Increased Yield in Sawmills by Applying Alternate Rotation and Lateral Positioning

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Abstract

Modern sawmills are increasingly like process industries, running continuously with very large volumes flowing through the process every second. This fact makes it vital for every company to utilize its equipment and raw material as effectively as possible to maximize yield and value. The objective of this simulated breakdown study was to analyze the potential to increase volume yield in Swedish sawmills. While the commonly used horns-down position performs well on an average basis, the results show that the optimal rotation position for an individual log is most often found at another position.

Results from extended simulations show that the average volume yield can be increased further by applying the optimal combination of rotation and parallel positioning in cant and deal saw. An increase in average volume yield by 4.5 percentage points (8.6%) would enable a typical Swedish sawmill to produce a further 17,300 m^3 of boards per year and thereby increase potential annual income by US$3.7 million per year. This optimization concept requires a preevaluation of every log in order to define the optimal combination of settings.

Some of these procedures must be performed online within a split second to accommodate production speed demands. Modern technology such as industrial x-ray in combination with traceability methods, multivariate models, breakdown simulation software, and high-performance computers enables evaluation and optimization of every log online at full production speed. Sawing machines will need development in order to be able to perform optimization online without loss of production capacity.

Modern sawmills are becoming increasingly like process industries. This type of industry is often characterized by a production process continuously running at all hours with very large volumes flowing through the process every single second. This fact makes it vital for every company to utilize its equipment and raw material as effectively as possible to achieve high volume and thus value yield.

A correct sawing pattern, rotational positioning, and parallel positioning in sawing machines (Fig. 1) and correct usage of curve or straight sawing techniques are crucial breakdown factors that influence the achieved yield.

Optimal positioning can be defined in basic terms as the means of placing and handling a log during the sawing process in order to maximize the volume yield. In a typical Swedish sawmill, this procedure involves log rotation (horns-down), centering the log face to the saw blades and, when curve sawing is applied, calculating and controlling the log through the second sawing machine according to a predicted optimal kerf line (Maness and Stuart 1994, Selin 2001). As simple as they might appear, some of these actions must in reality be performed in a split second to fulfill the requirements for speed and productivity on the production line.

The basic concept for an optimal breakdown process is that the highest possible volume and value yield should be achieved from every single log by applying optimal sawing pattern, positioning, and rotation in the sawing machines. Therefore, an essential aspect of the optimization of the breakdown process is defining the sawing classes and their related sawing patterns, i.e., the posting list.

The posting list also defines the position and width of the sawing classes, and the logs are initially sorted into these predefined classes when they arrive at the sawmill. A posting list with static sawing-class limits is, however, a compromise, because it will not maximally utilize all logs. An analysis of some logs in the Swedish Pine Stem Bank

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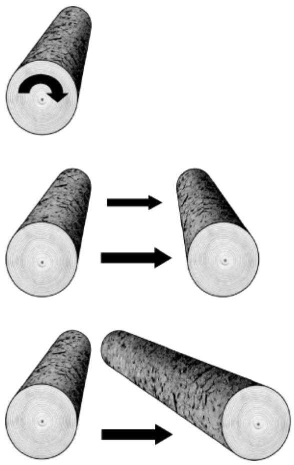

Figure 1.—Definition of positioning parameters for logs (Drake and Johansson 1986).

(SPSB) reveals a potential to achieve higher volume yield by applying an adjacent sawing pattern in the posting list. Logs close to the class limits can in reality also be incorrectly classified due to sorting errors and thus affect the yield (Johansson 1978, Lundahl 2007).

Table 1 shows the effects on yield when logs close to a sawing class limit are sawn with an adjacent sawing pattern. This effect could also appear if logs are incorrectly measured and sorted into the adjacent sawing class. For example, the top diameter on Log 32-2-2 is situated 2.4 mm from the lower sawing class limit, and the normal sawing pattern for the center boards according to the posting list is 50 by 100. The total yield would increase by 2.0 percentage points if the lower adjacent sawing pattern, 38 by 100, was applied to the log.

