THE INFLUENCE OF CUTTING-BILL REQUIREMENTS ON LUMBER YIELD USING A FRACTIONAL-FACTORIAL DESIGN PART II. CORRELATION AND NUMBER OF PART SIZES

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Abstract. Cutting-bill requirements, among other factors, influence the yield obtained when cutting lumber into parts. The first part of this 2-part series described how different cutting-bill part sizes, when added to an existing cutting-bill, affect lumber yield, and quantified these observations. To accomplish this, the study employed linear least squares estimation technique. This second paper again looks at the influence of cutting-bill requirements but establishes a measure of how preferable it is to have a given part size required by the cutting-bill. The influence of the number of different part sizes to be cut simultaneously on lumber yield is also investigated.

Using rip-first rough mill simulation software and an orthogonal, 2^{20-11} fractional-factorial design of resolution V, the correlation between lengths, widths, and 20 part sizes as defined by the Buehlmann cutting-bill with high yield was established. It was found that, as long as the quantity of small parts is limited, part sizes larger than the smallest size are more positively correlated with high yield. Furthermore, only 4 out of the 20 part sizes tested were identified with having a significant positive correlation with above average yield (65.09%), while 10 were found with a significant negative correlation and above average yield. With respect to the benefit of cutting varying numbers of part sizes simultaneously, this study showed that there is a positive correlation between yield and the number of different part sizes being cut. However, Duncan's test did not detect significant yield gains for instances when more than 11 part sizes are contained in the cutting-bill.

Keywords: Cutting-bill requirements, lumber yield, rip-first rough mill, fractional-factorial design, interaction between cutting-bill requirements and yield, influence of part size and quantity on yield.

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INTRODUCTION

Having a better understanding of the relationship between cutting-bill requirements and lumber yield will help producers of secondary wood products lower their production costs. Reducing production costs becomes ever more important for the survival and success of domestic manufacturers given the increase in global competition (Buehlmann et al 2003b; Schuler and Buehlmann 2003). These producers, in order to manufacture their products, cut slightly oversized, rectangular pieces from better quality, kiln-dried lumber. A cutting-bill is a list of parts to be cut during a production run. Cutting-bill requirements refer to all the parameters that are defined in a cutting-bill, such as part sizes, quantities, qualities, and other pertinent information (Buehlmann 1998). The goal is to produce these parts in the rough mill at the lowest overall cost in the quality and quantity defined. Lumber yield, the ratio of aggregate part surface area produced to aggregate lumber surface area input (Gatchell 1985), determines production costs to a large extent, as lumber accounts for roughly 70% of total rough mill costs (Wengert and Lamb 1994).

The first publication in this series, "*The influence of cutting-bill requirements on lumber yield using a fractional-factorial design—Part I: Linearity and least squares*" (Buehlmann et al 2008a), used the standardized and simplified Buehlmann cutting-bill (2008b, 2008c), and the USDA Forest Service rough mill simulation software ROMI-RIP (Thomas 1995a, 1995b) to simulate the cut-up of lumber in a rip-first rough mill. The cutting-bill requirements were set based on a 1/2048 replicate of a 2-level 20 factor fractional-factorial design with resolution V, ie a 2^{20-11} fractional-factorial design (Box et al 1978). ANOVA testing revealed that all 20 main effects, and 113 of a total of 190 unique secondary interactions have a significant ($\alpha = 0.05$) impact on yield. Four part sizes were found to have a negative parameter estimate (eg adding these particular parts to a cutting-bill will lower yield based on main effects), 13 parts had a positive parameter estimate that was less than 1, and 3 had parameter estimates that were greater than 1 (eg those 3 parts will increase yield the most when added to a cutting-bill).

Part II of this paper will look at the correlation of individual part groups and yield. While the parameter estimates generated in the first part of this study answer the question: "*What benefit can be gained of adding a part group to the existing cutting-bill?*" the correlation coefficient will show how influential, on average for the 512 different cutting-bill requirement combinations tested, each particular part group is for achieving high yield. Part II also will look at the diminishing benefit of having an increasing number of different part sizes being cut in the same run.

