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Title : The Effect of Edging Red Alder Lumber on Cut Stock Production

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It has been observed that edging flitches into lumber unnecessarily reduces the yield of cut stock. This research investigated the yield of cut stock from unedged red alder (*Alnus rubra*) flitches, and compared it to yields attained from boards subjected to a variety of edging strategies: conventional, light-edging, actual, severe and no edging. Results showed that unedged lumber yielded 18%,12%,9%,4% more cutting volume than severe, actual, conventional and light-edging, respectively. An economic analysis showed that a vertically-integrated sawmill/roughmill operation producing 20 million board feet of red alder lumber could increase its net revenue by $1,000,000.00 per year by reducing the amount of material removed during edging. These gains can be realized even when the additional costs of handling, drying, and trucking unedged or partially edged flitches are considered.

The Effect of Edging Red Alder Lumber on Cut Stock Production

by

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The vision system would never have functioned without the programming knowledge and computer-vision expertise of Dr. David Butler. The software that enabled me to classify the defects and create the edging scenarios was diligently created by Alberto Maristany. The cut-up program CORY was initially created by Dr. Charles Brunner and made accessible to me by the ever-patient Jim Anderson. Scott Leavengood's advice, along with Dr. Jim Funck's and Johan Forrer's inputs also proved invaluable. I sincerely hope that this thesis represents the quality of the computer-aided manufacturing group as a whole.

Additional thanks are to be paid to the taxpayers and our government who provided the funds to the U.S.D.A. Forest Service Red Alder Initiative.

Above all, I would like to thank Ms. Melinda Brock whom I met during the literature review, and married during the final editing.

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1. INTRODUCTION

The declining availability of softwood timber in the Pacific Northwest has increased the interest in the region's hardwood resource. This resource in 1990 supported an industry that employed roughly 1000 people and produced 331 million board feet (Mbf) of hardwood lumber of which 85% to 90% was red alder (Alnus rubra) (Warren, 1992). Any effort that extends this resource through better utility would be beneficial to the hardwood industry and to the Pacific Northwest as a whole.

Edging lumber has been identified as a significant source of wood fiber loss. Poor edging practices result in lost lumber value, lower lumber recovery, and reduced cutting-parts yield. Wengert and Lamb, 1990, estimate that each one-sixteenth decrease in edging width will increase yield by 1.5% and provides additional revenue of over $50/Mbf. This study quantifies the effect of various edging practices on cutting yield and value.

Lumber producers edge boards to maximize their grade by removing wane and defects. This process removes sound wood that is at the periphery of the board and generally of high quality and value as cut stock. Opportunities exist in cut-stock production to more efficiently use our resources while reducing the cost of manufacture (Kline *et al.*, 1993).

Previous studies on the effect of edging on cutting-part yield and value show substantial evidence supporting the use of unedged or lightly-edged flitches (Neilson *et al.*, 1970a, 1970b; Beaudoin *et al.*, 1982; Kline *et al.*, 1993; Flann and Lamb, 1966, Flann *et al.*, 1967). Neilson *et al.*, 1970, reported that the combined use of live sawing and no edging resulted in a 20% greater yield of cutting parts than grade sawing and optimal edging for the National Hardwood Association lumber grades. Kline *et al.*, 1993, reported that the use of unedged/untrimmed lumber for cutting-part production instead of conventionally edged and trimmed lumber increased yield by 25%.

The fact that cutting yield increases with decreases in edging is obvious. What is not obvious is whether the increase offsets the added costs of handling, transporting and drying unedged flitches. This study compared the increase in costs to the value added through increased cutting yield. Recommendations on edging practices for vertically-integrated red alder lumber and cut stock producers are presented.

2. LITERATURE REVIEW

The body of work available on cutting yield can be divided into three categories:

1. Computer simulation programs
2. Yield studies
3. Studies on the effect of edging on yield

All three of these components will be addressed separately.

A. COMPUTER SIMULATION PROGRAMS

There are a number of computer programs that simulate the cutting of a board. These programs differ in the manufacturing systems modeled, the board-data entry strategies, the dimensions of the cutting parts, and in the value system used to establish cutting size priorities. This section will describe the evolution of these cut-up programs, and why the program CORY was selected for this project (Brunner *et al.*, 1989)

Thomas, 1962, developed the first computer simulation program used to estimate the cutting yields of lumber grades. This program simulates a crosscut-first operation with two stages. The number of stages refers to the number of changes in breakdown operations within a cut-up process. A two-stage process will have both rip and cross-cut operations. A three-stage process will have rip, cross-cut and salvage (rerip) operations. An unlimited number of stages means that any number of changes in operation are allowed to maximize the board yield. Thomas's program used a Cartesian coordinate system with units of 1"x 3" to record the dimensions and the location of defects for each board. These board descriptions were then entered into the computer via punchcards. The program can estimate the cutting yield of nine cutting bills with each of three grades of cuttings: clear-one-side, clear-two-sides, and solid-two-sides. The program produces random-width cuttings of fixed-lengths specified by the user in the cutting bill. The user chooses the relative priority of the cutting sizes in the bill. Cutting volume may be maximized by summing the product of length and width;

$$\sum_{i=1}^{n} (L_i W_i) \qquad (2.1)$$

where L_i = length of cutting i

W_i = width of cutting i

n = number of cuttings

alternatively, cutting length may be emphasized by raising it to a power greater than one. In Thomas's program the exponent for length was 2.

$$\sum_{i=1}^{n} (L_i^2 W_i) \qquad (2.2)$$

Wodzinski and Hahm (1966) wrote program YIELD to simulate the hardwood furniture cut-up process. It produces fixed-width, fixed-length cuttings of specified dimensions. The board data-entry strategy and the length weighting system are the same as Thomas's, but the coordinate system is based on 1/4 inch units. The program is neither crosscut or rip first but uses a subroutine of the program, CUTOUT, to determine which uses the fewer sawing stages. If the number of stages required is the same, the program will crosscut first.