The measured top diameter for Log 32-2-2 is 156.4 mm and should, according to the posting list from Table 1, be sorted into Sawing Class 3 and thus be broken down with sawing pattern 50 by 100. However, applying the lower adjacent sawing pattern, 38 by 100, would in this case increase the yield by 2.0 percentage points. This study illustrates the difference in concept between a log being assigned to the ''correct'' sawing class and assigning the ''optimal'' sawing pattern to every log. The normal log positioning in the cant saw, where the initial log breakdown occurs, is defined as rotating the log to the horns-down position and an ideal centering to the saw blades (Drake and Johansson 1986). The term *horns down* refers to the log orientation in which a log with crook or sweep (end-to-end curvature) is positioned such that the log ends are set down on the log carriage while the middle section of the log is off the carriage. Because of their geometry, straight logs are in theory not affected by rotational position, whereas crooked logs are considerably affected by deviations from the horns-down position. This positioning of logs in the cant saw is governed by parameters defined in three degrees of freedom: rotation, parallel translation, and skewed (end-to-end) displacement.

The horns-down concept is based on a maximized-area presumption wherein the area of the cant cross section is theoretically maximized. Applying this technique, a log with an ideal sweep and circular cross section can theoretically produce the same yield as straight logs by using the horns-down concept combined with curve sawing. Results from studies (Drake and Johansson 1986, Lundahl 2007) show that the volume yield generally gains from applying the horns-down concept.

The volume yield can be further increased by finding and applying an optimal rotation and lateral centering of every log. The yield can thus gain from a deliberate offset positioning or rotation in some cases. An offset in the center positioning can result in more board volume being gained compared with what is lost on the opposite side (Drake and Johansson 1986). The consequence of a normal centering in the cant saw is that both side boards may be lost, whereas an offset can produce one side board. This is, however, a risky tactic, because an offset can also create an asymmetric cant, which in the end can cause volume yield to suffer. Other factors such as ovality and taper can govern optimal positioning and rotation. For these reasons, simulations were performed in order to evaluate the combined effects of applying correct sawing patterns as well as optimal rotation and parallel position for every individual log.

Objective

The objective of this work was to study potential center- and sideboard yield improvements by alternative rotation and lateral positions in comparison to the normal log positioning case applying the horns-down position and the log centered in the lateral direction.

Knot definitions were deactivated in the simulation software, and equal price was set for all products in order to achieve an explicit volume yield optimization without knot- or price-related influence.

Table 1.—Results from a sensitivity analysis of six individual logs.[a]

Log ID	Top diameter (mm)	Limit of closest adjacent SC top diameter (mm)	Distance to closest adjacent SC limit (mm)	Normal SP	Alternate SP	Yield (%) Normal SP	Yield (%) Alternate SP
25-5-4	148.6	154.0	5.4	38 by 100	50 by 100	47.5	48.2
52-1-1	149.0	154.0	5.0	38 by 100	50 by 100	47.4	41.2
1-1-1	151.1	154.0	2.9	38 by 100	50 by 100	41.2	37.7
53-4-2	154.3	154.0	0.3	50 by 100	38 by 100	48.5	49.8
32-2-2	156.4	154.0	2.4	50 by 100	38 by 100	51.1	53.1
4-1-3	158.5	154.0	4.5	50 by 100	38 by 100	45.0	46.0

[a] The results show the effect on yield, depending on whether logs are sorted into the nominally correct or into the adjacent sawing class because of incorrectly measured top diameter. SC = sawing class; SP = sawing pattern.

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Materials and Methods

The Swedish Pine Stem Bank

The SPSB is a database containing detailed information about 200 Scots pine (*Pinus sylvestris*) trees (Grundberg et al. 1995). These trees were chosen from 33 plots throughout Sweden and were carefully documented through their growth. A medical computed tomography (CT) scanner (Siemens SOMATOM AR.T) was then used to scan the logs. The resulting images from CT scanning of a log are detailed descriptions of outer shape, heartwood border, location of the pith, and a parameter description of the knots. Each knot is depicted by nine parameters that describe the knot geometry, position, and direction in the log (Oja 1999). The data stored in the SPSB make it possible to re-create the outer shape and inner structure of every log using dedicated saw simulation software.

Sawing simulation

Simulation is an efficient method to study the impact of log properties, different sawing strategies, and saw machinery on the sawing process. Several studies and research projects have been performed in order to create software imitating a sawmill breakdown process. This technique has been verified and used, for example, by Johansson (1978), Todoroki and Rönnkvist (1999), Grundberg and Grönlund (1999), Usenius (1999), Chiorescu and Grönlund (2000), Nordmark (2005), Pinto et al. (2002, 2005), and Lundahl (2007).

Saw2003 simulation software

The Saw2003 simulation software (Nordmark 2005) is a PC-based C++ application developed to utilize the digitized data information contained in the SPSB and is used to simulate the breakdown process according to the common structural board grading rules used in Swedish sawmills, the Nordic Timber Grading Rules (Anonymous 1997). Figure 2 shows the Saw2003 breakdown simulation software interface.

