Impact of Board-Marker Accuracy on Lumber Yield

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ABSTRACT

The production of wooden furniture parts, mouldings, and flooring requires the removal of unacceptable character marks (also called "defects") such as holes, rot, knots, etc., from boards. The majority of the wood processing industry manually identifies such unusable areas and marks them with fluorescent crayons. Automated saws scan these marks and computers optimize the available clear areas and activate automated chop saws to make the cuts. If the fluorescent marks delineating the defect are not made accurately (i.e., too far away or inside the characteristic), then either valuable clear wood is regarded as unacceptable and lost during production or parts are produced containing undesirable characteristics leading to rejects. In an earlier study, the error rate of typical rough mill markers was quantified. However, no data is available as to the impact of these errors on yield. For a rough mill manager, this is critical information needed to decide on the money that should be spent to train employees performing marker duties.

Using simulation and data from an actual rough mill, this study found large yield improvements due to improved marker accuracy. When marker accuracy improved by 25 percent, yield of usable parts increased by 5.3 percent. For an average-sized rough mill in the U.S., this translates to more than a million dollars in cost savings in lumber costs alone. This range of cost savings detected shows that significant improvement efforts for human markers can be justified to improve marking accuracy.

Keywords: Marking accuracy, human error, lumber yield, material loss, production cost

1. INTRODUCTION

The production of wooden furniture, kitchen cabinets, mouldings, or flooring requires the removal of unacceptable character marks (also called "defects", this paper uses both terms interchangeably) such as holes, rot, knots, etc., from lumber boards used as raw material. Rough mills, where such "defect-free" dimension parts are produced, have seen far-reaching changes in technology over the last decades. Although automated vision systems exist, the majority of the lumber processing industry still uses human operators to identify the unusable areas in boards and to mark them with fluorescent crayons. These marks are then scanned by vision systems and an optimum cut-up plan is generated by the computer and passed on to the automated chop saws, which make the cuts.

If the fluorescent marks are not made accurately on the board (i.e., too far away or inside the characteristic), then either valuable, clear wood is regarded as unacceptable and lost, or parts are produced that contain undesirable characteristics, leading to rejects. While an earlier study quantified the errors made by typical markers in rough mills, no data is available as to the impact of improved marker accuracy on yield [1]. However, this information is critical for a rough mill manager. Only by knowing the potential savings from improved marker accuracy can decisions be made regarding the amount of money to be spent on employee training to improve marker accuracy or to justify an investment to replace humans by vision technology.

Buehlmann and Thomas, in an earlier study, researched the frequency of operator error when marking defects on lumber [1]. The authors defined three different types of operator error: 1) marking a defect where there is none (called a Type II error), 2) not marking a defect when there is one (a Type I error), and 3) marking a defect inside its boundaries (a partial Type I error). Theoretically, a fourth type of error exists: when a defect is marked too far away from its boundaries. However, due to the low impact on yield and costs, this type of error was not considered in this earlier study.

The 158 boards used in this study contained 1,303 defects. The ripsaw produced 404 strips: 59, 1.75 in. wide; 259, 2.00 in. wide; and 86, 3.50 in. wide, respectively. The operator made an average of 3.45 marks per strip, for a total of 1,331 marks. Marks were not needed at the beginnings and ends of the boards, as the chop saw automatically trimmed 1 inch from both ends of each strip.

Seventy-eight percent of all marks (1,041) made by the operator deviated from the optimum decision. This high error rate consisted of 26 Type II errors (marking areas where there was no defect), 578 Type I errors (not detecting an error when there was one), and 473 partial Type I errors (marks placed inside a defective area). These errors reduced the original yield from 63.5 percent (average of four test runs) before accounting for rejected parts to 47.4 percent (average of four test runs), e.g., by 16.1 percent. In fact, a full 22 percent of all parts produced in these simulated tests would have been rejected.

This high error rate find is surprising, yet has to be taken with some precautions in mind. Whereas in actual rough mills markers know that there is some "slack" in their marks in that dimension parts are normally cut half an inch or so larger than actual final part size, the simulation tests did not account for this possibility. Also, the digital simulation did calculate positions of marks to the point, whereas actual rough mills operate to quarter inches or so. Nevertheless, the part rejection rate found was beyond acceptable quantities. Such a high part rejection rate does cost an average-sized U.S. furniture rough mill several million dollars annually [2].

