

# THE EFFECT OF LOG ROTATION ON VALUE RECOVERY IN CHIP AND SAW SAWMILLS

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## ABSTRACT

Advances in three-dimensional scanning techniques and computer optimization permit real time solution and implementation of optimal log rotation before it is fed into the chipper heads. A random sample of 834 S-P-F logs from the interior of British Columbia were examined using simulation to determine the effects of log rotation strategies on value recovery for a small log Chip and Saw. Both log sweep and cross-sectional eccentricity are shown to cause significant reductions in value recovery. Eight rotation placements from 0° to 315° were studied to determine if a single rotational placement could be found that performs best. On average, the "horns up" position (0° rotation) was found to significantly outperform all others in maximizing value recovery. The ability to rotate each log into the optimal position produced significant benefits. The benefits were more highly related to the degree of cross-sectional eccentricity present in the log rather than the degree of sweep present in the log.

*Keywords:* Sawmilling, sawing optimization, lumber manufacturing, computer-aided manufacturing.

## INTRODUCTION

Loss of value recovery in sawlog conversion to lumber can be attributed to several geometric factors. Diameter, log roundness, sweep and crook, taper and length all play an important part in determining the positioning of the log in relation to the saws to obtain the highest value recovery. Modern networks with double-length infeeds in Chip and Saw (CNS) sawmills are capable of scanning the logs, determining the optimal set position, and executing the optimal decision in seconds. In the past, sawing optimization systems have set the log in relation to the saws without regard to rotating the log into the optimal position. This paper explores the costs and benefits from determining and setting the correct rotation position in a small log CNS mill.

## BACKGROUND

Early sawing optimization systems focused solely on log diameter, length, and taper as principal components in determining the log set (Hallock and Lewis 1971; Shi et al. 1990). The main assumptions in this type of analysis are that the shape of the log cross section is the same at all points along the log (and usually circular), and that the log exhibits no sweep, or deviation from a straight line along the log's length. When these assumptions are made, the rotation of the log can have no effect on the yield whatsoever. Steele et al. (1987) found that when using these assumptions, the complex three-dimension analysis can be replaced by a much simpler and faster method that predicts the optimal Best Opening Face position well.

However, it is well known in the sawmill that the sweep of the log and its cross-sectional shape play a very important part in determining the optimal set position. It is also known that these factors have a particularly important negative impact on value recovery with smaller diameter logs (Wang et al. 1992). Simplified methods that predict the optimal BOF position may not perform well in the sawmill, particularly with decreasing log size.

Currently there are three methods for dealing with log sweep at a CNS. The most technologically advanced method involves curve sawing, in which a two-sided cant is sawn parallel to curve in the log (Hasenwinkle et al. 1987; Lindstrom 1979). Curve sawn logs are generally sawn "horns down" to produce a two-sided cant, and then the cant is sawn with a variable curve linebar.

A second, less expensive method, involves choosing a rotation position in which, on average, the highest value yield can be obtained from sweepy logs. While opinions differ on this ideal position, generally the log is sawn either "horns up" (concave-up or 0 degree rotation), "horns down" (180°) or "horns up 45" (45°). For illustration, Fig. 1 shows a side view of both "horns up" and "horns down" cant sawing. Of these positions, machinery designers favor the "horns down" position as the most accurate and simplest mechanism to hold the log in place as it is being sawn. Once the ideal position is chosen, all logs are rotated at the infeed of the machine to this position prior to sawing.