The software is capable of regenerating and displaying the log in a three-dimensional representation of the outer shape as well as the internal structure, i.e., sound and dead knots, knot position, and knot geometry. Each generated board can be viewed and checked on the screen as well as in a detailed printable report.

The default report shows achieved board dimensions, volume yield, board value, total value, etc. The software is furthermore capable of utilizing predefined quality definitions combined with posting and price lists. These lists and definitions thus govern the sawing procedure, imitating a real sawmill.

Software settings

Table 2 shows the posting list used in this study. Default simulation software settings imitate the real sorting procedure under normal production conditions in which logs are sorted into accurate sawing classes governed by top diameter. Each sawing pattern is applied to a sawing class in which the volume yield is theoretically maximized. This is, however, not a yield optimization, because enclosed logs are broken down according to which batch they belong to and not based on individual log properties.

Cant sawing combined with curve-sawing technique is the breakdown procedure generally used in Swedish sawmills. The simulation software imitates this procedure. This means that the log is rotated to the horns-down position; i.e., the

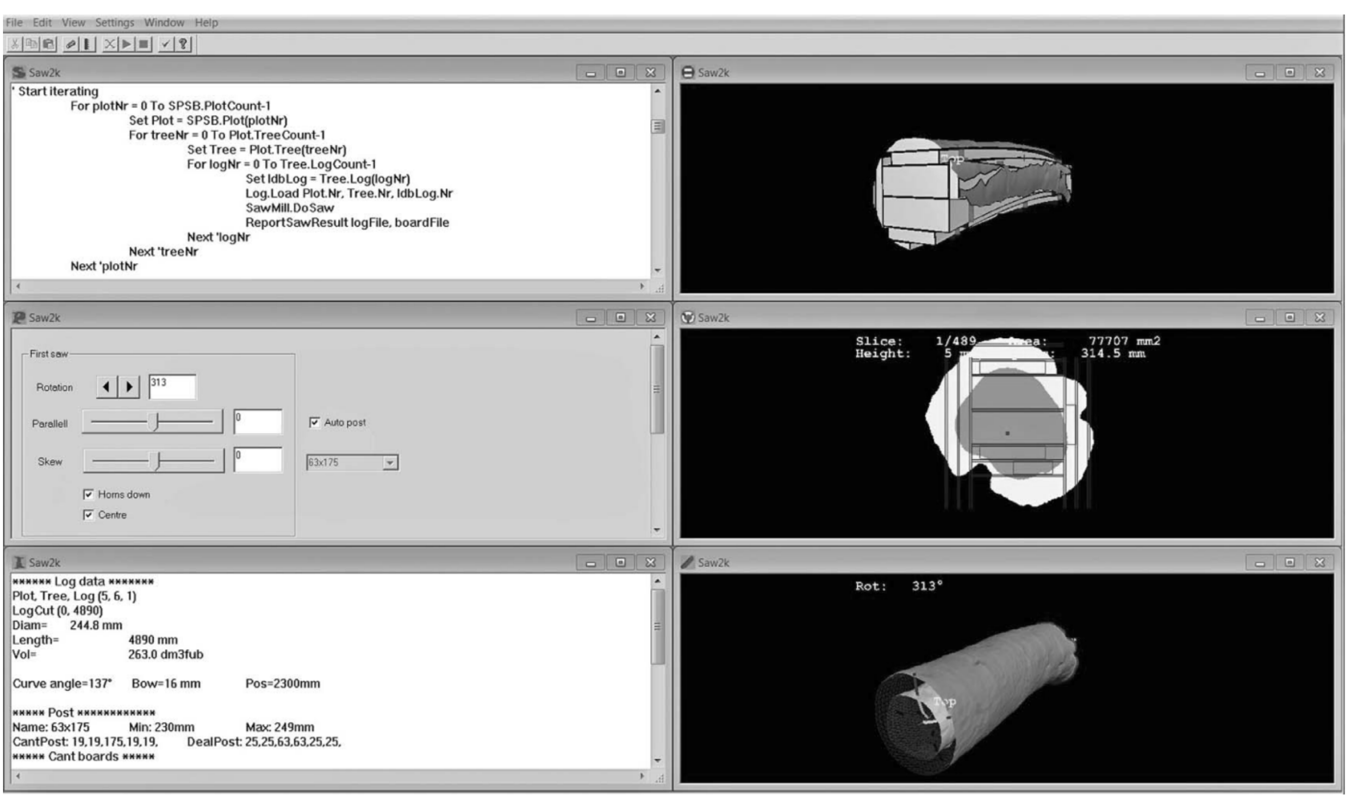

Figure 2.—The Saw2003 breakdown simulation software interface (Nordmark 2005).

