The Potential of Computer Controlled Optimizing Equipment in the Wooden Furniture Industry

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ABSTRACT

The goal of the wooden furniture industry is to convert lumber into parts by using the most efficient and cost effective processing methods. The key steps in processing lumber arc removing the regions that contain unacceptable defects or character marks and cutting the remaining areas to the widths and lengths of needed parts. Such equipment has been used in furniture mills in for more than 30 years, but it has been difficult to exploit its full potential. Studies have determined the error rate of average furniture-mill workers and the impact of these errors on the efficiency of rough mills. With the increasing sophistication and capabilities of today's rough-mill equipment and software, it is now possible to remove human operators from most decision making roles during processing. Scanning systems are available that can locate defects with a high degree of accuracy, and rough mi1J simulation programs can quickly process digital board images and determine optimal cut solutions. The inefficiencies of Current wood-processing methods are discussed and potential gains from processing station integration and global optimization strategies and explored. How these goals can be achieved in practice also is discussed.

Keywords: Automation, Rough mill, Wood Simulation, products.

1. INTRODUCTION

The wooden furniture, moulding, and millwork industry has historically been a labor intensive operation. These manufacturing facilities, called rough mills, convert boards into parts that are used in the final product. Two distinct cutting operations can be used to produce parts. In a rip-first rough mil! the board is ripped into long strips of the widths required by the cutting bill. These strips are then crosscut to the correct length in a second cutting operation. In a chop-first rough mill the board is first cut into sections of the required part lengths. A ripping operation follows which saws the sections into the required part widths. In this paper we focus on rip-first systems, which are the most common processing system in today's rough mills.

Cutting bills--lists of required parts--indicate the quantity of each part required as well as any quality requirements of the part. The latter indicate the type and number of detects or "character marks" that can be allowed on a particular part. The location of the defect allowed is another important aspect of a part's quality requirements. A part that will be machined along the edge, for example, the rounded edge profile of a table top, cannot have defects along the edge where machining occurs, because the defects likely will chip out and the part will be rejected.

Ripping and chopping of boards into parts is simple in theory, but can he chaotic in practice. The operator feeds boards through the ripsaw to obtain the best yield possible in strips. The strips then move to an operator who marks the location of defects that are not acceptable in the final parts after which the parts are cut to length by the chopsaw. Cutting bills can consist of dozens of part sizes and several quality requirements. Given the complex combination of part requirements (quality, quantity, and size), it is difficult to keep track of everything.

2. METHODS FOR ASSESSING HUMAN ERROR

The frequency and impact of human error on yield and processing et1lciency have been documented in studies of an actual rough-mill operation [1,2,3] that compared the types of errors and associated yield decreases with the yield of an automated rough-mill system simulated by the ROMI-RIP 2.0 (RR2) simulator program [4, 5]. In these studies, a sample of red oak lumber was obtained, measured and graded to NHLA 1998 rules [6], and the sizes and locations of a11 defects on the boards were recorded. This data were processed by the RR2 simulator and the actual boards processed by the rough mill to allow a direct comparison between simulation and the actual rough-mill processing results.

Working in a rough mill is difficult at best, it is noisy, dusty, and heavy work that requires the use of potentially hazardous equipment. These conditions along with the natural limitations of human operators create an environment conducive to making errors. Further, the speed at which operators must work makes it difficult for them to identify every defect correctly.

2.1. Errors at the Ripsaw

In a fully automated scanning environment, the board is scanned and measured and all or specific defect types located. The controlling computer then decides where to place the board with respect to the ripsaw arbor such that the board is sawn into the highest yielding combination of strip widths. There is some degree of human interaction in most rough mills. In the most primitive mills, the operator is solely responsible for determining the strip widths that will be sawn from the board. Here the operator might be aided by laser lines that show how the board will be sawn before it is fed into the arbor. Or, the operator uses laser lines to measure the width of the board, and a computer then determines how to rip the board into tile snips.