YIELD locates the defects in a board, finds the clear areas, and places the cuttings to give the maximum utilization of the board. Given a choice of two cuttings equal in total area, the program will choose the longer cutting. This leads to situations where the program selects a long and a short cutting as opposed to two medium (and more valuable) cuttings (Giese and Danielson, 1983). Furthermore, YIELD did not accurately model a cut-up operation in that few operations can select either a crosscut or rip-first strategy for each board.

Program CUTUP, written in 1972 by Erickson and Markstrom, simulates the rip-first cutting system used in the softwood cut-up and edge- and end-glue operations. The cutting bill specifies fixed-width, random-length sizes. CUTUP's format for board and defect data matches those for YIELD and Thomas's program. CUTUP maximizes clear area volume only.

RIPYLD simulates the multiple rip-first process used by the hardwood flooring industry, and the softwood cut-up industry (Stern and McDonald, 1978). It was developed with the intention of being coupled to an automatic defect scanner (Giese and McDonald, 1982). Boards are represented as an array of 0's(clear) and 1's(defect) oriented on a grid of 1/4 inch units. It produces fixed-width parts that can be either fixed-length or random-length. As with program CUTUP, only clear area volume is maximized. No weight is placed on longer cuttings.

MULRIP, based on the computer program RIPYLD, simulates a gang-ripping operation with fixed arbors (Hallock and Giese, 1980). The boards are ripped and then crosscut. Salvage pieces are then either ripped or crosscut to size. The program was written to compare the yields from a multiple rip-first process with those from the process simulated in program YIELD. The data entry and weighting system are identical to YIELD's to facilitate that comparison.

OPTYLD models a multi-rip, then crosscut and then re-rip process used by the moulding and millwork industry (Giese and McDonald, 1982). Boards are represented by the same binary array used in RIPYLD. OPTYLD uses a value index table to assign priority to each cutting dimension. If the objective of the operator is to maximize yield instead of value, numbers on the value table are all set to one.

More recent simulation programs include the CROMAX, ALPS, and GR-1st (Giese and Danielson., 1983, Klinkhachorn *et al.*, 1989, and Hoff *et al.*, 1992, respectively). CROMAX was developed from OPTYLD to model a crosscut-first process. Board descriptions are stored in binary form and a value index table is used to assign a priority to each cutting dimension. ALPS programs were written to be used in conjunction with high-powered lasers which remove cuttings in a "cookie-cutter" fashion. It is designed to use board data produced by a computer-vision system that locates and identifies defects on the lumber surface. The weighting system is based on a value table. GR-1st is an extension of MULRIP used to evaluate different gang-rip-first possibilities.

CORY was developed as an unlimited-stage, random-width, fixed-length model for both crosscut-first or rip-first operations (Brunner *et al.*, 1989). The original program was developed to analyze short, low grade, unedged boards with a large number of defects and excessive wane. The weighting function is the same as those developed for Thomas's work and program YIELD. CORY has since evolved into a family of simulation programs that differ by type of first operation, number of stages, and type of dimensions produced. Two additional versions were developed and are described in the methodology section.

B. PREVIOUS YIELD STUDIES

According to Dunmire and Englerth (1967) studies were completed prior to computer simulation by chalk-marking cuttings on boards to determine yields. Thomas's work in 1962 introduced the computer as a tool for determining yields. Thomas reported yield figures for a mixture of twelve hardwood species in FAS and No.1 common lumber grades (Thomas, 1962).

Program YIELD (Wodzinski and Hahm, 1966) resulted in a wealth of cutting yield articles. The first study estimated yields for clear-one-face 4/4 hard maple (Englerth and Schumann, 1969). The study results were verified by comparing them to actual commercial sawing of the same material. Once the program results were considered acceptable; Englerth and Schumann compiled them into nomograms. These graphical nomograms provide mill managers with easy access to the yields of different lumber grades, cutting dimensions, cutting grades, wood species and machining processes (Schumann and Englerth; 1967a,1967b, Schumann; 1971,1972, Gilmore *et al.*, 1984, Lucas, 1973, Hallock, 1980, McDonald et al.;1981,1983).

These computer simulation studies allowed researchers to examine the effect of lumber grade on yield for different processing strategies. The effect of board edging on product yield is another example of this type of research.

C. EDGING STUDIES

It has been estimated that each edging reduction of 1/16 inch will increase yield by 1.5%, and reduce costs by over $50/Mbf of parts (Wengert and Lamb, 1990). In fact, according to Bousquet (1989), the average hardwood sawmill is edging away $600-$2000 per shift. These substantial losses have inspired a number of board-edging studies.

The first such study was conducted by Flann, Lamb, and Nielson at the Canadian Department of Forestry in Ottawa. They edged No.1 and No.2 Common, 4/4 hard maple boards with five different edging practices.