METHODS

The methods used for this study are identical to the ones used in Part I (Buehlmann et al 2008a). Therefore, only a brief summary of the methods is given here except for a more detailed discussion of the principles used for the derivation of the correlation coefficients.

Lumber Cut-up Simulation

ROMI-RIP 1.0 (Thomas 1995a, 1995b), the USDA Forest Service rip-first lumber cut-up simulation program was used for this study. The ROMI-RIP 1.0 settings employed are described in Buehlmann et al (2008a). Yields are reported in absolute terms, and include both primary and smart salvage yield, unless otherwise specified. Digital representations of the lumber were taken from Gatchell et al (1998) kiln-dried red oak data bank using the board quality and size distribution published by Wiedenbeck et al (2003). The standardized and simplified Buehlmann cutting-bill (Buehlmann et al 2008b, 2008c) was used throughout all tests. This cutting-bill was derived using group technology in order to make the 20 part sizes representative of all possible part sizes within defined boundaries. In this way, any cutting-bill with parts falling within defined max/min limits could be represented by the

Buehlmann cutting-bill with a defined maximum error. Since this cutting-bill was derived to represent parts within well-defined part-size ranges, the term "part group" is used for part, part size, or blank to refer to a specific part with a defined size.

Statistical Analysis

As described in Part I (Buehlmann et al 2008a), an orthogonal, 2-level 20-factor fractional-factorial design with resolution V, ie a 2^{20-11} fractional-factorial design (Box et al 1978) was used to derive the data for this study. The DOE required 512 simulations with separate cutting-bill requirements, each with 3 replicates, to be performed. The coefficient of linear correlation (r) then was used to investigate the benefit of producing a given part size when cutting parts, and in determining the importance of the number of different part sizes to be cut simultaneously.

Coefficient of linear correlation (r). The coefficient of linear correlation (r) is a measure of strength of the relationship between 2 variables (Ott 1993). The formula for the correlation coefficient, is (Ott 1993):

$$\rho = \frac{\sum_{i=j=1}^{i=j=n} x_i y_j - \frac{\left(\sum_{i=1}^{i=n} x_i\right)\left(\sum_{j=1}^{j=n} y_j\right)}{n}}{\sqrt{\left(\sum_{i=1}^{i=n} x_i^2 - \frac{\left(\sum_{i=1}^{i=n} x_i\right)^2}{n}\right)\left(\sum_{j=1}^{j=n} y_j^2 - \frac{\left(\sum_{j=1}^{j=n} y_j\right)^2}{n}\right)}} \tag{1}$$

where ρ is the coefficient of linear correlation, X_i is the i^{th} setting of variable X, Y_j is the j^{th} result of variable Y (average of 3 replicates), and n is the number of tests (ie 512).

Employing the correlation coefficient to measure the linear relationship between one independent variable (for example, a particular part size or length group, etc.) and the corresponding dependent variable (yield), a measure of the positive or negative correlation of that independent variable to the dependent variable can be established. The correlation coefficient is indeed closely related to the parameter estimates (slopes) derived in Buehlmann et al (2008a). However, instead of establishing a directional measure of an independent variable, it establishes the strength of a relationship between an independent and a dependent variable. The correlation coefficient, thus, measures the correlation of the independent variable to the dependent variable based on all 512 cutting-bills tested. The least squares estimation parameter, on the other hand, measures the expected change in the dependent variable, when a particular independent variable is added or removed from a set of existing independent variables.

An approximate $100(1-\alpha)\%$ confidence interval for correlation, ρ, (Draper and Smith 1981) is found by solving

$$\frac{1}{2}\ln\left(\frac{1+r}{1-r}\right) \pm z\left\{\frac{1}{n-3}\right\}^{1/2} = \frac{1}{2}\ln\left(\frac{1+\rho}{1-\rho}\right) \tag{2}$$

where r is the sample correlation and z is the critical value for the normal distribution for the chosen level of confidence (ie 1.96 for 95% confidence). Using the confidence interval, one can establish if the correlation coefficient is significantly different from 0 at the chosen level of significance.