Both of the above methods select the rotational position based primarily on sweep rather than the cross-sectional eccentricity of the log. A third sawing method would involve optimizing networks that calculate the correct rotation for each log and automatically set it into this position as it is being sawn. The advantage of this networks system is that both sweep and cross-sectional eccentricity can be taken into account when determining the sawing position. This method is now possible due to two new technological advances in the sawmilling industry: 1) the availability of real shape scan-

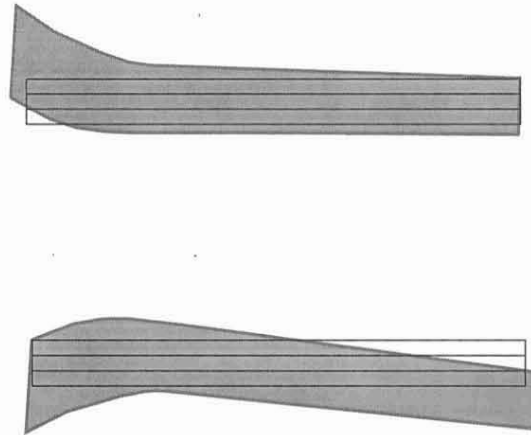


FIG. 1. "Horns up" (top) and "horns down" (bottom) sawing position for log with asymmetrical sweep pattern.

ning devices at the headsaw; and, 2) the enormous increases in computer power that enable real time solution of complex real-shape logs.

The majority of lumber production from CNS mills is sawn using method 2. The technology currently exists to implement method 3, but uncertainty concerning the economic benefits of such a system may impede its widespread implementation. Therefore, objectives of this study are:

1. determine if an ideal rotation position exists which on average maximizes the value recovery from a population of small diameter logs from a typical CNS sawmill; and,
2. estimate the economic benefits from calculating the optimal rotation and setting the log accordingly prior to sawing.

#### METHODOLOGY

##### *Sawing simulation*

To determine the actual optimal rotation for a sawlog it would be necessary to saw the log in many different rotations and calculate the value recovery from each position. Since this is impossible, another solution is to use computer simulation to saw the log. To satisfy the objectives of this study, the simulation package used must be able to look at the three-dimensional geometry of actual scanned logs,

TABLE 1. Summary statistics on the 834 logs used in the study.

| Variable               | Minimum | Maximum | Mean  | SD   |
|------------------------|---------|---------|-------|------|
| Dia—Small end diameter | 3.40    | 12.95   | 8.40  | 2.49 |
| Len—Log length         | 8.20    | 20.60   | 15.46 | 3.55 |
| Tpr—Log taper          | 0.02    | 4.17    | 1.11  | 0.61 |
| Swp—Log sweep          | 0.15    | 2.03    | 0.56  | 0.34 |
| Ecc—Log eccentricity   | 0.01    | 5.70    | 0.48  | 0.62 |

perform sawing cuts with realistic constraints imposed by the CNS sawing system, and allow carefully controlled positioning of the log in relation to the saws. For these reasons, the sawing simulator SAWSIM was chosen to determine the value recovery from each set position.

The logs used in this study were randomly chosen from a log database maintained at the University of British Columbia containing two-axis scan data from thousands of logs taken in interior British Columbia (BC) small log sawmills. Two-axis scanning is the scanning method used when logs are modeled as elliptical in cross section. Although it is understood that this type of log modeling results in inaccuracies (Mongeau et al. 1993), it was the best method of modeling applied in the industry available to provide data for the purpose of this study. The sampling procedure was stratified to cover log diameters in the range of 3 in. sed (small end diameter) to 13 in. sed, and log lengths from 8 ft to 20 ft. The sample was not stratified with respect to taper and sweep. Summary sta-

istics for the 834 logs used in the study are shown in Table 1.

A set of cross-sectional cant profiles was created to mimic the possible set of profiles available to a four-side chipping profiling machine without band saws (no side boards) for the purpose of producing dimension lumber. It was assumed that the system would use a 0.5- by 1-in. "multispline" combination to guide the log through the machine center. This assumption reflects the trend towards this practice as opposed to the use of a 2 × 4 spline board.

Each profile represents a stack of lumber separated by saw kerfs. Profile widths ranged from 4 to 12 in. nominally. Profile heights start with the combination of the heights of one 2-in. board up to the height of seven 2-in. boards, with the top board of each profile alternating between a 1-in. and a 2-in. board as the profile heights increase. It was assumed that 1-in. boards would be recovered in 4- and 6-in. widths only.