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Table 2.—Posting list used in this study.[a]

A. SC	B. Sawing pattern	C. Lower limit SC (mm)	D. Upper limit SC (mm)	E. Post cant saw	F. Post deal saw
1	38 by 75	0	135.9	19, 75, 19	19, 38, 38, 19
2	38 by 100	136	153.9	19, 100, 19	19, 38, 38, 19
3	50 by 100	154	169.9	19, 100, 19	19, 50, 50, 19
4	38 by 125	170	181.9	19, 125, 19	19, 38, 38, 19
5	50 by 125	182	199.9	19, 125, 19	25, 50, 50, 25
6	50 by 150	200	221.9	19, 150, 19	19, 25, 50, 50, 25, 19
7	63 by 150	222	234.9	19, 150, 19	19, 25, 63, 63, 25, 19
8	50 by 175	235	249.9	19, 175, 19	19, 25, 50, 50, 25, 19
9	50 by 200	250	264.9	19, 200, 19	19, 25, 50, 50, 25, 19
10	63 by 200	265	274.9	19, 200, 19	25, 25, 63, 63, 25, 25
11	75 by 200	275	291.9	19, 200, 19	19, 25, 75, 75, 25, 19
12	75 by 225	292	307.9	19, 225, 19	19, 25, 75, 75, 25, 19
13	50 by 200 by 4	308	329.9	25, 200, 25	19, 25, 50, 50, 50, 50, 25, 19
14	50 by 225 by 4	330	499.9	19, 225, 19	19, 25, 50, 50, 50, 50, 25, 19

[a] SC = sawing class. Post cant saw (first saw) defines the height of the cant (block) and the thickness of the sideboards achieved in cant saw. The height of the cant thus defines the height of the center boards. Post deal saw (second saw) defines the thickness of the center boards and further sideboards. Thickness and width measures in the table are nominal target values.

largest crook is turned to a vertical position, and one cant and two sideboards are extracted in the cant saw. The notation in column E of Table 2 defines the height of the cant and thickness of the two extracted sideboards. The height of the cant thus defines the width of the center boards. The height of the cant in Sawing Class 1 is thus 75 mm, and the thickness of the side boards is 19 mm. The software is set to optimize the board value, thus the final sideboard width is determined in the edger. The cant is then rotated 90 degrees and broken down into two 38-mm-thick center boards and two additional 19-mm sideboards (Table 2, column F). This second sawing stage is conducted on a saw known as a deal saw in Sweden—in other places this saw is more commonly known as a gang saw.

For sawing allowance, i.e., sawing procedure deviations and shrinkage, 4 percent was added to the nominal value for each board dimension. The boards were priced according to Table 3. No wane was allowed on the center boards; thus no quality B or C boards were produced. Boards classified as D were chipped.

Performing the simulations

Log geometry data from the SPSB provided log data for the breakdown simulation software in this study. By default, the Saw2003 software uses the SPSB data containing full information about knots and defects. However, this study was mainly focused on increasing the volume yield. The breakdown simulations thus evaluate the effects of log geometry such as diameter, taper, surface unevenness, ovality, etc.

Table 3.—Price list used during simulations.[a]

Grade	Center board (US$/m^3)	Side board (US$/m^3)
A	231	375
B	200	175
C	125	137

[a] B and C qualities were not applied on center boards because of allowed wane presence; knot definition was deactivated. Quality classifications were governed by the common rules stated in Nordic Timber Grading Rules (Anonymous 1997).

The Saw2003 software was used to curve saw 200 logs from the SPSB utilizing the posting and price lists shown in Tables 2 and 3. The saw kerf width was set to 4 mm in both sawing machines.

The logs were sawn using the Saw2003 software applying alternate sawing patterns, rotation, and parallel positioning within the stated limits as follows (plus sign denotes a rotation or parallel offset to the right).

- Sawing pattern defined in Table 3 applied to adjacent classes.
- Rotation in cant saw: −90 to +90 degrees, step 5 degrees.
- Parallel positioning in cant saw: 0 to +20 mm, step 2 mm.
- Parallel positioning in deal saw: −20 to +20 mm, step 2 mm.