Duncan's multiple range test was used to create groups that are significantly different from one another based on average yield levels achieved due to the number of different part sizes being cut simultaneously. Duncan's test provides greater power and is protective against Type II errors, while incurring a somewhat higher potential of a Type I error as compared with other comparison of means tests (Mays 1995).

Table 2. *Correlation coefficients for length groups, main effects and secondary interactions.*

Width group	Yield
L_1L_1	−0.17**
L_1L_2	0.17**
L_1L_3	0.13**
L_1L_4	−0.30**
L_1L_5	−0.42**
L_2L_2	0.28**
L_2L_3	0.47**
L_2L_4	0.06*
L_2L_5	0.05
L_3L_3	0.20**
L_3L_4	0.04
L_3L_5	0.03
L_4L_4	−0.24**
L_4L_5	−0.44**
L_5L_5	−0.49**

* significant at 95% level
** significant at 99% level

RESULTS

Results are first presented regarding the correlation of different cutting-bill characteristics (such as part sizes, part lengths, or part widths). Then, results regarding the importance of the number of different part sizes to be cut simultaneously on lumber yield are given.

Contribution of Individual Part Groups on Yield

The correlation coefficients for the main effects and secondary interactions, and yield on the 4 width groups are displayed in Table 1. Table 2 shows the correlation coefficients found for the 5 length groups and the 10 secondary interactions. The interpretation of the results for length is the same as for width.

Table 1. *Correlation coefficients for width groups, main effects and secondary interactions.*

Width group	Yield
W_1W_1	0.14**
W_1W_2	0.35**
W_1W_3	0.03
W_1W_4	−0.01
W_2W_2	0.12**
W_2W_3	0.01
W_2W_4	−0.03
W_3W_3	−0.23**
W_3W_4	−0.35**
W_4W_4	−0.30**

* significant at 95% level
** significant at 99% level

The individual influence of width and length on yield has been considered. However, parts are not unidimensional; they combine these two size attributes. Therefore, the most revealing information is found in the correlation between part sizes (length and width) and yield. Table 3 displays the correlation coefficients found for the 20 part sizes contained in the Buehlmann cutting-bill.

Actually, only 5 part groups (L_1W_1, L_2W_1, L_2W_2, L_3W_1, and L_3W_2) were found to be positively correlated with high yield (all significant at $\alpha = 0.01$). Five part group (L_1W_2, L_2W_3, L_2W_4, L_3W_3, and L_4W_1) correlation coefficients were found to be not significantly different from 0 ($\alpha = 0.05$). Thus, little impact on yield would result from a cutting-bill that requires parts from

Table 3. *Correlation coefficients for the 20 part groups.*

Width/length	Yield				
	L_1	L_2	L_3	L_4	L_5
W_1	0.14**	0.14**	0.19**	−0.03	−0.20**
W_2	−0.01	0.26**	0.13**	−0.14**	−0.31**
W_3	−0.19**	−0.03	−0.04	−0.17**	−0.28**
W_4	−0.13**	−0.02	−0.13	−0.27**	−0.35**

* significant at 95% level
** significant at 99% level

these nonsignificant part groups, based on the average of the 512 cutting-bills researched. Note that this examination does not take into account secondary interactions. Eleven part sizes had negative correlation coefficients with yield (highly significantly different from 0 [α = 0.01]). To obtain high yield, few (if any) parts from the 11 negatively correlated parts sizes should be specified in the cutting-bill.