They compared the lumber values produced by four edging practices; conventional, severe, optimum, and wide (Flann and Lamb, 1966). See Table 2.1. The conventional

EDGING PRACTICE	NO.2 COMMON $/Mbf	NO.1 COMMON $/Mbf
CONVENTIONAL	$67.10	$155.30
SEVERE	$49.25	$119.50
WIDE	$67.90	$107.09
OPTIMUM	$97.40	$171.30

Table 2.1. Increases in lumber value derived from No. 1 and No. 2 Common hard maple boards due to changes in edging strategy (from Flann and Lamb, 1966)

practice followed the 50-50 rule which placed the edger lines so that the edges (after edging) will consist of equal parts of clear and waney edge. The severe practice placed the edger lines so that 50% of the wane extending from points one foot from the ends of the boards was removed. The optimum practice placed the edger lines so as to achieve the highest lumber value according to NHLA standards, and the board produced by the wide edging practice was a 1/4 inch wider than the conventional board. These results showed the dramatic effect of edging practices on No.1

Common and No.2 Common boards and the importance of an edger operator having grading skills.

Flann et al. (1967) then analyzed the effect of these different edging practices on furniture-component yield. The edging practices were expanded to include a no edging category. This practice created a basis for comparing all the other edging practices. The same database of 4/4 hard maple flitches was used. Dimension-stock yields were estimated for each edging practice using program YIELD.

The cuttings were all clear-two-face cuttings of between 10 inches and 70 inches in length, and between 1.5 inches and 6 inches in width for the No. 1 Common boards, and between 10 inches and 55 inches in length and between 1.5 inches and 6 inches in width for the No.2 Common boards.

The unedged practice produced furniture-component yields based on the area of the conventional boards that were 25.2% higher than the severe practice, and 11.8% higher than the optimum practice for the No.1 Common boards. The yield from the unedged practice for the No. 2 Common boards was 28.4% higher than the severe practice, and 20.7% higher than the yield from the optimum practice.

The severe yields are especially important because over edging is still prevalent in mills (Flann and Lamb, 1966, Bousquet, 1989). The results also showed that even when lumber is optimally edged there are significant possible increases in part yields. These studies put into question the industry's edging practices and provided evidence that vertically-integrated mills are the most efficient producers of furniture components because they do not have to comply with the wane requirements outlined in the grade rules. Neilson *et al.*, 1970a, addressed the idea of vertical integration more specifically. The study's objectives were to examine the effect on yield of three sawing patterns independent of edging, and five edging practices independent of sawing patterns. This investigation was developed to determine the best practices for a vertically-integrated sawmill and rough mill to use when processing hard maple logs.

Dimension-stock yields were provided by program YIELD for the same edging practices as in Flann et al. (1967). The length-squared times width weighting system was used to give priority to the longer cuttings. Study results provided more evidence that unedged boards will increase cutting yield and revenue to the mill (Table 2.2).

EDGING PRACTICE	SURFACE AREA (Sq.ft./M bf)	VALUE ($/ M bf)
Unedged	725	457
Wide	703	445
Conventional	700	443
Optimum	689	435
Severe	672	425

Table 2.2. Increases in dimension stock surface area and value yield due to changes in edging strategy (from Neilson *et al.*, 1970a)

Pnevmaticos and Bousquet (1972) extended Nielson's work by investigating the relative effects of the same three sawing patterns and five edging practices on the yield of lumber and cutting parts from medium and low quality hard maple logs. The results showed live sawing in combination with the no-edging practice maximized both the cutting-part volume and value.

Richards (1973) analyzed the effects of log diameter, log length, log taper, board thickness, kerf width, edging method, and sawing method on lumber yield using computer simulation based on a truncated cone. His model was based on the hypothetical shape of a log and was not species specific. His results showed that kerf thickness, board thickness, and edging method had a marked effect on lumber yield and that a change from conventional (50-50) edging to severe or wane-free edging dropped the lumber yield 9.7%.

Beaudoin *et al.* (1982) approached the edging issue from a different perspective. Their study focused on the effect of edging on the furniture-stock yield from short hardwood lumber produced in a vertically-integrated bolter mill/roughmill. Bolter mills convert short logs to turning squares, dowel stock and lumber. The study addressed some of the inherent problems associated with using unedged material including increased drying costs.

Beaudoin *et al.* (1982) obtained figures on the kiln space required by unedged lumber and compared it to heavily-edged, and lightly-edged lumber. Lightly-edged, and heavily-edged lumber required 21% and 44% less kiln space than the unedged material, respectively. The quantity of wood in each lot of unedged, light-edged, and heavy-edged material was also estimated by weighing after edging. With this information, a total drying cost was obtained using drying cost per Mbf, and assuming a split of 50% fixed cost and 50% variable cost. The cost of edging and reduced furniture-part yield was also included. The analysis indicated that the light-edging practice was the only one which showed a net gain and did not significantly reduce yield.

Kline *et al.* (1993) compared the yields from unedged and untrimmed 4/4 red oak lumber with optimally- and actually-edged and trimmed lumber. Like Beaudoin *et al.*, they performed a cost analysis. Kline *et al.* reported that the volume of cuttings from the unedged and untrimmed boards was 25% greater than that from the actual edged and trimmed boards. Furthermore, their analysis showed that the net cost of cut-stock production from the unedged/untrimmed boards was 8% less than the net cost of cut-stock production from the edged/trimmed practice even when considering the additional handling, drying, and processing costs (Kline *et al.*, 1993).