2. Objectives

Given the high part rejection rates due to human marker error discovered in the previous study [1], the study presented here, was designed to find the impact of decreased human marker error. The objective was to find the decrease in yield and rejected parts (part count and area) due to improved marker accuracy. Two levels of improvement in marker accuracy were researched:

1) Reduction of the human marker error by 25 percent
2) Reduction of the human marker error by 50 percent

3. Methodology

To evaluate the impact of the rough mill markers' marking solutions on yield, a sample of lumber was processed in a rough mill typical for the U.S. wood industries. The same lumber, whose defect and geometry data was digitized prior to its cut-up, was then used to perform simulated lumber cut-ups. Digitized lumber data and human marker decisions recorded from actual test runs from an earlier study allowed analyses of a variety of scenarios concerning human marker accuracy. Detailed information about the methodologies used for the original study can also be found in [1], [3], and [4].

Materials

The lumber sample obtained from a sawmill in the Southeastern U.S. consisted of 930 bdft of FAS, 1 Common, and 2A Common lumber. To establish a basis of performance comparison through simulation, this lumber sample was manually scanned (digitized) for all defects and board geometry prior to cut-up. This process recorded the board's geometry along with every defect's size, location, and type following the methodology described by Anderson et al. [5]. Using the UGRS lumber grading program [6], the boards were graded to NHLA 1998 grades [7] and their volumes and counts tallied (Appendix 1).

The boards were processed to meet the part requirements of the cutting bill shown in Appendix 2. This cutting bill was obtained from an actual rough mill operation in the U.S. The part quantity requirements of the cutting bill were scaled such that the cutting bill requirements could be satisfied using the 930 bdft lumber sample available. Parts were prioritized by the same values in both simulation and rough mill. For prioritization, the L^2W method was used and the values proportionally scaled such that the maximum value was 1,000 [286].

Rough Mill

Processing in the actual rough-mill began by gang-ripping the boards on a 24-inch Mereen-Johnson 424 gang ripsaw equipped with a Barr-Mullin Compu-Rip gang ripsaw optimizer and optimization software for determining optimum rip solutions. The optimizer did not consider the required quantity or area of parts by width required by the cutting bill. The strips from the ripsaw processed were then marked by an experienced rough mill marker, who was told to produce clean parts, e.g., no defects allowed. The mark locations on each strip were manually recorded.

Computer based rough mill simulation

The USDA Forest Service's ROMI-RIP 2.0 rough mill simulation program (RR2) was employed to do the cut-up simulations necessary [286]. Also, a series of custom developed programs specifically developed for this study were used to measure the impact of human marker error on yield and rejected parts. These custom developed programs overlaid the locations of the marker's grade marks with the actual defect locations on the board or on the parts, respectively. Based on this comparison, the computer programs could recognize four distinct error conditions:

A) Not marking a defect when one is present (Type I error)
B) Marking a defect inside the defect area (partial Type I error)
C) Marking too far away from a defect (partial Type II error)
D) Marking a region as defective when no error exists (Type II error)

These error conditions are shown in Figure 1. Errors A and B are the most severe ones. In these two cases, the error can result in a defect being placed in a part, which would later result in a rejected part. This does not only result in a loss of wood, but also in a loss of production costs involved in producing the part. For the remaining two situations (errors C and D, Figure 1), the error results in the loss of clear or acceptable wood for part production. Although less costly, this type of error can result in the loss of long clear areas from which longer, more difficult to obtain parts could be sawn.

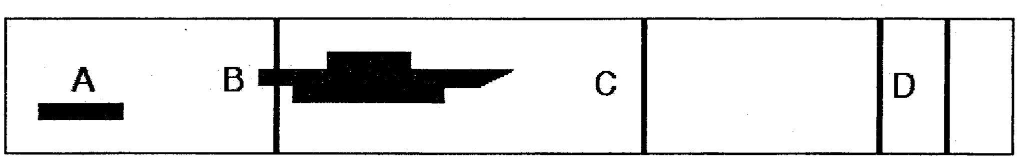

FIGURE 1: Four error conditions possible: A) not marking a defect, B) marking inside the defect area,

C) marking too far away from a defect, and D) marking an error when no error exists.

Using the RR2 simulator, the boards were processed using the marked areas, cutting clear parts and parts that contained characters due to marker error. The strip solution from the actual ripping operation in the rough mill was used for these simulation runs to assure relevance of the results for practice [3]. Thus, the results obtained are applicable to actual rough mills and managers should be able to calculate potential savings from actions taken to improve human marker accuracy.