Number of Parts Being Cut Simultaneously

The number of different part sizes required in a cutting-bill is positively correlated with higher yield. The correlation coefficient found between the number of different part sizes and high yield was 0.64. This value is highly significantly different from 0 (α = 0.01). Thus, there must be a positive influence on yield from having more part sizes in a cutting-bill. Selected observations from the 512 average yield results obtained confirm this claim. The lower 10% of the 512 yield-results obtained required an average of 7.10 unique part sizes per cutting-bill and achieved an average yield of 57.28%. The upper 10% of the 512 yield-results required an average of 12.00 unique part sizes per cutting-bill and achieved an average yield of 69.71. ANOVA indicated that there is a highly significant difference (α = 0.01) in level of yields achieved depending on the number of part sizes required by the cutting-bill. Duncan's multiple range test (α = 0.05) defined 6 significantly different cutting-bill part quantity groupings. These results are shown in Table 4.

Even though the increase in yield observed for cutting-bills with varying numbers of part sizes is somewhat erratic, the general trend is for yield to increase when more part sizes are cut simultaneously. However, when more than 11 different part sizes are cut simultaneously, the increase in yield was not significant (α = 0.05, Table 4). There seems to be a diminishing return as the number of part sizes in a cutting-bill is increased. When the number of part sizes required by a cutting-bill was raised from 5 to 6, yield increased by an average of 6.39%. In contrast, increasing the number of parts in a cutting-bill from 13 to 14, achieved a yield increase of only 0.08%. The study design did not allow us to make observations about the influence of more than 14 part sizes on lumber yield.

DISCUSSION

Understanding the results of both research questions: 1) "*Which part sizes are more closely correlated to high yield?*" and 2) "*What is the effect of increasing the number of different part sizes scheduled for simultaneous production?,*" can assist rough mill managers in their quest for higher yield. The following discussion tries to shed further light on the results to facilitate this understanding.

Contribution of Individual Part Groups to Yield

The interpretation of the correlation coefficients, especially of the interaction terms, is much

Table 4. *Statistically significant differences in yield-levels and yield groups using Duncan's testing due to number of parts in a cutting-bill.*

Test no.	No. of parts in cutting bill	No. of observations	Yield	Difference between tests	Std. dev.	Duncan grouping (α = 0.05)		
1	5	6	54.56%		3.94%	**A**		
2	6	25	60.95%	6.39%	4.39%		**B**	
3	7	44	60.95%	0.00%	3.53%		**B**	
4	8	65	63.38%	2.43%	3.60%	**C**		
5	9	72	64.57%	1.18%	2.43%	**C**	**D**	
6	10	70	65.57%	1.00%	2.24%		**D**	**E**
7	11	84	66.74%	1.17%	1.78%	**F**		**E**
8	12	76	66.80%	0.06%	2.22%	**F**		**E**
9	13	50	67.85%	1.05%	1.73%	**F**		
10	14	17	67.93%	0.08%	1.29%	**F**		

easier than it was for the least squares estimates discussed in Part I of this series (Buehlmann et al 2008a). The closer the correlation coefficient is to +1.0, the more closely this term is associated with above average yield (65.09%). The closer the correlation coefficient is to −1.0, the more closely this term is associated with below average yield. As Table 1 shows, the interaction between width groups W_1 and W_2 has the highest positive correlation coefficient of all widths tested. Thus, having parts from these two width groups in a cutting-bill has a positive impact on yield. Having only, say, parts from width group W_1, will lead to a lower yield, on average, than having parts from both groups, W_1 and W_2. This is because the correlation for group W_1 with high yield is lower than the correlation for groups W_1 and W_2 combined. If parts from groups W_3 and W_4 have to be cut, one should avoid pairing parts from these two width groups with only 1 of 2 smaller width groups (ie W_1 or W_2). The more narrow part sizes that can be cut simultaneously, the lower the yield reduction associated with cutting the wide parts. However, this observation is a generalization, since tertiary interactions are confounded with secondary interactions, with certain exceptions. Also, there are always pairs of values with opposite signs. For example, the interaction of the 2 groups W_1 and W_2 has a correlation coefficient of 0.35. The interaction of the 2 remaining groups, W_3 and W_4, has a correlation coefficient of –0.35. This makes sense, since establishing the correlation coefficient for all four width groups would yield no detectable correlation (ie the sum of all correlations is 0).