Kline *et al.* estimated that the unedged boards occupied 25% more dry kiln space. The additional kiln space and handling were therefore assumed to increase manufacturing costs 25 percent. Drying, stacking, sorting and regrading costs were estimated to be $150/Mbf (Kline *et al.*, 1993). The study completed by Kline et al. is similar to the study reported in this thesis with a few exceptions: 1) this study involves red alder; 2) this study's board data are in units of 1/10 inch instead of the 1/4 inch units used in Kline *et al.*,(1993); 3) the cost analysis is tailored for red alder lumber manufacturing; 4) the computer simulation models a two-stage, fixed-width, random-length process; 5) the cutting bills were derived from information supplied by roughmills in this region; and 6) the edging categories include unedged, severe, light, conventional and actual. Finally, this thesis does not consider the trimming variable because Regalado et. al., 1992, found that the major factor in lost value is overedging, not overtrimming.

3. METHODS AND MATERIALS

A. SAMPLING PROCEDURE

This study used 255 unedged, 4/4 inch, dry, skip-planed, red alder flitches equally distributed among Select, No.1, and No. 2 Shop grade boards (WWPA, 1988). Boards were randomly selected by taking one board every 40 seconds at a point between the headrig and the edger station at Cascade Hardwoods in Chehallis, WA. A certified grader then established a preliminary grade. It represented the highest possible grade for each board when edged and trimmed. The boards were labeled with numbered aluminum tags. After grading, the lumber was sent to the edger where each board was placed on the feed deck, and laser lines (representing the path of the edger saws) were positioned by Cascade's edger-operator. Laser line locations were then marked establishing the actual edging practice for the mill. The unedged boards were placed on stickers and dried. After drying, the flitches were skip-planed, and then regraded. The initial intention was to sample 300 boards to be equally divided amongst the three grades. Unfortunately, there were only 85 No. 2 Shop boards after drying. In the interest of maintaining a balanced study, the number of boards in No. 1 Shop and Select grades were reduced to 85 each.

B. DATA COLLECTION USING THE IMAGING SYSTEM

Color images of the boards were acquired with a JVC Model BY-110 three-tube color camera connected to a Targa-32 image capture board (Truevision Inc., Indianapolis, IN) providing 256 intensity levels of red, green, and blue per pixel. The width of the board was aligned with the X-axis of the Targa board resulting in 256 pixels covering approximately 15.5 inches. Due to overlap, twelve images covered approximately 124.2 inches along the Y-axis which equals the longest length of the boards. Studies showed that the imaging system has an accuracy of approximately 1/10 inch and is very repeatable. The resolution of the imaging system is 17.03+/-.05 pixels/inch in X, and 15.46+/-.009 pixels/inch in Y. A description of the imaging system's accuracy is provided in appendix A. The camera was transported along the length of the board by a track coupled to a model 1250 Series Controller provided by Accu-FAB, Inc (Corvallis, OR). The boards were illuminated by four 130 Volt, 300 Watt, quartz-halogen lights (Figure 3.1).

The data represent 255 unedged boards with 85 boards in the Select, No. 1 Shop, and No. 2 Shop grades. Total volume was 985 bd.ft. based on the actual edger line locations, with 345, 322, and 318 bd. ft. in each grade, respectively. Additional board size information is supplied in Table 3.1.