The volume yield is calculated as trimmed dry-board volume divided by the total log volume, solid under bark (sub). The concept ''sub'' means that only solid log volume without bark is used in the calculation. The total volume of logs utilized in the simulations is 37.5 m^3 sub from 200 logs. Initial simulations were performed in order to verify effects and find an optimal rotation position. Subsequently, more extended and complex simulations were performed in which combined effects on yield from optimal posting, rotation, and parallel positioning in both cant and deal saw were evaluated.

Volume yield

The volume yield is defined as

$$\{[\text{Nominal volume of trimmed boards } (\text{MC} = 18\%)]/$$
$$(\text{True volume logs})\} \times 100\,(\%)$$

Results

Effects of optimal rotation

The comprehensive simulation results in Figure 3 show that the highest aggregated true yield was achieved when all logs were rotated −10 degrees from the horns-down position. The improvement achieved from the −10 degree offset is, however, very small, and not significantly determinative. The results indicate that, in general, volume yield benefits from the horns-downs cross-section–maxi-

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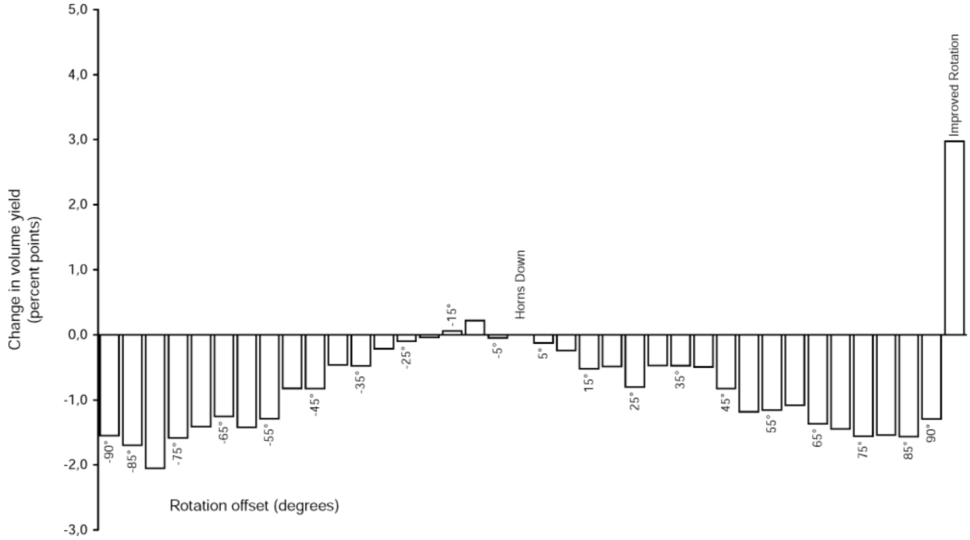

Figure 3.—Simulated true volume yield in reference to horns-down position. Each position includes simulation yield results from 200 logs. Each bar shows the average yield value change in comparison to the horns-down position for given rotation. Improved Rotation bar shows the total aggregated yield improvement on 200 logs, 3.0 percentage points.

mizing approach. Nevertheless, the aggregated yield is increased from 52.1 to 55.1 percent by applying the optimal rotation for every log in the batch (Fig. 3, Improved Rotation bar).

A detailed review of one specific log is shown in Figure 4. The log properties show that the minimum top diameter is 229.1 mm, maximum sweep is 8.5 mm, and length is 4.5 m. The log is thus rather straight and located in the center of the sawing class. This specific log clearly gains from the altered rotation; lumber yield is increased by 3.6 percentage points from 56.0 to 59.6 percent when the log is rotated −75 degrees (Fig. 4).

Simulation results show that the increased yield after altered rotation is obtained by the production of one extra side board in the cant saw and one side board of increased length in the deal saw. The altered rotation has in this case decreased the occurrence of wane on the side boards, thus producing more board volume. The graph also shows that the achieved yield can be vulnerable to relatively small positioning errors, since the optimal position is often ‘‘pointed.’’ For example, the yield is decreased by 2.3 percentage points if the log is rotated +5 degrees in comparison to the horns-down position, and 1.3 percentage points if rotated −5 degrees. The −65 degree position is even more vulnerable to a positioning error, and the yield drops rapidly from 58.4 to 54.5 percent if the log is rotated to −60 degrees. The most obvious solution in this case would be to aim for the −75 degree position, thus maximizing the yield. For this specific log, this position is also relatively invulnerable to a positioning error. One consequent approach to dealing with the challenge of achieving a high yield and at the same time minimizing the vulnerability caused by positioning errors could be to aim for the middle of the safest plateau, in this case between −70 and −75 degrees.