Up to eight possible profile patterns were created for each of four log diameter ranges. Table 2 lists the diameter ranges used and their assigned profiles. The profile codes are interpreted as follows: the rightmost digit if equal to 1 represents the existence of a 1-in. top board in the stack, a zero indicates all 2-in. boards in the stack; the second rightmost digit represents the number of 2-in. boards in the stack; the remaining digits to the left indicate the nominal width of the profile; cns is the name given to the simulated machine center.

TABLE 2. Log diameter ranges and assigned profiles.

| Diameter Range 1 | Assigned profiles | Diameter Range 2 | Assigned profiles | Diameter Range 3 | Assigned profiles | Diameter Range 3 | Assigned profiles |
|------------------|-------------------|------------------|-------------------|------------------|-------------------|------------------|-------------------|
|                  | cns-411           |                  | cns-621           |                  | cns-831           |                  | cns-1051          |
|                  | cns-420           |                  | cns-630           |                  | cns-840           |                  | cns-1060          |
| 3.40"            | cns-421           | 6.50"            | cns-640           | 8.50"            | cns-841           | 11.50"           | cns-1061          |
| to               | cns-430           | to               | cns-830           | to               | cns-1041          | to               | cns-1250          |
| 6.49"            | cns-621           | 8.49"            | cns-831           | 11.49"           | cns-1050          | 12.95"           | cns-1251          |
|                  | cns-630           |                  | cns-840           |                  | cns-1051          |                  | cns-1260          |
|                  | cns-640           |                  | cns-841           |                  | cns-1060          |                  | cns-1261          |
|                  |                   |                  |                   |                  | cns-1061          |                  | cns-1270          |

Profile codes are interpreted as follows: the right most digit if equal to one indicates the presence of a 1-in. top board in the stack, a zero indicates all 2-in. boards in the stack; the second rightmost digit represents the number of 2 in. boards in the stack; the remaining digits to the left indicate the nominal width of the profile; cns is the name given to the simulated machine center.

The schematic in Fig. 2 illustrates an applied profile, the CNS-831 profile. The dark shaded region is the profile; the light shaded areas within it are the sawing pattern. Below the cant profile is the profile of the “multispline.” The profile has one 1-in.-thick board and three 2-in.-thick boards.

Sawing simulation was used to determine which of the possible profiles was optimal for each log in the study when rotated to each of the angles of the set of rotation angles. To accomplish this, the sample logs were first oriented to the same starting rotation angle of 0°—“horns up.” The possible cant profiles respective of each log’s profile-group/diameter range were applied, and the resulting sawing pattern was determined. The sawing pattern that yielded the greatest value for each log was recorded as the optimal sawing pattern. The simulations were repeated for rotation increments of 45° until simulations for all the possible rotation angles were complete. This resulted in an optimal sawing pattern for each rotation angle and log combination.

Each log was sawn using the method known as split taper log–full taper cant (Williston 1981), as shown in Fig. 2. The sawing patterns were determined by finding the best combination of horizontal and vertical placements for the log with respect to the saws and chipping heads for each profile. The optimal combination of horizontal and vertical placement was found by exhaustive search iteration. Horizontal placements of the log were considered using 0.25-in. offsets from the center sawn position for both sides of center for a total of 10 offsets. For each horizontal placement of the log, the best vertical placement was determined by simulating a gang edger with a variable linebar. We assume that all boards from the sawing pattern except the innermost board can be edged to remove wane. This ensures that the cant made in the simulation would have two parallel planer faces, a requirement assumed necessary for the proposed real machinery to firmly hold the log while processing. Optimal board skewing at the edger was determined by choosing from two possible skew-

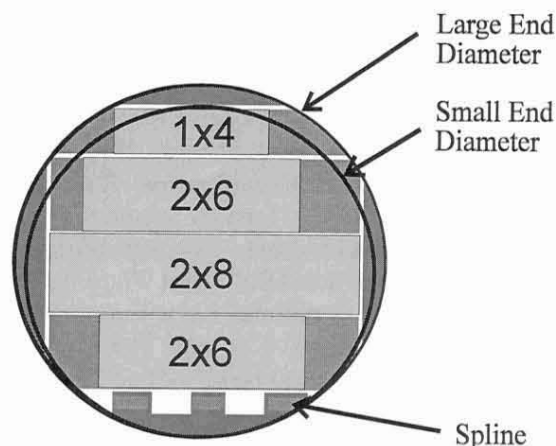


FIG. 2. The CNS-831 profile with a likely sawing pattern.