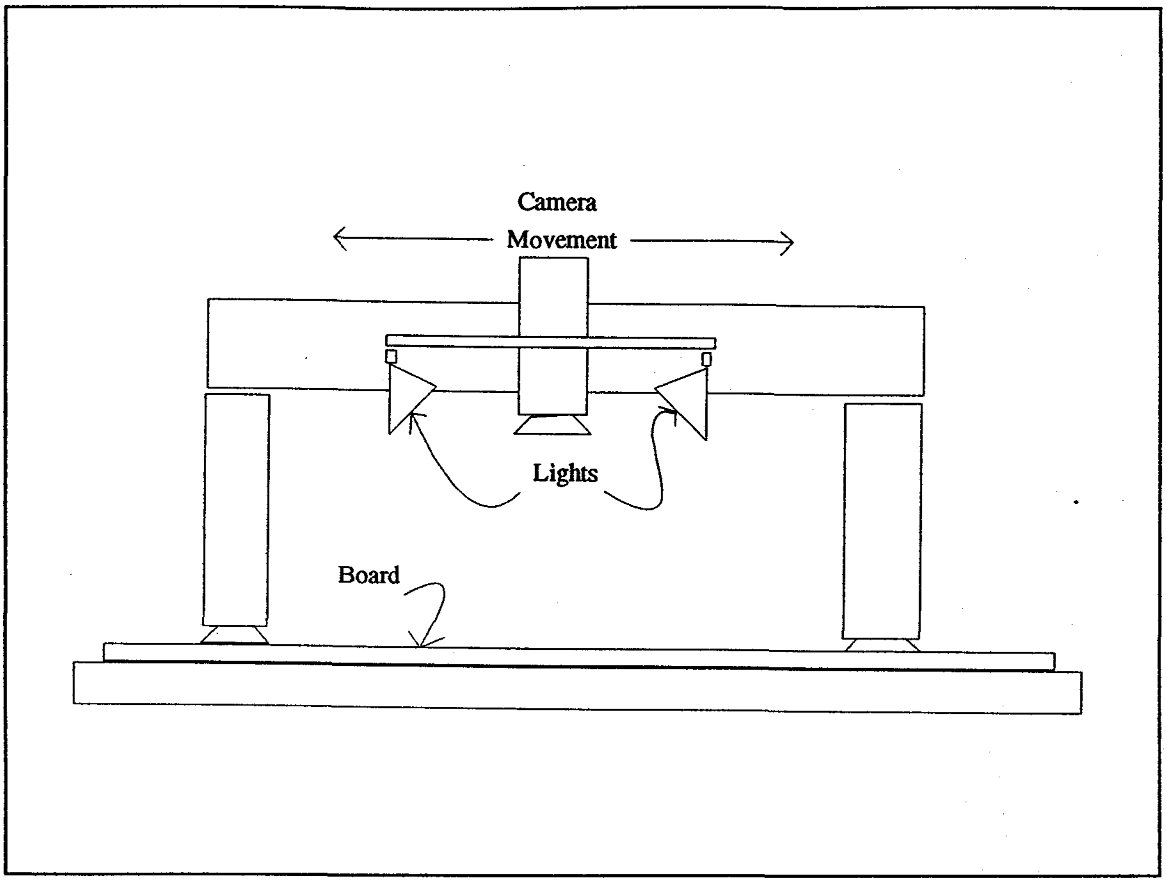

Figure 3.1. Imaging System

Board Measure	Grade	Average	Standard Deviation
Length (feet)	Select	9.68	.80
	No.1 shop	9.47	.93
	No.2 shop	9.52	.91
Width (inches)	Select	5.04	.96
	No.1 shop	4.80	.96
	No.2 shop	4.71	.84
Volume (bd. ft)	Select	4.06	.72
	No.1 shop	3.79	.60
	No.2 shop	3.74	.67

Table 3.1. Calculated sample board size information based on the actual edger line locations

After the images were captured, the defects were outlined and classified using computer vision software entitled Classi32 developed by the computer-aided manufacturing group at the Forest Research Laboratory at Oregon State University. Groups of pixels within the image representing a single defect were outlined on screen using a mouse. These pixel groups were then coded with a unique defect code for the following defects: pith, splits, wane, sound knots, loose knots, worm holes, bark pockets and rot. Edger lines were marked at this point as well.

C. COMPUTER SIMULATION

The yield of clear-two-side components for each grade and edging practice was determined using computer simulation. Program CORY was used to simulate a rip-first, two-stage, fixed-width, random-length, cut-up process. Program CORY was selected because it was available and could be customized to match the sawing process used in the PNW. The cutting bill used for the CORY runs was designed to approximate the bills used by Northwest rough mills. A survey of four mills showed widespread use of a random-length, fixed-width cutting bill and a two-stage sawing process. The sawing process produces random-length, finger-joint blocks from 6 to 38 inches in length that are 1.5, 2.0, 2.5 or 3.0 inches in width. Mills desire the longest possible finger-joint blocks; therefore, the simulation uses the full length of a clear area. If the clear area is longer than 38 inches (or its multiple) but not long enough to permit another block, then the clear area will be cut into two equal length blocks. The rip and cross-cut kerf widths were .1 inch and .2 inch, respectively and approximate the widths used in industry. The 1/10 inch kerf increments also match the board data's accuracy which helps avoid combinatorial effects.

D. EDGING PRACTICES

The edging practices compared are conventional, severe, actual, lightly-edged, and nominally unedged. See Figure 3.2. The conventional-edging practice, as used by

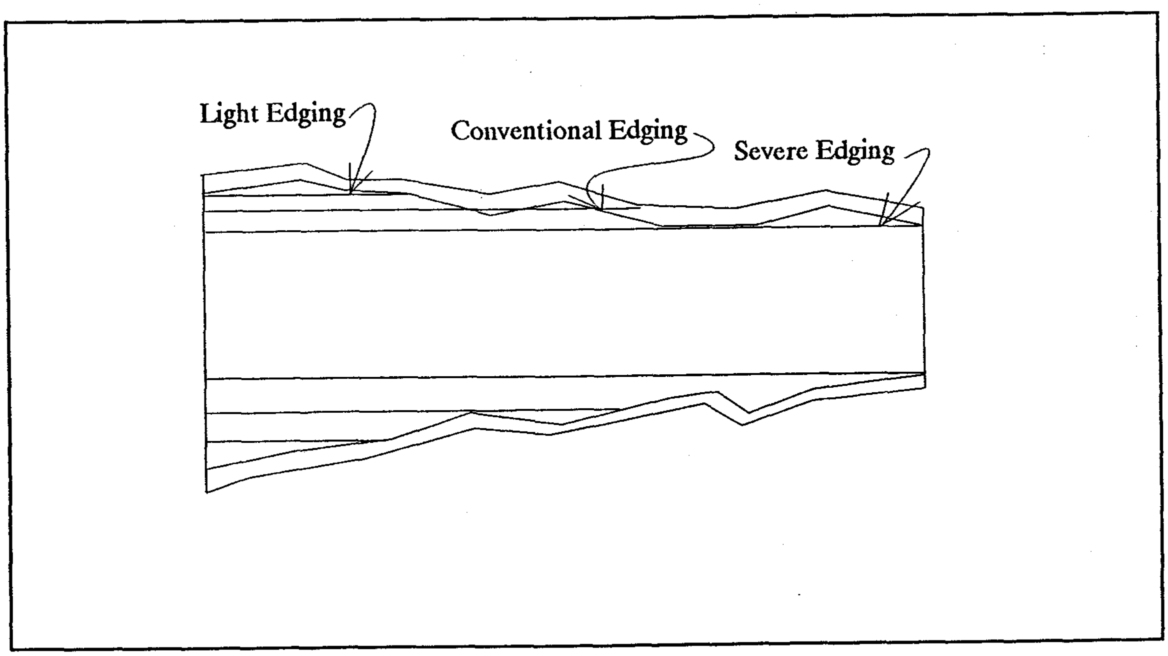

Figure 3.2. Edger saw position for light-edging, conventional and severe edging practices