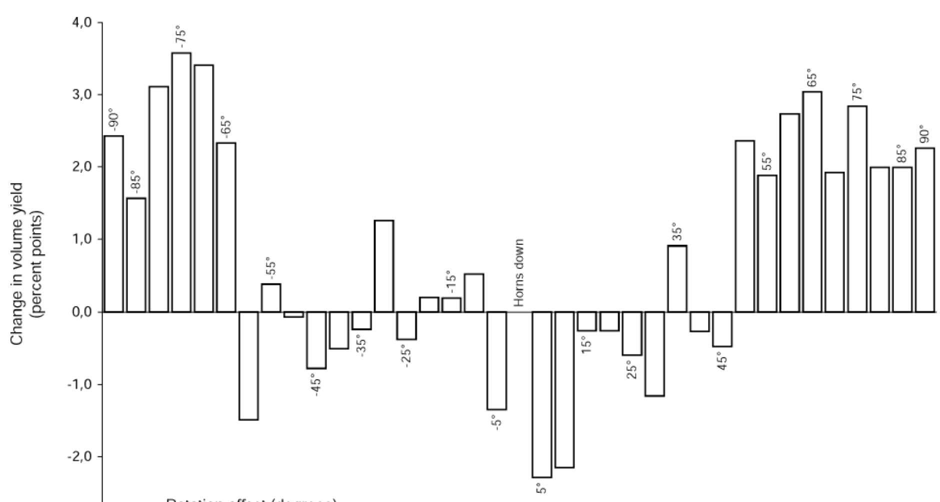

Figure 4.—Example of simulated true volume yield in reference to horns-down position (for a single log).

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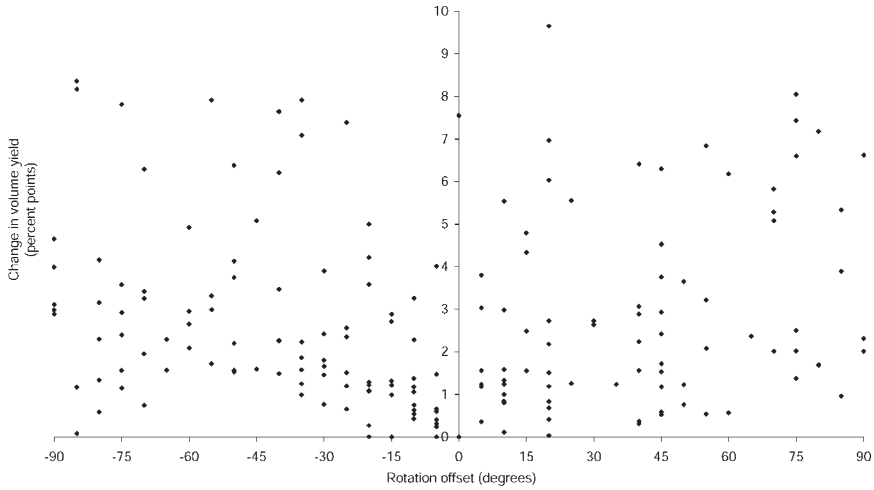

Figure 5.—Change in yield by improved log rotation in reference to horns-down positioning, 200 logs. The optimal position is found to be evenly spread between the simulated limits of rotation, but only one log is optimal at the horns-down position.

Figure 5 shows the plotted location of optimal rotation for every individual log and the yield improvement. If logs show the same maximum yield at two or more rotational angles, the position closest to the horns-down position is plotted. The results also show that the improved rotation position for the logs is spread throughout the 180 degree range. The logs used from the SPSB are relatively straight, since the maximum crook is 28 mm, and a distinct horns-down position can thus be difficult to clearly define. This further accentuates the difficulties and challenges of defining a correct horns-down position.

Figure 6 shows the yield improvement for every single log plotted against the log crook. The improvement is, as before, achieved by rotating the log to different positions in relation to the horns-down position. The two logs with the highest sweep plotted in Figure 6 show no yield improvement with rotation. This is explained by the fact that the optimal yield is found close to the horns-down position, thus producing the highest yield in the regular position. The impact of finding such an optimal position for all logs is highly significant in order to achieve an improved breakdown process.