The greatest opportunity for error at the ripsaw is feeding the board in such a way that the wrong combinations of strip widths are sawn. This can result in larger than nom1al unusable areas called edgings (Figure 1). In a study which compared the performance of RR2 to an actual rough mill, it was determined that RR2 achieved on average 3.4 percent better yield at the ripsaw than did the actual rough mill operation [7]. Also, the quantities of strips in each part width generated by the rough mill did not correspond as closely to the actual part requirements as those generated by RR2. This results in extra lumber being processed to meet part requirements and overages in some part widths that mayor may not be of use. In most cases, the overage can be regarded as a loss of both material and labor.

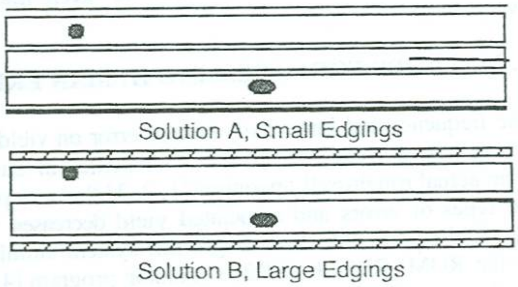

Figure 1. Combination of strips sawn from a board shows (A) a good ripping solution and (B) a poor solution with large edgings (edgings are the shaded sections).

2.2. Errors at the Chop saw

The standard means of converting strips into parts in the required lengths is having workers to mark sections of strips containing unacceptable defects with fluorescent crayons. The crayon marks are then read by a mark-sensing automatic chopsaw and an optimal combination of lengths is cut from the acceptable area between the marks. There are two problems with this process. First, it can be difficult to accurately define defect with respect to size, shape, and type. Often, several workers at the same rough mill disagree as to what is acceptable or unacceptable in the parts. This problem is exacerbated when operators are required to mark multiple grades. Multiple grades are useful when costly Clear-Two-Face (C2F) parts are not needed for all parts. For example, yield can be improved when a defect can be hidden on a part that will not be exposed to view. Had the defect would been removed, part material and the opportunity to obtain a longer part would have been lost When defects are allowed on one lace of a part, the part is referred to as Clear-One-Face (C 1 F). Part grades where defects are allowed on both faces are called Sound-Two-Face or (52F) grades.

In an earlier case study, the error rate for marking clear parts was determined. There are three types of errors that can occur when marking strips: 1) marking an area as defective when no detect is present or the defect is acceptable; 2) not marking a defect that is present; and 3) marking inside a defect (Figure 2). The first error is the least severe as it will not result in the production of parts that later would be rejected. The rejection of parts is the most expensive error as it includes both a loss of material and labor.

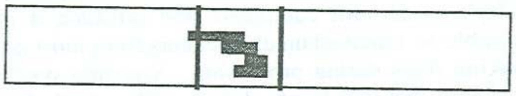

Figure 2. Marker error example showing a mark made inside a defective area.

The numbers and percentage of detects missed or marked incorrectly arc shown in Table I. Two percent of all marks made were the marking of a nonexistent defect (or a defect that was in fact acceptable). Particularly disturbing was the high error rate (32.8 percent) where a mark was placed inside a defective area, as shown in Figure 2. This type of error can lead to the rejection of a part later in the processing stream. The most common mistake was marking an area ti1at was defective when in fact there was either no defect present or the defect was acceptable.

Table 1. Marker accuracy assessment results

Type of mistake	Number of mistakes	Percentage of mistakes
Marking a nonexistent detect	578	43.4
Missing a detect	26	2.0
Marked inside a defect	437	32.8
Total	1,041	78.2
Average mistakes per strip	2.696	
Total marks made	1,331	
Total strips marked	386	
Number of boards used	158	

2.3. Cost of Human Error

The impact of these mistakes on yield and processing efficiency resulted in the average rejection of 22 percent (number) *of* all parts processed. The area of rejected parts amounted to 16.1 percent of the volume of all lumber processed and 25.4 percent of the volume of all parts produced. Thus, when rejects are excluded, the effective yield decreased from 63.5 percent (all parts including rejects) to 47.4 percent! In normal circumstances parts rejected during processing would be reworked using additional ripping and chopping operations to produce smaller yet required parts when possible. The additional processing is expensive and usually yields only smaller parts with substantially lower value. Further, the opportunity to obtain one or more larger, more valuable parts has been squandered.