The RR2 simulator reports lumber yield and the sizes and quantities of parts obtained [9]. More importantly, RR2 also lists the geometrical location of every part cut within a board/strip. Using this part geometry and location data, a computer program was written to overlay the part location data with the lists of defects not properly marked. This produced a list of parts that contained defects due to human marker error. This data allowed quantifying rejects due to human marker error. This test with unchanged human marker errors is called the "*Normal Error Rate*" in the following discussion.

Another computer program was written to process and change the human marker errors. This program allowed specifying levels of change of the human marker error by a given percentage. Two levels of improvement were chosen, 25 and 50 percent, called "*25% Error Reduction*" and "*50% Error Reduction*", respectively. These terms will be used throughout the following discussion. Improvement in this context, with exception of Case C indicated in Figure 1, does not mean more accurate marking on the strips (e.g., if the marker marked 1 inch away from the end of the defect, a 25 percent improvement would mean marking 0.75 inch from the end of the defect), but randomly correcting the marker error in 25 percent of the cases (e.g. 25 percent of the erroneous marks were reset to perfect marking). For example, when the operator marked an area as being defective, when in fact no defect existed, the erroneous marks were randomly removed at the percentage rate assumed. Thus, using a 25 percent correction factor and a strip with 8 such errors would result in the random removal of 2 such errors. The 50 percent correction factor would remove 4 errors. Similarly, when a defect was not marked or the defect was split by the operator's mark, the program would randomly correct the selected percentage of erroneous marks. Only in the case of error condition C, where the operator marked too far away from the defect, were the marks improved by shifting the mark closer to the perfect location. For example, if a 50 percent error correction was being used and the operator marked 2 inches outside a defect's end, the corrected mark would be placed 1 inch from the defect. Figure 2 shows a sample board with strips showing the actual defect locations along with the original marker solution for clear parts as well as the 25 and 50-percent corrected versions of the marker solution.

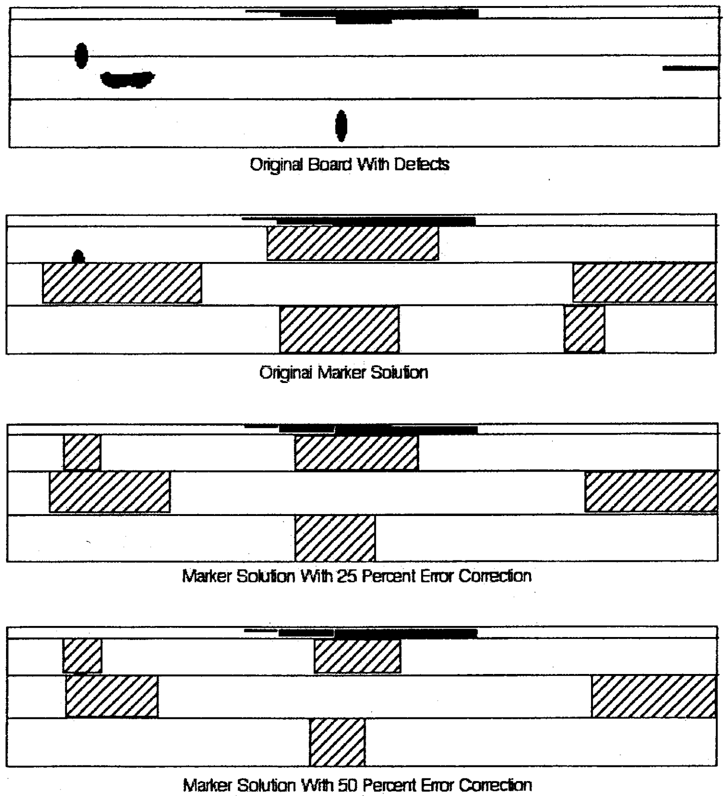

FIGURE 2: Example of board with strips showing original defect locations along with the original marker solution, a 25 percent improvement, and a 50 percent improvement.

The strip data with the improved marks was then processed using RR2. The results were thereafter analyzed with a program that looked at the parts "produced" and determined if there were any defects remaining in these parts. Parts that contained unallowable defects were then rejected and their yield was deducted from the original yield achieved.