Flann and Lamb, 1966, Flann *et al.*, 1967., Bousquet., 1989., Neilson *et al.*, 1970a, Nielson *et al.*, 1970b and in this study, applied the 50-50 rule, where 50% of the board's edge was waney, and 50% was clear. The lightly-edged practice required that 33% of the edge be clear, and 66% be waney. The severe-edging practice removed all the wane. The nominally unedged practice required that enough wane was removed to create 6 inches of clear edge which represented the shortest length in the cutting bill and removed considerable sweep and flare in the process. The mill-edger operator's edger lines define the actual edging practice.

Those procedures that required a percentage of clear edge could not always be satisfied and required adjustment. Irregularly shaped boards and lumber restrictions that mandate five inch minimum width for Select, and a four inch minimum width for No.1 shop, and No.2 shop made absolute percentages of 50%, 33%, and 100% occasionally unobtainable.

The edging procedure was altered as follows: For the severe category, edger lines were placed to remove all the wane. If the board width was less than the minimum required, the edger lines were moved to meet minimum width. With this change in procedure, the severely edged boards had an average of 69% of their wane removed and the average width of these boards was 4.45 inch.

The same problem arose when applying the 33% wane removal procedure in the light-edging category. The edger lines were placed so as to remove 33% of the wane but then expanded if the minimum width requirement was not met. This resulted in an average of 41% wane removal and an average width of 5.85 inches. The conventionally-edged boards had an average of 57% wane removal and an average width of 5.23 inches. Even after the edger line expansion, the percentage of wane removal for the conventional and light edging is higher than expected. This is due to the discrete nature of the board data and the software developed to determine edger line location. The software first placed potential edger lines at the perimeter of the board's bounding box which is illustrated in Figure 3.3. The edger lines were then moved

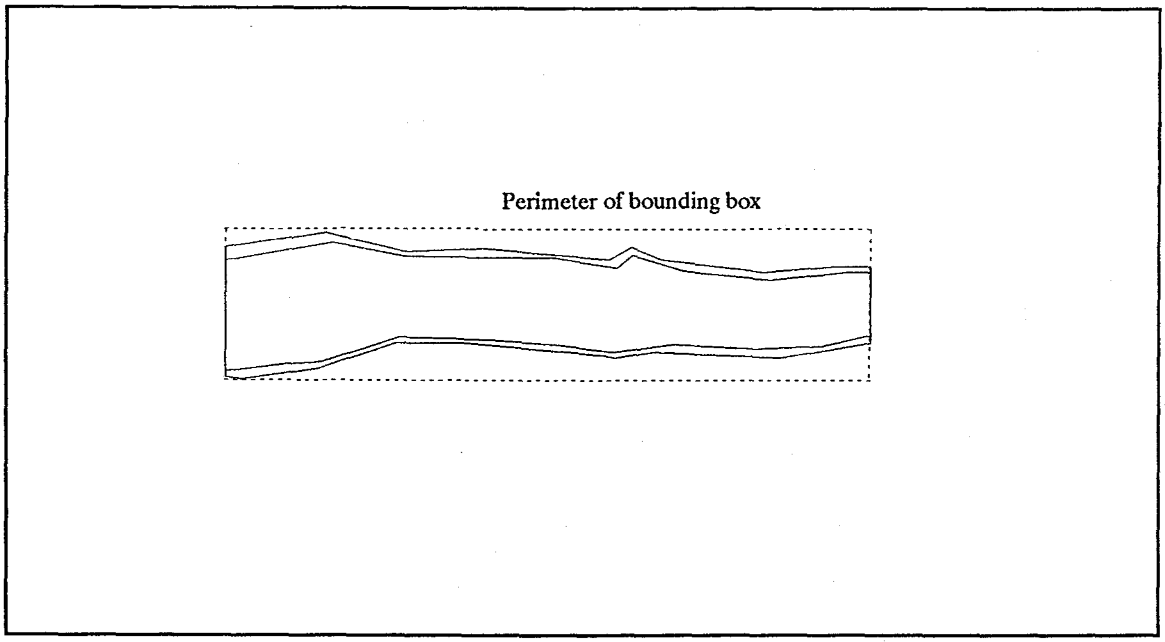

Figure 3.3. Area of bounding box vs. area of board

toward the center of the board in 1/10 inch increments which is equal board data's resolution. Each increment of 1/10 inch does not necessarily correlate with a uniform percent increase. As the edger lines are stepped in, it is possible that the percentage of wane removal jumps up 10% in a single 1/10 inch step. High jumps in percent of wane removal increased the reported average wane removal figures higher than expected.

Simulated edging was performed on all boards and cutting yields calculated with the CORY program. The yields were statistically analyzed for the effect of edging by grade. The statistics were based on a one-factor experiment with repeated measures (Cody and Smith, 1987). When applicable, a Duncan's multiple range test (alpha=0.05) was used to determine the significance and difference between edging practices. The SAS programming language was used for the analysis SAS Institute, 1988).