ing angles for each board. Gang sawing and subsequent edging processes were iterated with the linebar shifting left of the saws on 0.5-in. increments for a total of 10 iterations. The combination of profile and horizontal and vertical placements resulting in the greatest value was considered the optimal sawing pattern.

The horizontal and vertical placement increments and rotation angle increments were chosen to optimize a trade-off between simulation accuracy in finding an optimal solution, simulation processing time, and the volume of resulting data. Horizontal and vertical placements were in increments of 0.25 and 0.5 inches respectively for 10 increments each. This resulted in a trial of 100 placement positions, an acceptable total. The increment for horizontal placement was twice that of vertical placement because the starting references for each placement are different. For the vertical placement, the cant is aligned with the simulated gang-saw’s linebar and the point of reference is the linebar. The 0.5 in. was necessary to cover the worst possible sweep situation. These increments provided enough profile coverage for 5 in. of sweep. In the case of the horizontal placement, the point of reference is the horizontal geometric center of the log. As a result, there was less horizontal distance for necessary profile coverage, which allowed the finer increment. The 45° rotation increment was chosen as small enough for accuracy and

falls among those angles that are commonly used in industry, namely: 0°, 45° and 180°.

The product values used for the simulation are shown in Table 3. These reflect average dimension lumber prices of early 1992, and were taken from the publication Random Lengths (Anon. 1992). Two-in. products were assumed to be kiln-dried "Western Spruce-Pine-Fir," either Std.&Btr. Light Framing (2 × 4) or #2&Btr. Structural Light Framing (2 × 6, 2 × 8, 2 × 10, 2 × 12). The one-in. boards were assumed to be kiln-dried "Engelmann Spruce," #3 Common.

## RESULTS AND DISCUSSION

### Determination of ideal rotation

First, we wish to determine the effect of the different log rotation classes on value recovery. To accomplish this, we use the regression approach, analysis of covariance procedure (Neter et al. 1990). In this procedure, we employ seven indicator variables taking on the values of 1, -1, or 0 to represent the eight rotation classes according to the following rule:

1 if from rotation class 1 (0°)

$Rot_1 = -1$  if from rotation class 8 (315°)

0 otherwise

·  
·  
·

1 if from rotation class 7 (270°)

$Rot_7 = -1$  if from rotation class 8 (315°)

0 otherwise

Thus there are seven treatment variables.<sup>1</sup> The covariance model is expressed as:

$$Vrc = \beta_0 + \beta_1 Dsq + \beta_2 Len + \beta_3 Tpr + \beta_4 Swp + \beta_5 Chp + \beta_6 Ecc + \beta_7 Rot_1 + \beta_8 Rot_2 + \dots + \beta_{13} Rot_7 + \epsilon \quad (2)$$

<sup>1</sup> Only seven coefficients are estimated in the model. The value of the coefficient for the eight rotation groups (315°) is obtained as  $\beta_{13} = -\beta_6 - \beta_7 - \dots - \beta_{12}$ . See Neter et al. (1990) Chapter 23 for a full discussion.

TABLE 3. Product prices using in the sawing simulation.