It is estimated that every 1-percent increase in part yield saves the average rough mill $150,000 a year [8]. In the case study described, the 3-percent loss at the gang-ripsaw' cost the rough mill about $450,000 a year. If the reject rate could be cut in half from 16.1 percent (volume) of the lumber processed to 8 percent, the approximate savings to the company in a single year would be $1.2 million.

3. OPTIMIZING ROUGH MILL PROCESSING

Given this result from an actual rough mill, it is not difficult to recognize the need for better optimization techniques in the mill. There are essentially three technologies that promise to improve production efficiency: scanning, optimization, and integrated control. Scanning is the automated detection of board characteristics, including width, length, and defect sizes and locations. Once the characteristics of the board are known, the fitting of the parts into the board is optimized, creating a cutup solution. Using integrated control the cutup solution is distributed to the computers that control how the board is cut up.

3.l Scanning for Defects

Scanning is the weakest link in an automated rough mill. Depending on the wood species, there can be little color difference between defect and the background of normal wood color, and the lumber does not always have a clean uniform surface. It can be uneven (planer skip) or have marks that could indicate a defect to the camera when it is in fact not a defect, i.e.. a boot print, a mark from handling, or stain from a sticker. Thus, the scanning system must be sufficiently robust to recognize marks and defects on the lumber for what they are-- a true defect or not. A three-way scanner developed at Virginia Tech uses laser profiling, color line-scan cameras, and X-ray to overcome the limitations of single-sensor scanning systems [9].

3.1.1. Scanning at the Ripsaw

In a fully optimizing rip-first rough mill, defects are first scanned and detected before the board is fed into the gang-ripsaw. Often the scanner is not programmed or designed to detect every defect but to detect wane and other major defects and accurately measure the board's width. The scanner usually is a laser line or a color/grayscale line-scan camera. Depending on the board's width, edge defects if any, and the widths on the arbor, the board is positioned and fed through the arbor to produce an optimal yield in strips.

A better solution is to expand the error detection capabilities at the gang-ripsaw so that most if not all detect types are detected. With the improved defect information, the system can optimize for part placement rather than for strips. Consider situation in which only long lengths are needed for a specific width. If a strip is generated for that width with detects placed such that the lengths needed cannot be cut, the strip must be reworked into other narrower parts.

3.1.2. Scanning at the Chopsaws

After the board has been ripped into strips, the strips are scanned to determine defect locations before being sawn into the required part lengths. It may seem redundant to rescan the strip. but this step is necessary because of the unordered sequence or jumble on the chain fanned by the strips are they are conveyed to the chopsaws.

The scanner at the chopsaws must be as accurate as possible to avoid generating parts with unacceptable defects. The ideal scanner at the time of this study would be the three-parameter scanner discussed earlier [9]. Implementing a second scanning system avoids the problems and errors associated with strip marking. In addition, the automated scanner can be trained to recognize an almost unlimited number of user-defined qualities. By optimizing the parts 'with respect to the range of acceptable qualities, better utilization of the lumber can be achieved. Further, the scanning system accurately measures the size and location of all defects. This allows the scanner to process for proximity rules and to recognize when an acceptable defect would be in the path of a machining operation, e.g.. moulding the edge of a cabinet door frame.

3.2. Optimization and Integrated Computer Control

In most gang rip-first rough mills, two local optimum solutions are generated during processing. One is at the gang-ripsaw where a solution is generated to rip the board into strips such that the resulting strip widths occupy as much as possible of the board's width. Here the usability of the strips downstream in the processing flow are of little concern to the gang-ripsaw controller or operator. A second local optimum solution is generated by the chopsaw optimizer to process the strips into parts in the required lengths. The chopsaw must do the best it can with the strips it is given. If the strips were generated with no concern for the defects they contain or for current part size needs of the cutting bill, yield will suffer.