The analysis was done for primary parts only. Primary parts are the ones that are obtained from the normal strip and crosscut processing sequence, whereas salvage parts are obtained from primary parts, subjected to another cutting sequence. This salvaging process is done to increase overall yield. However, since salvage parts mainly result from rejected parts from primary processing, no consideration of salvage parts was done for this study. Five repetitions of the simulation runs for each marker accuracy scenario were made to obtain a valid mean response.

4. Results

Yield from primary parts including rejects was found to be 55.6 percent, when no adjustments for human marker errors were made. For a 25- and a 50-percent error reduction the yield was 57.3 and 57.0 percent, respectively. Yield losses due to rejected parts were found to be 16.5, 12.9, and 11.2 percent for the normal error rate; 25 percent error reduction; and 50 percent error reduction scenario, respectively. Usable yield after rejecting for these three scenarios was thus found to be 39.1, 44.4, and 45.7 percent, respectively. The required board footage of lumber needed to satisfy the cutting bill requirements dropped from 1283.9 bdft to 1130.9 and to 1097.5 bdft for the normal error rate, 25 percent error reduction and 50 percent error reduction scenario, respectively. TABLE 1 shows the total board footage of lumber processed, part yield, part yield rejects, usable yield after rejects, and projected total board footage of lumber required given the reject rate measured.

TABLE 1
Yield summary for primary parts, overall and rejects

	Total lumber processed	Part yield	Part yield in rejects	Usable yield After rejecting	Projected total bdft required given current reject rate
	(bdft)	(percent)	(percent)	(percent)	(bdft)
Normal Error Rate	937.0	55.57	16.47	39.10	1283.89
25% Error Reduction	915.8	57.30	12.91	44.39	1130.89
50% Error Reduction	911.4	56.98	11.24	45.74	1097.51

TABLE 2 shows more information on the parts produced. The cutting bill (Appendix 2) required 1,096 parts to be produced. As can be expected, the simulation produced slightly more parts, namely 1,138 (+3.8%), 1,144 (+4.4%) and 1,140 (+4.0%) for the normal error rate, 25 percent error reduction and 50 percent error reduction scenario, respectively. This "overshooting" is necessary to allow the program to obtain the minimum quantity demanded of all part sizes in the cutting bill. Three hundred (26.4%), 233 (20.4%) and 205 (18.0%) of the respective primary parts contained unallowable defects and were rejected, resulting in a loss of 154.4, 118.2, and 102.4 bdft of lumber for the normal error rate, 25 percent error reduction and 50 percent error reduction scenario, respectively. The average area of the parts rejected decreased only slightly when human marker errors were reduced. A similar observation can be made for the average reject part length and part width, as TABLE 2 shows.

TABLE 2
Primary part reject counts and volumes

	Total number of parts	Number of parts rejected	Board feet of parts rejected	Average bdft of reject parts	Average reject part length	Average reject part width
	(#)	(#)	(bdft)	(bdft)	(in.)	(in.)
Normal Error Rate	1138	300	154.4	0.525	33.150	2.280
25% Error Reduction	1144	233	118.2	0.508	32.524	2.264
50% Error Reduction	1140	205	102.4	0.501	32.120	2.245

5. Discussion

Using indefatigable computer accuracy to assess work done by a human working under severe time constraints is likely to lead to an inferior assessment of the individuals' work. The computer simulation bases its decision on pure numbers, whereas the human operator works using rule-of-thumb accuracy in the rough mill. Thus, what is considered "clear parts" in rough mills in fact contains defects of 0.25 in. to 0.5 in. in maximum size. However, the human marker employed for this study was instructed to produce really "clear parts," therefore it is really surprising to observe the large number of rejected parts found by this study. This observation underlines the fact that wood is a natural product, and therefore what constitutes a character isn't always easily determined and instructions for operators provided by the company are not always much help [10].

In any way, the yield improvement of more than 5 percent when decreasing human marker error by 25 percent has to draw attention from rough mill managers. Five percent is a significant yield increase when one knows that in daily operations, manager and operators try to achieve yield gains of a fraction of a percent at one time. Also, with fewer parts containing defects, the work of the persons sorting and staking the parts at the end of the line is made easier since they have to reject fewer pieces.

Given the lumber quality used for these tests, the usable yield of 39.1 percent under the "Normal error rate scenario" in TABLE 1 is extremely low. Very likely, no mill would report such a low yield, but would have parts including some with defects being processed through machining, finishing and assembly. Along this way, the defects in the parts due to human marker error would be discovered and the part removed from the process. However, the longer a defective part remains in the production process prior to being rejected, the costlier the error of the marker gets. Therefore, the higher yield supposedly achieved in the rough mill due to incorporation of defective parts into the result is a very costly practice to any operation.

