.5-, 1.0-, and 2.0-inch diameter character-marked parts, respectively. The average difference between actual and simulated chopsaw yield ranged from 0.6 to 5.2 percent. It is difficult to statistically compare the differences between simulated and actual chopsaw yields. This is due to the fact that they do not process the same strip solutions. Thus, any real difference in chopsaw yield could be masked by strip differences.

The validation of RR2 (8) performed a comparison between simulated and actual chopsaw yields. For the Clear runs, the actual chopsaw performed significantly better at the 95 percent significance level (76.06% yield vs. 74.27%) (8). For all other runs, there was no significant yield difference between

Table 3. Sim ulated and actual rough mill yield data, in percent.

Character mark size	Board data file	Simulated yield		Actual rough mill yield	
		Strip yield	Overall yield	Strip yield	Overall yield
		(%)			
Clear	a	87.5	71.1		
	b	87.4	70.9		
	c	86.8	71.1		
	d	88.4	71.5		
	Mean/actual	87.5	71.1	84.1	64.0
	Difference	3.4[a]	7.1[b]		
	SD	0.649	0.229		
0.5	a	86.9	73.1		
	b	87.6	73.6		
	c	87.9	73.6		
	d	88.0	74.2		
	Mean/actual	87.6	73.6	84.1	68.3
	Difference	3.5[b]	5.3[b]		
	SD	0.509	0.455		
1.0	a	87.2	75.5		
	b	87.0	75.0		
	c	88.0	76.2		
	d	88.7	75.9		
	Mean/actual	87.7	75.7	84.1	72.0
	Difference	3.6[a]	3.7[b]		
	SD	0.797	0.520		
2.0	a	87.3	76.4		
	b	86.2	74.8		
	c	87.9	77.3		
	d	87.0	75.8		
	Mean/actual	87.1	76.1	84.1	72.9
	Difference	3.0[a]	3.2		
	SD	0.726	1.066		
Overall	Mean	87.5	74.1	84.1	69.3
	Difference	3.4[b]	4.8[b]		
	SD	0.65	2.10	0.00	4.05

[a]Significantly different from actual yield at 95 percent level.
[b]Significantly different from actual yield at 99 percent level.

chopsaw yields. This observation proves that the rough mill's chopsaw optimization software performs well compared to the RR2 algorithm. Whenever the yield of the rough mill's chopsaw was lower than the one from RR2, it was assumed to be caused by the mill's gang-ripsaw producing inferior strips.

Overall yield comparison

When ROMI-RIP was not forced to adhere to the strip solutions produced by the actual ripsaw, as was done for the validation study published earlier (8), overall yield was found to be 71.1, 73.6, 75.7, and 76.1 percent for clear 0.5-, 1.0-, and 2.0-inch diameter character marks allowed in the parts, respectively (**Table 3**). The actual rough mill's overall yields were 64.0, 68.3, 72.0, and 72.9 percent, respectively (**Table 3**). The differences for the runs where parts containing no character marks (i.e., clear parts), 0.5-inch, and 1.0-inch character marks were significant at the 99 percent level. Yields allowing 2.0-inch character marks in parts did not produce a significantly different yield.

When performing overall optimization (i.e., optimize strip and chop solutions simultaneously), RR2 produced an average 4.8 percent higher yield (highly significantly different at the 99 percent level) for all four scenarios when compared to the actual rough mill. The benefit of ripping strips with the final parts in mind is evident when examining these overall yield differences. The yield improvement achieved by RR2 was highest when there were many character marks in the boards and no characters are allowed in the parts. When clear parts were produced, RR2 out-performed the rough mill by 7.1 percent (significant at the 99 percent level). This advantage dropped to 5.3 and to 3.7 percent (both results significant at the 99 percent level) when 0.5- and 1.0-inch diameter character marks were allowed in the parts, respectively. When 2.0-inch diameter character marks were allowed, the advantage of RR2 dropped to 3.2 percent (not significantly different at the 95 percent level). This indicates that lower lumber quality and higher part quality requirement (in terms of allowable character marks) situations reap greater benefit from the implementation of RR2-type global optimization systems. The yield improvements found are large for rough mills. Achieving even a 3 percent yield increase only by improved operational practices is difficult in most rough mills even though the savings from such an increase could be in the hundreds of thousands of dollars (6). However, improved scanning and optimization systems can achieve such large yield increases and may thus be able to pay back the investment in a short time. Further research is needed to establish the economic viability of these types of investments.

Average yield comparisons over four scenarios

The average of the overall yield differences between simulation and actual operation for the four test scenarios (clear, 0.5-, 1.0-, 2.0-in. character marks) was found to be significantly different at the 99 percent level (69.3% vs. 74.1%). RR2 average yields from the four scenarios were 87.5, 84.7, and 74.1 percent for strip, chopsaw, and overall yields (**Table 3**). The actual rough mill produced average yields from the four scenarios of 84.1, 82.4, and 69.3 percent for strip, chopsaw, and overall yields. Both strip and overall yield were significantly different from those observed in the actual rough mill at the 99 percent level.

Yield for the scenario where the lowest lumber grade was processed (i.e., when clear [C2F] parts were produced) was 7.1 percent higher from simulation than in the rough mill (significant at the 99% level). Since mills are tending to use progressively lower quality material (mills that predominantly use 2A and 3A Common hardwood lumber are becoming more numerous) for their dimension parts production in order to save money, overall optimization as practiced by RR2 promises significant yield increases.

The validation study (8) showed that when ROMI-RIP is used as a simulation tool to assess a rough mill, the software will produce yields that are 3 and 7 percent higher than the average mill actually achieves. This observation was confirmed by this study. Only if the software can be forced to adhere to inferior strip solutions produced by actual ripsaws is the program a valid representation of the real world. However, forcing the software to adhere to the inferior strip solutions can be done only by a software specialist. There is a need to add this capability to RR2 that will allow the user to choose which level of performance is needed.

As vision systems become a reality (6), secondary solid wood products producers will be able to tap into the power of lumber yield optimizing software packages such as RR2. ROMI-RIP's processing algorithms were designed to generate optimal yield for user-specified rough mill conditions, cutting bills, and lumber samples (9). Using an exhaustive strategy, RR2 examines every possible method of processing each board to obtain the set of parts that has the maximum prioritized value or greatest area (yield). By searching for the overall optima, RR2 achieves significant yield increases and helps reduce raw material and processing costs while saving lumber. RR2 also will enable mills to use lower grade materials while still achieving acceptable levels of yield.

Conclusion

There is much potential benefit to using computer power to develop optimum cut-up solutions. Current gang-rip-first rough mills do not search for an overall optimum yield solution, but search for the local optimum yield twice, once for optimum strip yield and once for optimum chopsaw yield. In today's rough mills, the strip solution at the gang ripsaw does not consider character marks other than the ones along the edges, nor does it take into account final parts required by the cutting bill. This results in inferior yield solutions compared to optimization systems that include these points in the strip decision. For this reason, it was important to compare the yields obtained from an actual rough mill using local optima to determine yield to the ones from RR2. With the reality of vision systems that allow digitization of board information (3), rough mills will be able to improve their yield significantly and thus lower production costs.

When RR2 was allowed to search for the overall optimum solution, simulated yields were 3.2 to 7.1 percent higher than those achieved in the actual rough mill. For the four scenarios examined, average yield was 4.8 percent higher (significant at the 99% level) using the optimization software compared to the actual mill. Yield improvements were greatest when lower-grade lumber was used.

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

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