A better solution is to optimize both ripping and chopping in a single solution to produce the maximum yield or value of parts are produced from each board. To generate the global optimum solution, a feedback loop between the gang-ripsaw and chopsaw controllers must be established. A central controlling computer would generate the optimum solution and track overall part counts during production. Figure 3 is a simplified flow diagram of how such a system would work. Boards would be scanned as they enter the rough mill. The central computer would receive defect and board information and generate a global optimum cutup solution, sending the rip solution to the ripsaw computer. The latter would move the fence and blade(s) depending on the arbor type and according to the optimum strip solution. The strips would move on to the strip scanner and be scanned individually. The strip optimizer would examine the current part requirements and the quality map of the strip and then generate and execute the optimum cutup solution. The chopsaw would continually update the controlling computer with the number of parts obtained for each size cut. Global optimization allows the system to maximize the yield and value of parts cut from each board and allow the gang-rips to avoid producing part widths whose requirements already have been satisfied. This strategy promises to reduce both the amount of lumber required to satisfy cutting-bill requirements and labor costs.

Using the RR2 rough mill simulator, a series of analyses examined the impact of such a feedback loop and two arbor optimization algorithms on strip and pm1 yield. Recall that the objective behind the feedback loop is to provide updated part requirement information to the gang-ripsaw optimizer/computer. The simulation runs used a data file consisting entirely of I Common boards 6 feet and longer graded to NHLA 1998 rules [7].

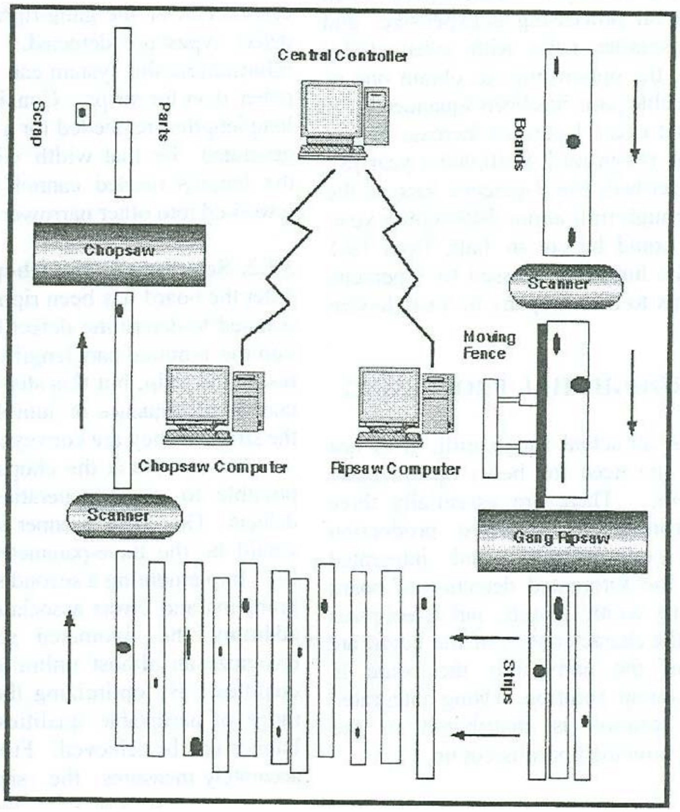

Figure 3. Rip-first rough mill material and information/data now.

Five random sorts of the input board data files were created for the runs. The five data sets were run for each cutting bill/feedback loop combination and the results averaged.