"Usable yield after rejecting" increased from 39.1 percent at the "Normal error rate" to 44.4 percent with a "25% error reduction," and to 45.7 percent with a "50% error reduction," respectively. Reducing the marker error rate by 25 percent results in a 5.3 percent usable part yield improvement. This is a proportionally larger impact on usable yield than the one achieved from the additional 25 percent error rate reduction for the "50% error reduction." With the 50% error reduction usable yield rises only an additional 1.4 percent over the "25% error reduction" scenario. On the one hand, there is a decreasing rate of return for improved marking accuracy, whereas on the other hand there is an over-proportional increasing cost to improve marker accuracy. Rough mill managers thus have to find the optimum cost/benefit level when making decisions on improving human marker accuracy. However, when doing such an analysis, managers should look at the overall cost of defective parts due to human marker error and not at yield alone. Cost of defective parts will show steeper increases or decreases per unit of yield change since the errors of the marker are leveraged by pieces rejected late in the production process, when substantial costs are already spent on the part.

It is interesting to note that the average size, length, and width of the parts rejected shown in TABLE 2 do not markedly decrease with the reduction of marker errors. Average rejected part area decreased by 0.017 bdft for the "25 error reduction" scenario and by 0.024 bdft for the "50% error reduction" scenario compared to the "Normal error rate" scenario, respectively. Rejected average part length and width decreased by 0.626 and 0.016 in. for the "25% error reduction" scenario and by 1.030 and 0.035 in. for the "50% error reduction" scenario, respectively compared to the "Normal error rate" scenario. These are rather small increases in average size, length and width of rejected parts, although they translate into substantial yield gains. One reason for these small increases is that Type II errors, (the marking of a defect where there is none), according to the study by Buehlmann and Thomas, are far less frequent than the other error types [1].

Future research is necessary to find the optimum point of marker accuracy improvement that rough mill managers should strive to achieve. As this research has shown, yield increases are diminishing with increasing accuracy. To make a reasonable decision, rough mill managers must know the yield improvements due to increased marker accuracy and the cost savings achievable. For this, research is needed to find the rejection point of parts containing defects due to human marker error throughout the production process and the cost associated with such rejects. Also, to make optimum decisions, managers will need to know the relationship between cost of marker training and marking error reduction achievable due to this training. However, given the large yield improvements found in this study for relatively small marker accuracy improvements, managers should be eager to try to improve accuracy by small increments.

6. Conclusions

Using data from an earlier study, research was conducted into the impact of human marker error in a rough mill of the secondary wood industry on yield. Marks made by a human operator on strips to be processed in an actual rough mill were recorded along with geometrical and defect data of lumber boards. The study was initiated by the high percentage of marker errors found in an earlier study. The USDA Forest Service ROMI-RIP lumber cut-up simulator and special software were used to assess the impact of human marker error on rough mill yield. Four marker errors were considered: a) not marking a defect when one is present (Type I error), b) Marking a defect inside the defect boundaries (partial Type II error), c) marking too far away from a defect (partial Type II error), and d) marking a region as defective when no error exists (Type II error). In two simulated scenarios, the rate of human marker error was reduced by 25 and 50 percent, respectively.

Usable yield increased by an average (5 replicates) of 5.3 percent when human marking error was reduced by 25 percent. When reducing human marking error by a more aggressive 50 percent, usable yield increased by 6.6 percent versus the normal rate of human marker error. These numbers show that increases in usable yield and decreases in human marker errors are not proportionally related, but that increases in usable yield are higher when decreasing human marker errors by a small amount. Thus, rough mill managers potentially could reduce costs in their operation by achieving rather small improvements in marker accuracy. However, more work in the area of understanding costs incurred throughout the entire production process in secondary wood industries facilities needs to be done to be able to decide on optimal levels of investment into improving human marker accuracy versus cost savings due to reduced part rejects.

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APPENDIX 1

Quality classification of the lumber sample used.

Lumber grade	Board footage	Board count	Board footage as percentage of total	Board count as percentage of total
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%

APPENDIX 2

Cutting bill part size and quantity requirements.

Part number	Part width (in.)	Part length (in.)	quantity	Part prioritization value
1	3.50	67.00	12	1000
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