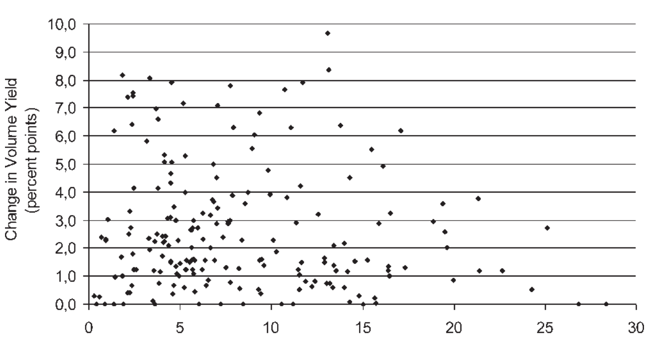

Figure 6.—Simulated yield improvements at optimized log rotation position versus log sweep, 200 logs. The highest yield improvement is found on relatively straight logs, probably because of difficulties in defining a correct horns-down position. The graph indicates a decreased change in yield when the crook exceeds 15 mm.

The graph also indicates less change in yield when the crook/sweep exceeds 15 mm. This is consistent with results presented by Johansson (1978). The explanation may be that it becomes easier to define the correct horns-down position at this bow height. The conclusion may also be that whereas the horns-down concept is most effective on sweeped logs, geometrical properties such as taper, cross-sectional ovality, and other anomalies probably produce more bias on straight logs.

More extended simulations were performed in order to evaluate the combined effects of sawing classes/patterns, optimal rotation, and parallel positioning in the cant and deal saws. Different parallel offsets within the limits of ± 20 mm were applied in addition to improved rotation during these simulations. The simulation results indicate a potential to increase the volume yield by a total of 4.5 percentage points if a more comprehensive optimization is applied (Fig. 7). However, only a few logs had their yield improved when the nominal sawing pattern was altered to an adjacent pattern.

The results show that the highest total simulated board volume yield does not always correspond to the highest value. In this study, the price of A-quality side boards was set 62.5 percent higher than the price of A-quality center boards. Production of center boards is generally prioritized in Swedish sawmills, but a strategy with a higher proportion of extracted high-priced side boards can result in higher value yield and a somewhat lower volume yield. Figure 7 shows that the highest achieved aggregated yield for 200 logs is 56.6 percent when yield was prioritized in the analysis (Opt Yield). The maximum yield result is somewhat lower when board value is prioritized (Opt Value).

Board value can be increased by close to 10 percent by applying a more comprehensive optimization strategy including sawing class, rotation, and parallel offsets. These results are based on a limited volume of logs, 37.5 m^3 sub. The difference in calculated income between concepts of prioritizing yield or value is thus relatively small. However, the value-optimization concept scaled onto the full produc-

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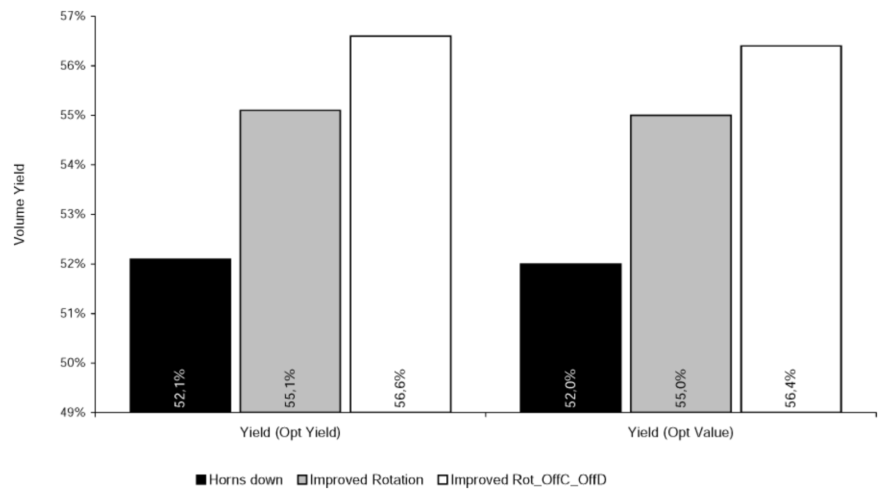

Figure 7.—Simulated yield results by improved rotation (Opt Rotation) and extended optimization of rotation and parallel offset in cant and deal saws (Opt Rot_OffC_OffD) in comparison to simulated yield achieved by applying the normal horns-down position and nominal sawing pattern. The maximum achievable yield is somewhat lower when board value is prioritized (Opt Value).

tion volume of a typical Swedish sawmill can result in large sums gained.