For length, the results obtained show that parts required in group L_5 have the most negative correlation with high yield (–0.49, highly significantly different from 0 [$\alpha = 0.01$]). On the other hand, group L_2 with a value of 0.28 has the highest positive correlation with high yield (highly significantly different from 0 [$\alpha = 0.01$]). Group L_1 was found to be negatively correlated with high yield. Its value, which is significantly different from 0 ($\alpha = 0.01$), was –0.17. This shows, as discussed in Buehlmann et al (2008a) and in Buehlmann et al (2003a), the limitations of the rule of thumb that the shortest parts determine yield when part quantities to be cut are limited. However, if an unlimited number of parts from the shortest length group could be cut, this group would have the highest positive correlation with high yield (also see Buehlmann et al 2003a). Unfortunately, this is very rare in real operations. Thus, for length, the best selection of parts to achieve high yield is to have parts from length groups L_2 and L_3 in a cutting-bill since these lengths tend to frequently fit into the clear areas on boards but are more in line with the part sizes demanded by industry. If long length parts (ie parts from groups L_4 and L_5) have to be cut, it is best to cut them concurrently with parts from length groups L_2 and L_3. Therefore, mixing long parts (ie groups L_4 and L_5) with a sufficient number of medium length parts (ie groups L_2 and L_3) is the appropriate course of action. Mixing length L_4 and L_5 with length L_1 results in high yield only when a large enough quantity of length L_1 is required.

The most positive influential part size was L_2W_2 (445 × 57 mm). This part correlation coefficient with yield was found to be 0.26 (highly significant at $\alpha = 0.01$). The observation is consistent with findings derived from the parameter estimates (Buehlmann et al 2008a). However, contrary to what was found for the parameter estimates, whereby the influence of adding a specific part to a cutting-bill was established, and the smallest part groups contributed positively to yield, here, the smallest part group L_1W_1 is negatively correlated to high yield with a value of –0.14 (significant at $\alpha = 0.01$). This reflects the subtle difference in the meaning of these two approaches–the parameter estimates indicate the influence on yield of a part when it is added to a cutting-bill while the correlation statistic indicates the influence of a part required by a given cutting-bill. When adding parts, the small parts can still help increase the yield achieved. When composing a cutting-bill, it would be better to have parts from medium size part groups (ie L_2W_1, L_2W_2, L_3W_1, L_3W_2) in the cutting-bill instead of the ones from the smallest part group (ie L_1W_1) to effectively utilize lumber better relative to specified demand.

This statement is supported by an analysis of the 512 individual cutting-bills tested under the fractional-factorial design. Six out of the 10 cutting-bills that achieved lowest yield did not require any parts from the four part groups with positive correlation to yield (ie L_2W_1, L_2W_2, L_3W_1, L_3W_2), the remaining four required parts from only 1 of 4 part groups. Conversely, 5 of 10 cutting-bills that achieved highest yield required parts from all 4 of the most positively correlated part groups with yield, 3 required parts from 3 of these part groups, and 2 from 2 of these part groups. Thus, parts in the approximate range of 381- to 889-mm length and 25- to 76-mm width are absolutely crucial to achieve high yield. Figure 1 gives a graphical depiction of these findings by presenting the yield response surface of the correlation of part sizes to high yield. This surface was extrapolated from the 20 data points derived for the correlation coefficient of the main effects (Table 3) and should give a good approximation of how beneficial different part sizes are for high yield.

Figure 1 shows that only a small number of the part sizes in a cutting-bill are positively beneficial to yield (ie serve to contribute to higher than average yields). Luckily, these parts, ranging 381–889 mm length and 25–76 mm width, constitute approximately 45% of the total part quantity required by the average cutting-bill according to Araman et al (1982). Therefore, it should be possible to balance cutting-bills such that high yield can be achieved. However, cutting-bills used by industry are often dominated by parts of a limited size range, leading to cutting orders that produce highly variable yield. By better spreading the different part sizes, especially the ones with a positive correlation to high yield, over all cutting-bills to be processed, a higher average yield should be realized.