| Product               | Prices by product length |     |     |     |     |     |     |
|-----------------------|--------------------------|-----|-----|-----|-----|-----|-----|
|                       | 8                        | 10  | 12  | 14  | 16  | 18  | 20  |
| 1 × 4                 | 215                      | 215 | 215 | 215 | 215 | 215 | 215 |
| 1 × 6                 | 235                      | 235 | 235 | 235 | 235 | 235 | 235 |
| 2 × 4                 | 185                      | 211 | 172 | 178 | 223 | 210 | 210 |
| 2 × 6                 | 188                      | 206 | 174 | 170 | 196 | 225 | 222 |
| 2 × 8                 | 190                      | 172 | 187 | 173 | 204 | 240 | 240 |
| 2 × 10                | 190                      | 190 | 256 | 268 | 250 | 235 | 235 |
| 2 × 12                | 190                      | 190 | 256 | 268 | 250 | 235 | 235 |
| Chip prices (\$/ton)  |                          |     |     |     |     |     |     |
| Low    Medium    High |                          |     |     |     |     |     |     |
| 25    50    75        |                          |     |     |     |     |     |     |

where

$Vrc$  = value recovery of the log in \$/cubic meter (gross)

$Dsq$  = square of the average small end diameter of log in inches

$Ecc$  = measure of maximum log cross section eccentricity:

$$\max(\text{dia axis 1} - \text{dia axis 2})^2 / Dsq$$

$Len$  = log length in feet

$Tpr$  = log taper (expressed in percent)

$Swp$  = log sweep (expressed in percent)

$Chp$  = chip price indicator:

1 high prices

0 moderate prices

-1 low prices

Equation (2) was estimated using the statistical analysis system (SAS 1991) with all terms and interaction terms for  $\beta_1 - \beta_6$ . Model coefficients were eliminated using the partial  $F$ -test procedure with an alpha value of 0.05 to remain in the model. Only one variable was eliminated at each step. Once a variable was eliminated, it was not considered for re-entry into the model. Regression results showing remaining coefficients in the full model are presented in Table 4. All remaining variables in the model are highly significant. All treatment effects ( $Rot$ ) are left in the full model as these are the variables of interest.

The signs of the primary coefficients in Table 4 agree with intuition. Both diameter and length have positive effect on value recovery. Increasing taper has a positive effect on value recovery. This is because diameters are measured from the small end, and logs with larger taper

TABLE 4. Statistical estimation of full model and Duncan's Multiple Range Test on treatments.

| Source of variation          | Linear regression results |          |          |                | P-value |
|------------------------------|---------------------------|----------|----------|----------------|---------|
|                              | df                        | SS       | MS       | F              |         |
| Model                        | 802,306.9                 | 2        | 53,487.1 | 1,182.0        | 0.0     |
| Error                        | 301,185.0                 | 665      | 45.2     |                |         |
| Total                        | 1,103,491.9               | 667      |          |                |         |
| R-square                     | 0.727                     |          |          |                |         |
| Source of variation          | Estimate                  | t        | P-value  | SE of estimate |         |
| Intercept                    | 38.929                    | 42.6     | 0.0000   | 0.9125         |         |
| Dsq                          | 0.046                     | 4.3      | 0.0001   | 0.0105         |         |
| Len                          | 0.050                     | 9.8      | 0.0001   | 0.0506         |         |
| Tpr                          | 1.479                     | 5.6      | 0.0001   | 0.2613         |         |
| Swp                          | -9.691                    | -35.9    | 0.0001   | 0.2693         |         |
| Ecc                          | -1.035                    | -7.2     | 0.0001   | 0.1427         |         |
| ChipPrc                      | 3.224                     | 31.9     | 0.0001   | 0.1009         |         |
| Dsq·Len                      | 0.011                     | 19.7     | 0.0001   | 0.0006         |         |
| Dsq·Tpr                      | -0.035                    | -12.6    | 0.0001   | 0.0028         |         |
| 0                            | 1.222                     | 5.6      | 0.0001   | 0.2179         |         |
| 45                           | 0.705                     | 3.2      | 0.0012   | 0.2179         |         |
| 90                           | -1.617                    | -7.4     | 0.0001   | 0.2179         |         |
| 135                          | 0.155                     | .07      | 0.4740   | 0.2179         |         |
| 180                          | -1.159                    | -5.3     | 0.0001   | 0.2179         |         |
| 225                          | 0.108                     | 0.5      | 0.6173   | 0.2179         |         |
| 270                          | 0.024                     | 0.1      | 0.9102   | 0.2179         |         |
| Duncan's Multiple Range Test |                           |          |          |                |         |
| Duncan grouping              | Mean                      | Rotation |          |                |         |
| A                            | 58.140                    | 0        |          |                |         |
| B A                          | 57.624                    | 45       |          |                |         |
| B                            | 57.478                    | 315      |          |                |         |
| B                            | 57.074                    | 135      |          |                |         |
| B                            | 57.027                    | 225      |          |                |         |
| B                            | 56.943                    | 270      |          |                |         |
| C                            | 55.748                    | 180      |          |                |         |
| C                            | 55.300                    | 90       |          |                |         |