Fixed-blade arbors were used and the arrangement of saw spacings on the arbors were determined using the Gang-Ripsaw-Optimizer module within the beta version of Romi-Rip 3.0[1 1]; an arbor optimization system was used, Fixed-Blade-Best-Feed, which optimizes the total yield or value of parts that can be obtained before ripping. Three feedback loop configurations were used: 1) the optimizer was updated continuously, 2) the optimizer was updated after every 500 board feet were processed, and 3) no feedback to the ripsaw optimizer. All other processing options, e.g., kerf sizes, and trim, part scheduling and prioritization were held constant throughout the simulations.

The three cutting bills used are comprised of both solids and panel parts (Table 2). These are industry cutting bills from rough mills for actual products. The cutting bills used can be classified as moderately difficult as all bills required an even distribution of part sizes and required mostly shorter parts. The longest part required was 52.5 inches long and most of the parts were shorter than 40 inches.

Table 2. General characteristics of the cutting bills used in the sample analysis.

Cutting hill	Number solid parts	Number panel parts	Number widths	Number lengths
A	22	3	5	15
B	19	J4	4	27
C	30	J S	7	29

The results in Table 3 show that the highest part yields are obtained when a continuous feedback loop is established among the chopsaw(s) and the ripsaw(s). The strip yields changed little between continual updating, updating after every 500 board feet processed. and no feedback loop settings. The greatest decrease in strip yield occurred with cutting bill C between the continual and 500 board feet update settings. It is interesting that strip yield increased for all three cutting bills between the 500 board feet update and no feedback loop setting. However, in all but one case, part yield decreased as strip yield increased. Thus, although a higher strip yield was produced, it was not necessarily in the required widths or did not allow the parts required to be obtained due to defects present

Table 3. Observed yields from simulation for the cutting bill and arbor configurations.

Cutting hill	Feedback loop	Strip yield	Reported part yield
A	Yes	81.6	64.5
A	500	80.9	54.6
A	No	82.8	53.1
B	Yes	81.5	63.9
B	500	79.9	60.6
B	No	81.8	01.1
C	Yes	86.9	67.9
C	500	84.9	61.8
C	No	85.2	61.7

In most cases, a steady decrease in yield was observed as continuous feedback was changed to feedback every 500 board feet and finally as the feedback loop was turned off. The greatest decrease (9.9 percent) was observed with cutting bill A between the continuous and 500 board feet feedback loop settings. In most situations there was little difference between no feedback loop and updating part counts after every 500 board feet was processed (0.5 percent with cutting bills A and B, 0.1 percent with cutting bill C). With cutting bill B part yield increased slightly (0.5 percent) as the feedback was turned off. However, yield with no feedback loop still was 1.8 percent less than that with the continual feedback option.

4. DISCUSSION AND CONCLUSION

The number of errors that occur in the rough mill has a large impact on productivity and operating costs. Errors at the gang-ripsaw result in wasted wood and in the production of strips that may not yield the needed parts at the chopsaw. In a comparison of gang-ripsaw operations of RR2 to an actual rough min, RR2 achieved 3.375 percent better strip yield (average of four tests) than the rough mill [7]. When strip yield is decreased, opportunities for improving yield at the chopsaw are diminished.

There arc several problems and errors that can occur at the chopsaw that also reduce rough-mill yield and productivity. The required speed at which markers must process strips naturally tends to cause errors, and different markers can have different ideas as to what constitutes a defect and which can be included in parts. Using an enhanced detect scanning system at the chopsaw\v to detect errors would improve the consistency of the end product wit1l respect to quality and appearance. Also, the scanning system would improve yield. In an one comparison, RR2 on average achieved 4.5 percent better yield than the actual rough mill. the yield improvement ranged from 3.2 to 7.1 percent for four scenarios[8].

Integrating the gang-ripsaw and chopsaw-controllers promises to dramatically improve rough mill yield by improving strip production. This feedback loop coupled with defect scanning at the ripsaw(s) and chopsaw(s) allows a global optimum solution and resulting improvements in rough mill yield. Given the significant yield improvements that are possible by replacing local optimization efforts with a global solution, industry should make every effort to implement this solution.

The simulation program used to determine the potential yield improvement over current practices is available free of charge from:

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