Number of Parts Being Cut Simultaneously

Thomas and Brown (2003) showed that yield increases when the number of parts cut simultaneously increases (or, to use their point of view, when more sorting stations are used). However, their study also showed that the influence of the number of parts simultaneously cut affects yield differently for different cutting-bills. The findings for the Buehlmann cutting-bill are shown in Table 4, where increasing the number of part sizes required is positively correlated with

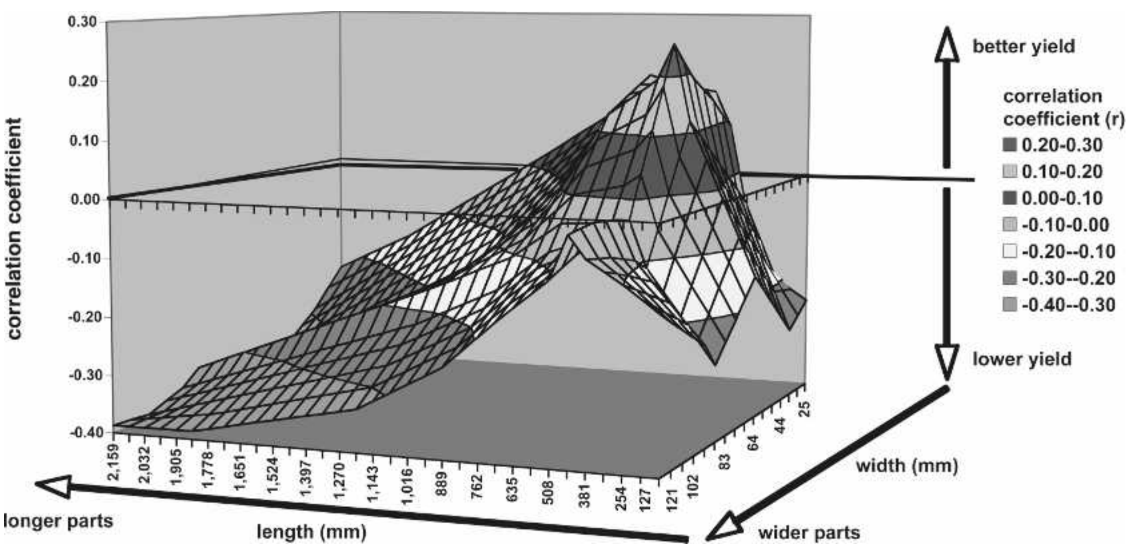

Figure 1. Yield response surface of the correlation of part sizes to high yield.

achieving higher yield up to 11 parts. The distribution of part sizes in a cutting-bill also affects this result. Little benefit is gained from adding one more part size to a cutting-bill when this part has a size that is very similar to one or several already contained in the cutting-bill. The most benefit is gained from adding part sizes that are diverse from the ones already required unless the parts are small in size (which always benefits yield levels, Buehlmann et al (2003a)).

This "diversification" of part sizes influences the level of yield achieved, and is borne out by the yield results obtained for cutting-bills requiring equal numbers of parts be cut simultaneously. For example, the range of yield from cutting-bills that required 11 parts to be cut (84 observations), was found to be between 62.34% (cutting-bill 266) and 69.80% (cutting-bill 191) yield, a 7.46% difference in yield. Table 5 shows the distribution of parts required by these two cutting-bills. The Max cells indicate part groups requiring maximum part quantity for this particular part size. The parts required by cutting-bill 266 are less evenly dispersed over the entire range of part groups (sizes) than the parts required by cutting-bill 191. However, it also is necessary to take into account that the part group distributions of these two bills are not equally favorable to high yield. For example, cutting-bill 191 asks for parts from part group L_2W_2, which, as was shown previously, is the most positively correlated part group to high yield. Cutting-bill 266, on the other hand, does not require parts from this group. Therefore, the difference in yield observed between these two cutting-bills cannot uniquely be attributed to the differences in the distribution of the part sizes. However, trying to design cutting-bills that require parts from different part groups that are well distributed over the entire range of all sizes helps to achieve higher yield. For example, assuming that parts from all the 20 part groups have to be produced according to the production plan, but only 10 can be cut at one time, making two cutting-bills where the parts included in each cutting-bill are selected evenly over all part groups, will lead to higher average yield than when each of the two cutting-bills asks for parts from 50% of the part group range (Buehlmann et al 1998; Thomas and Brown 2003).