E. COST ANALYSIS

The current lumber grade requirements and the related lumber pricing system makes using unedged or partially edged alder lumber on an industry-wide basis impractical. However, as previous studies have shown, there is a substantial opportunity for increased revenue in vertically-integrated operations, as well as operations with buy-sell agreements based on quality guidelines other than established lumber grades. This analysis estimates the differential income related to the changes in drying, handling, and transportation costs, as well as the losses in chip volume, and compares them to the changes in cutstock and pulp chip revenue.

$$\text{Differential Income (DI)} = \text{Differential Revenue (DR)} - \text{Differential Cost (DC)}$$

$$DI = \left[\text{DR from Cuttings} + \text{DR from Residue}\right] - \left[\text{DC of Drying} + \text{DC of Trucking} + \text{DC of Handling}\right]$$

The cost of drying is typically expressed as a cost per Mbf. However, when drying unedged flitches, or lightly edged boards gaps between boards are unavoidable given their irregular shapes. The opportunity costs from reduced kiln throughput was therefore an important cost factor. Quantifying this loss is difficult, but it was estimated by using the board's bounding box (Figure 3.3) which is the maximum area the board would occupy. This area was used to estimate the number of boards in a bundle twelve feet long, 48 inches wide and 60 inches tall including stickers. The volume for each edging practice was used to calculate a ratio based on the actual edging practice's volume. This ratio was used to adjust the drying costs. These ratios are very generous estimates of volume loss because efficient stacking of the boards by alternating the wide board-ends in the bundle was not considered. This stacking ratio is the most sensitive component of our cost analysis in that it effects both the drying and the trucking cost. Therefore, any adjustment to the stacking ratios has a tremendous impact on the results of our cost analysis. An average interstate trucking cost/Mbf was also adjusted for each category using the ratios developed for the drying costs.

As less wood is removed at the edger station, less wood is available for sale as pulp chips. Revenue from chip production can make the difference between profit and loss. This opportunity cost was estimated by calculating the volume of board edgings for each edging scenario. The difference in edging volume between the edging category and the actual edging category was then converted to weight using the density of red alder at 12% MC of 28 lbs/ft^3 (Panshin and de Zeeuw,1980). A conservative price of \$100/2400 lbs, was used to calculate overall chip value.[1] The overall chip value was reduced to compensate for the sale of hogfuel/particleboard furnish at the roughmill. The amount of hogfuel/particleboard furnish was calculated by subtracting the change in cutting volume for each edging category from the volume of edging for each category. This volume was then multiplied by a price of \$48/2400 lbs[1] and subtracted from the chip revenue. The differential revenue obtained from the sale of residue was estimated by subtracting the estimated revenue from hogfuel/particleboard furnish sales from the revenue from pulp chip sales.

Certainly, one could expect the cost of handling unedged material to be larger than the cost of handling edged material. However, quantifying this cost is difficult without completing a time-study analysis. In previous

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[1] Personal Communication, Jim B. Wilson, April, 1994.

studies, this cost was either ignored or increased by 25% (Beaudoin *et al.*, 1982, Kline *et al.*, 1993).

It seems appropriate to adjust handling cost for the unedged material given its irregular shape; however, it does not seem appropriate to adjust the handling cost for the other treatments because their boards' shapes are more regular. For this reason, the handling cost for unedged flitches was increased by 25%, and the other treatments shared the same handling cost estimate based on an industry quote.

Revenue from yield increases were calculated using current cutstock prices (Table 3.2). These values were supplied by industry sources. Note the low cutting value of the <9" category compared to the >9" categories.

Cutting Values ($/mbf)				
Widths	Lengths			
	<9"	9-24"	24-35"	35"+
1.5"	875	2150	2375	2600
2.0"	900	2175	2400	2625
2.5"	925	2200	2425	2650
3.0"	950	2250	2475	2700

Table 3.2. Values of finger-joint blocks used to calculate sawing solutions

4. RESULTS AND DISCUSSION

A. TWO-STAGE SAWING PROCESS ANALYSIS

The cutting volumes for the different edging practices are presented in Table 4.1 The unedged boards produced the highest volume of cuttings and the largest number of cuttings. The total unedged cutting volume was 18% greater than severe, 12% greater than actual, 9% greater than conventional and 4% greater than light.

Lumber Grades	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
Select	290.5	254.1	246.6	276.5	265.9
No.1	255.7	226.4	204.6	244.6	235.4
No.2	239.5	212.2	190.0	230.9	217.4

Table 4.1 Cutting volume (bd. ft.) by edging category and lumber grade sawn with the two-stage process

Although the yield figures are slightly smaller, these results are comparable to the findings of Flann *et al.* (1967) and Kline *et al.* (1993) The differences in sawing process and cutting bill probably account for the lower yield figures. Kline used a three-stage sawing process (instead of the two-stage simulated in this study) producing random-width, fixed-length red oak cuttings. Flann *et al.*

(1967) used program YIELD producing fixed-length, fixed-widths with hard maple. For this study, CORY produced fixed-width, random-length cuttings.

The total number of cuttings (Table 4.2) from the unedged boards was 26% greater than severe, 19% greater than actual, 16% greater than conventional and 9% greater than light.

Lumber Grades	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
Select	827	671	638	740	706
No.1	851	674	625	776	716
No.2	897	748	654	829	748

Table 4.2. Number of cuttings by edging category and lumber grade sawn with the two-stage process

Table 4.3 shows that unedged boards have the highest yield on a percent volume yield basis. The results are

Lumber Grade	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
Select	83.25	73.06	71.87	79.49	76.63
No.1	79.48	70.25	64.09	76.08	73.26
No.2	75.53	66.24	60.02	72.39	68.22

Table 4.3. Cut stock yields (percent) based on the volume of actual-edged boards sawn with the two-stage process

comparable to those of previous studies showing a significant yield increase from unedged or partially edged boards.