Means with the same letter are not significantly different.

have more volume. Sweep and cross-section eccentricity have a negative impact on value recovery. Increasing chip prices has a large positive effect on value recovery.

The signs of the interaction terms in the model are insightful. *Dsq·Len* (diameter squared times length), a well-known predictor of log volume, is positively correlated with value recovery. The negative sign on *Dsq·Tpr* (diameter squared times taper) indicates that high log taper will tend to reduce the expected increase due to larger logs. This indicates that value recovery would be higher on larger diameter logs with low taper than the reverse.

The primary statistical test with this model

is whether or not the rotation class has any effect in the model, and if so, which of the various classes has the most beneficial effect. The other variables are included in the model only to account for the known effects of diameter, length, and so on and reduce the error variability. This test is similar to the fixed treatment effects of analysis of variance models. The test hypothesis is:

$$\begin{aligned}
 H_0: \beta_7 = \beta_8 = \dots = \beta_{13} = 0 \\
 H_A: \text{Not } H_0
 \end{aligned}
 \tag{3}$$

The test is carried out using the general linear model test approach fitting full and reduced

TABLE 5. Statistical estimation of reduced model and Duncan's Multiple Range Test on treatments.

| Source of variation | Linear regression results |     |          |         |         |
|---------------------|---------------------------|-----|----------|---------|---------|
|                     | SS                        | df  | MS       | F       | P-value |
| Model               | 797,049.3                 | 1   | 99,631.1 | 2,166.2 | 0.0     |
| Error               | 306,442.6                 | 665 | 45.9     |         |         |
| Total               | 1,103,491.9               | 667 |          |         |         |
| R-square            | 0.722                     |     |          |         |         |

| Source of variation | Estimate | t     | P-value | SE of estimate |
|---------------------|----------|-------|---------|----------------|
| Intercept           | 38.929   | 42.3  | 0.0000  | 0.9199         |
| Dsq                 | 0.046    | 4.3   | 0.0001  | 0.0106         |
| Len                 | 0.050    | 9.8   | 0.0001  | 0.0511         |
| Tpr                 | 1.479    | 5.6   | 0.0001  | 0.2634         |
| Swp                 | -9.691   | -35.6 | 0.0001  | 0.2714         |
| Ecc                 | -1.035   | -7.2  | 0.0001  | 0.1439         |
| ChipPrc             | 3.224    | 31.7  | 0.0001  | 0.1016         |
| Dsq·Len             | 0.011    | 19.5  | 0.0001  | .0006          |
| Dsq·Tpr             | -0.035   | -12.5 | 0.0001  | 0.0028         |

models. The full model is that presented in Table 4. The reduced model is that of Table 5 with  $\beta_7, \beta_8, \dots, \beta_{13}$  removed. The appropriate test statistic is:

$$F^* = \frac{MSR(X_7, \dots, X_{13} | X_1, \dots, X_6)}{MSE(Full)} = \frac{SSE(Reduced) - SSE(Full)}{p - q} \div MSE(Full) =$$

$$= \frac{306,442.65 - 301,185.07}{7} \div 45.25 = 16.60 \quad (4)$$

$F^*$  is significant at the 0.001 level. The null hypothesis is rejected. We conclude that log rotation has a significant effect on value recovery.