The question as to how many different part sizes need to be cut simultaneously to achieve highest yield is not only of great importance for minimizing raw material cost, but also is important for the investment decisions to be made when a rough mill is planned or modified. When planning a rough mill, the question as to how many sorting stations are needed is crucial because having more sorting stations increases investment costs, and adds to the complexity of the system. Even though this study found no significant yield increase when more than 11 different part sizes are cut simultaneously (Table 4), it would be wrong to limit the capacity of rough mill sorting stations to 11. Not only did Thomas and Brown (2003) show that yield improvements can be expected when cutting more than 11 parts sizes simultaneously, but also having more than 11 sorting stations may pay off for other reasons. For example, when different part qualities are cut simultaneously, more than 11 sorting stations are an absolute necessity to permit grouping of parts according to size and quality.

Table 5. *Distribution of parts for the 2 cutting-bills requiring 11 parts and achieving lowest and highest yield.*

Cutting-bill 266*						Cutting-bill 191*					
L\W	L_1	L_2	L_3	L_4	L_5	L\W	L_1	L_2	L_3	L_4	L_5
W_1	Max					W_1		Max		Max	Max
W_2	Max			Max	Max	W_2	Max	Max	Max		
W_3	Max	Max	Max	Max		W_3		Max			Max
W_4	Max		Max		Max	W_4	Max	Max		Max	

* Max means the group contains the maximum of the part quantity specified in the Buehlmann cutting-bill.

General Discussion

This study did not research the influence of cutting-bill requirements on lumber yield using other types of rough mills than rip-first (eg crosscut-first rough mills), nor did it look at species other than red oak. However, based on empirical observations, it also appears that in crosscut-first mills, certain part sizes are more positively correlated to high yield than others. However, preferred sizes may be different from the sizes identified in this study (eg in rip-first rough mills). Also, the findings presented in this study for red oak lumber may be different for other species, especially for lumber having different exceptions or entirely different rules than red oak under NHLA (2007). Differences in the distribution of defects among different species may also change the results and conclusions of this study.

Nonetheless, this study has shown that yield can be substantially increased by combining medium-sized parts in sufficient quantities with more difficult to obtain larger part sizes. However, this task is further complicated by the parts scheduling problem. At the same time, selecting the optimum lumber grade for a given production run (Zuo et al 200x; Buehlmann et al 2004; Lawson et al 1996) creates an additional challenge. Over the past years, research has advanced our understanding of these phenomena. However, true success will be achieved if the complex relationships and the advanced knowledge can be translated into applied, easy-to-use tools that help the industry to better use our natural resources.

SUMMARY AND CONCLUSIONS

The important role of small- to medium-sized parts for a cutting-bill to achieve above average yield was confirmed. The correlation of part group L_2W_2 (445 × 57 mm) with positive yield was the highest of all part sizes (+0.26). Parts of this or similar size should be included in well-designed cutting-bills in sufficient quantities to achieve above average lumber yield. Lengths <445 mm (length group L_1) and >699 mm (length groups L_4 and L_5) were found to be negatively correlated with above average yield. Combinations of part sizes (parts from groups L_2 and L_3) exist that allow achieving above average yield when long parts are required.

Duncan's multiple range test ($\alpha = 0.05$) revealed that higher yields are obtained when more part sizes are included in the cutting-bill up to 11 part sizes. There seems to be a diminishing return from adding additional part sizes to a cutting-bill as the number of different part sizes increases.

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