Discussion and Conclusions

A typical Swedish sawmill produces about 200,000 m^3 of sawn boards per year. An increase in average volume yield by 4.5 percentage points (8.6%) would enable such a typical Swedish sawmill to produce a further 17,300 m^3 of boards. This would increase potential income by US$3.7 million per year at an average value of US$212 per m^3. Alternatively, the impact of an increased yield can also be calculated in terms of its impact on log demand affecting a decrease in log demand by close to 31,000 m^3 sub. This scenario would result in a decrease in log purchase expenses by US$2.7 million per year, calculated at an average purchase cost of US$88 per m^3 sub.

Studies done on pine logs by Johansson and Liljeblad (1988) show that knots are a highly significant factor governing value yield. Final yield and quality classification of boards sawn for structural-use governed by size and position of knots on boards, and specifically edge knots cause board quality to degrade. Implementation of modern industrial x-ray technique enables acquisition of detailed information about log properties (Birkeland and Holöyen 1987, Oja and Grundberg 2004).

This knowledge can be used to optimize the log position in the sawing machines in order to minimize the influence of knots (Oja et al. 1998, Rinnhofer et al. 2003). Oja et al. (1998) showed that the number of high-quality boards increased by 11 percent when the sawing position was controlled based on x-ray log scanning technique. Studies indicate that the impact on value of applying the optimal rotation for each log is up to 22 percent higher when knots are taken into account (Johansson and Liljeblad 1988).

The simulation results presented in our study show a potential to increase the yield by 3.0 percentage points (5.8%) by optimizing the rotation position without consideration of knot locations. Superimposing the results presented in the study by Johansson and Liljeblad (1988) indicates that the true potential from rotation optimization could be even higher in comparison to the concept of horns-down position with pure volume optimization.

A full optimization including both rotation and parallel positioning indicates an even higher potential to improve yield and value. However, this will place demands on log traceability because the x-ray equipment is commonly situated in the log-sorting area. Logs must thus be identified once again when they approach the sawing machines and the information about optimal position for the target log must be fed into the control system. Studies done by Chiorescu (2003) and Flodin et al. (2008) using the fingerprint approach show possibilities for identifying and tracing logs from the outer shape and the tracheid effect (Nyström 2002).

Nevertheless, these concepts are vulnerable to errors in measuring accuracy and changes in log properties during the log handling process, e.g., debarking and butt-end reduction. Automated tracing and tracking are proposed by McFarlane and Sheffi (2003), where the use of radio frequency identification tags is one possible approach. However, this technique was regarded as too expensive for continuous usage (Uusijärvi 2003).

An alternative but more expensive approach could be to add one additional x-ray log scanner to the saw line prior to the first sawing machine.

The results in this study show a large potential for sawmills to increase volume yield and profit. The challenge is to be able to identify optimal breakdown settings online for every single log and execute them during the breakdown procedure without loss of production capacity.

To view, monitor, and control the entire breakdown procedure as a process is therefore most important, because all enclosed functions and changes affect the entire output from the system. This means that production capacity will suffer if online optimization of the breakdown requires too much time to perform, thus diminishing the impact from achieved volume–yield improvement.

The actual number of possible permutations in this limited simulation is 3 different sawing patterns × 37 different angles × 11 offsets in the cant saw × 11 offsets in the deal saw, which equals 13,431 combinations, indicating

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a rapidly increasing complexity. Further adding a skew variable within a similar ±20-mm range in the cant and deal saws would increase the number of simulations required to more than 1.625 million combinations.

However, the optimal sawing pattern for each log could be predefined during the log-sorting procedure, thus reducing the number of combinations to be considered during the breakdown. However, this study shows a relatively small number of logs gaining from changed sawing class, and a simplifying approach could be to ignore this factor.

This example shows a rapidly increasing complexity to the optimization of the breakdown process, which is a serious challenge, since some of these procedures must be performed online within a split second in order to accommodate production speed demands.

Modern technology such as industrial x-ray, breakdown-simulation software, and high-performance computers will some day make it possible to evaluate and optimize all logs online at full production speed. However, the sawing and log-handling machines of today are limited in their capabilities to perform all the necessary tasks needed to achieve a fully optimized breakdown. Machinery capable of positioning logs in the sawing machines without errors simply does not exist.

Every apparatus, automatic or semi-automatic, shows a distribution in its performance, thus causing divergence from the intended value (Johansson and Liljeblad 1988). A crooked log is relatively simple to position and hold in the horns-down position, while holding and managing the same log at, for example, the +20 degree position sets requirements that existing machinery is not suited to handle. Furthermore, an optimally performed rotational positioning also sets requirements for a controlled parallel positioning (Johansson and Liljeblad 1988). Further development of sawing and handling equipment is thus needed in order to achieve an improved log-breakdown process.

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