Since treatment effects are found in the model, we next determine which, if any, log rota-

TABLE 6. Statistical estimation of model with zero and optimal rotation.

| Source of variation | Linear regression results |     |           |       |         |
|---------------------|---------------------------|-----|-----------|-------|---------|
|                     | SS                        | df  | MS        | F     | P-value |
| Model               | 188,684.5                 |     | 209,264.9 | 463.5 | 0.0     |
| Error               | 74,986.5                  | 165 | 45.2      |       |         |
| Total               | 263,671.0                 | 166 |           |       |         |
| R-square            | 0.715                     |     |           |       |         |

| Source of variation | Estimate | t     | P-value | SE of estimate |
|---------------------|----------|-------|---------|----------------|
| Intercept           | 42.749   | 44.3  | 0.0000  | 0.9645         |
| Len                 | 0.393    | 6.5   | 0.0001  | 0.0600         |
| Tpr                 | 1.47     | 3.0   | 0.0021  | 0.4787         |
| Swp                 | -8.732   | -16.2 | 0.0001  | 0.5369         |
| Ecc                 | -0.457   | -4.7  | 0.0001  | 0.0970         |
| ChipPrc             | 3.051    | 15.1  | 0.0001  | 0.2017         |
| Dsq·Len             | 0.013    | 30.8  | 0.0001  | 0.0004         |
| Dsq·Tpr             | -0.036   | -7.2  | 0.0001  | 0.0050         |
| Opt                 | 1.458    | 3.0   | .0005   | 0.4167         |
| Opt·Ecc             | 0.289    | 2.1   | 0.0298  | 0.1331         |

tions perform superior to the others. This is determined using Duncan's Multiple Comparison procedure for treatment means for the eight rotation classes. The results of this procedure, shown in Table 4, show clearly that the "horns up" (0° rotation) position can be distinguished from all other rotations except the 45° position. However, the 45° rotation itself cannot be statistically distinguished from the large group of other middle performing rotations (grouping B). The "horns down" (180°) and 90° positions are clearly sub-performers (grouping C). Thus, the evidence supports the adoption of the "horns up" position as performing best, on average, on the test group of logs. The reason that "horns up" performs better than "horns down" can be seen in Fig. 1. Often sweep is more pronounced in the butt end of the log (as in Fig. 1) rather than uniform and symmetrical throughout the log. Recovery is much higher in the "horns up" case when saw lines are placed through such a log.

*Value of optimal rotation setting*

Next, we wish to determine the effect of implementing the optimal rotation for each log as it is being sawn in the CNS. To accomplish this, we again use the regression approach analysis of covariance procedure. In this case we employ a single dummy variable, which indicates the sawing position, as follows:

$$Opt = \begin{matrix} 1 \text{ if log is rotated to optimal} \\ \text{position before sawing} \\ 0 \text{ if log is sawn at the} \\ \text{"horns up" position} \end{matrix} \quad (5)$$

The model to be estimated is:

$$Vrc = \beta_0 + \beta_1 Dsq + \beta_2 Len + \beta_3 Tpr + \beta_4 Swp + \beta_5 Chp + \beta_6 Ecc + \beta_7 Opt + \beta_8 Opt \cdot Swp + \beta_9 Opt \cdot Ecc + \epsilon \quad (6)$$

We calculate the model coefficients using all 834 logs sawn in the optimal rotation (the experimental group) and the same 834 logs sawn in the "horns up" position (the control group). The "horns up" position is chosen as the control group since this position was found to be the "ideal log rotation" in the preceding section.

Equation (6) was estimated using the statistical analysis system (SAS 1991) with all terms and interaction terms for  $\beta_1 - \beta_9$  included. Model coefficients were eliminated using the same procedure as that described above. Regression results showing the model statistics are presented in Table 6. Signs on all model coefficients are the same as the model discussed above. The major difference between the estimation of Eq. 1 and Eq. 6 is that the variable *Dsq* dropped out of Eq. 6.

A significant benefit to optimally rotating logs prior to sawing would be indicated if the coefficient for *Opt* is statistically significant. The hypothesis is:

$$\begin{aligned} H_0: \beta_7 &= 0 \\ H_A: \beta_7 &\neq 0 \end{aligned} \quad (7)$$

Confidence limits around  $\beta_7$  at the  $\alpha = 0.05$  level are:

$$\begin{aligned} \beta_7 - \text{std. err.} \cdot t_{\alpha/2,df} &\leq \beta_7 \leq \beta_7 + \text{std. err.} \cdot t_{\alpha/2,df} \\ 1.459 - 0.4167 \cdot 1.961 &\leq \beta_7 \leq \\ &\leq 1.459 + \\ &+ 0.4167 \cdot 1.961 \\ 0.6413 &\leq \beta_7 \leq \\ &\leq 2.2759 \end{aligned} \quad (8)$$

Thus,  $\beta_7$  is concluded to be statistically different from zero since the 0.05 level confidence interval does not contain zero.

To determine if rotation optimization significantly mitigates the negative effects of sweep and cross-sectional eccentricity, we examine coefficients  $\beta_8$  and  $\beta_9$ . Both coefficients have positive signs indicating that benefits are obtained from rotational optimization. However, the coefficient on *Opt · Swp* ( $\beta_8$ ) was not significantly different from zero using a partial *F*-test (*P*-value = 0.76) and was dropped from the final model. However, the coefficient on *Opt · Ecc* ( $\beta_9$ ) is significant with a *P*-value of 0.0298. Thus, indications are that the beneficial effect of optimally rotating logs is more related to cross-sectional eccentricity than to sweep.

Using the same method as above, confidence limits around  $\beta_9$  are:



$$0.0284 \leq \beta_9 \leq 0.5506 \quad (9)$$

Therefore, we conclude that estimated benefits increase slightly with increasing eccentricity.

We use the confidence limits around  $\beta_7$  and  $\beta_9$  to determine the benefits from optimal rotation. Assuming a CNS line sawing 200,000 cubic meters annually and an average eccentricity of 0.48 (which we found in this study) we obtain the following confidence limits on the benefits to optimal rotation:

$$\$320,000 \pm \$189,000 \quad (10)$$

The cost of implementing an automated log turning device in a CNS is estimated to be between \$300,000 and \$1 million.<sup>2</sup> Assuming the highest implementation cost and the lowest benefits, the internal rate of return for automated rotation equipment with a ten year life-span would be approximately 5%. The mid-range scenario gives an IRR of 48%. The best case (lowest costs and highest benefits) IRR is 169%. The reader should note that these IRR estimates do not take maintenance costs into account.

#### SUMMARY AND CONCLUSIONS

Advances in three-dimensional scanning techniques and computer optimization permit real time solution and implementation of optimal log rotation before it is fed into the chipper heads. This study examined 834 S-P-F logs obtained from the interior of BC using SAWSIM to determine the effects of log rotation strategies on value recovery for a small log CNS. Results show that log rotation plays an important role in determining value recovery. Both log sweep and cross-sectional eccentricity are shown to cause significant reductions in value recovery.

Eight rotation placements from 0° to 315° were studied to determine if a single rotational placement could be found that performs best when the optimal log rotation cannot be implemented. On average, the "horns up" position (0° rotation) was found to significantly outperform all others in maximizing value recovery.

<sup>2</sup> Based on personal communication with Bob Chapman, President, Optimil Machinery, Ltd.

When compared to the "horns up" position, the ability to rotate the log into the optimal position produced significant benefits. These benefits were found to be related to the degree of cross-sectional eccentricity present in the log more so than the degree of sweep present in the log. Internal rate of return estimates for the installation of automatic log turner systems range from a low of 5% to a high of 169%. The mid-range estimate was found to be 48%.

More research is required prior to concluding that automatic log rotation setting should be implemented on a mass scale. This research should include the study of installed equipment at test sites and should concentrate on the following factors:

1. The degree of accuracy in rotational placement required to obtain the maximum financial return. This study demonstrates benefits using only 45° intervals. The benefits could be much larger when a higher accuracy in log placement is used.
2. The effect of full shape scanning information. This study used information collected from two-axis log scanning and assumes the log cross-sectional shape is elliptical.

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