The yield gain for unedged lumber is largely due to the increase of production of short cuttings (Tables 4.4,4.6, and 4.8). These smaller cuttings were probably from the flare and crook removed in the other edging practices. The large number of over 36 inch cuttings for all the edging categories is due to the emphasis placed on the longer cuttings. The cutting volumes generated by these cuttings are presented in Tables 4.5, 4.7, and 4.9 and show volume distribution by edging category and lumber grade.

The distribution of cuttings by length shows a large number of 18-24 inch cuttings across all grades and edging treatments. Inspection of the sample boards' clear-area length distribution showed a similar concentration of 18-24 inch cuttings which is apparently a natural characteristic of the red alder lumber.

An edging procedure that creates 2 feet of clear edge might be the best edging option. Such a procedure would reduce the yield of shorter cuttings, but might not significantly affect total cutting value and, indeed, preliminary investigation showed that this edging practice produced yields comparable to those for unedged boards. Further study of this type of edging strategy appears warranted and should involve incrementally increasing the

Length	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	#	%	#	%	#	%	#	%	#	%
6-12"	106	12.8	48	7.2	47	7.4	55	7.4	54	7.7
12-18"	58	7.0	45	6.7	41	6.4	47	6.4	36	5.1
18-24"	238	28.8	197	29.4	193	30.3	225	30.4	221	31.3
24-30"	102	12.3	97	14.5	84	13.2	102	13.8	83	11.8
30-36"	80	9.7	58	8.6	59	9.2	76	10.3	77	10.9
36"+	243	29.4	226	33.7	214	33.5	235	31.8	235	33.3
Total	827	100	671	100	638	100	740	100	706	100

Table 4.4. Distribution of the number of cuttings by length and edging category for Select boards sawn with the two-stage process

Lengths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%
6-12"	11.1	3.8	5.8	2.3	6.2	2.5	6.6	2.4	6.4	2.4
12-18"	11.0	3.8	9.7	3.8	8.2	3.3	8.8	3.2	7.4	2.8
18-24"	69.1	23.8	58.0	22.8	57.6	23.4	65.7	23.8	62.5	23.5
24-30"	36.7	12.6	35.6	14.0	32.3	13.1	36.4	13.2	31.6	11.9
30-36"	32.0	11.0	26.1	10.2	26.2	10.6	32.8	11.9	33.5	12.6
36"+	130.6	45.0	118.9	46.8	116.1	47.1	126.2	45.6	124.6	46.6
Total	290.5	100.0	254.1	100.0	246.6	100.0	276.5	100.0	265.9	100.0

Table 4.5. Distribution of cutting volume by length and edging category for Select boards sawn with the two-stage process

Lengths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	#	%	#	%	#	%	#	%	#	%
6-12"	127	14.9	79	11.7	69	11.0	91	11.7	77	10.8
12-18"	91	10.7	63	9.3	45	7.2	68	8.8	63	8.8
18-24"	225	26.4	172	25.5	169	27.0	207	26.7	192	26.8
24-30"	147	17.3	136	20.2	125	20	147	18.9	147	20.5
30-36"	93	10.9	79	11.7	67	10.7	93	12.0	79	11.0
36"+	168	19.7	145	21.5	144	23.0	170	21.9	158	22.1
Total	851	100	674	100	619	99	776	100	716	100

Table 4.6. Distribution of the number of cuttings by length and edging category for No. 1 Shop boards sawn with the two-stage process

Lengths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%
6-12"	12.7	5.0	9.5	4.2	7.7	3.8	9.6	3.9	8.8	3.7
12-18"	16.2	6.4	12.9	5.7	8.9	4.4	12.8	5.2	12.2	5.2
18-24"	59.1	23.1	48.8	21.6	47.8	23.3	56.1	22.9	53.0	22.5
24-30"	48.3	18.9	47.6	21.0	44.2	21.6	49.5	20.2	51.2	21.7
30-36"	39.4	15.4	36.0	15.9	28.1	13.7	38.2	15.6	36.8	15.6
36"+	80.0	31.3	71.6	31.6	67.9	33.2	78.4	32.0	73.4	31.3
Total	255.7	100.0	226.4	100.0	204.6	100.0	244.6	100.0	235.4	100.0

Table 4.7. Distribution of cutting volume by length and edging category for No. 1 Shop boards sawn with the two-stage process

Lengths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	#	%	#	%	#	%	#	%	#	%
6-12"	169	18.8	131	17.5	103	15.7	140	16.9	130	17.4
12-18"	128	14.3	94	12.6	84	12.8	112	13.5	96	12.8
18-24"	231	25.7	201	26.9	182	27.8	237	28.6	195	26.1
24-30"	138	15.4	114	15.2	103	15.7	124	15.0	117	15.6
30-36"	87	9.7	78	10.4	67	10.2	80	9.7	81	10.8
36"+	144	16.1	125	16.7	115	17.6	136	16.4	129	17.2
Total	897	100	743	99	654	100	829	100	748	100

Table 4.8. Distribution of the number of cuttings by length and edging category for No. 2 Shop sawn with the two-stage process

Lengths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%
6-12"	17.2	7.2	15.1	7.1	11.7	6.1	14.9	6.5	14.7	6.8
12-18"	22.8	9.5	18.5	8.7	15.7	8.3	20.1	8.7	17.6	8.1
18-24"	58.9	24.6	51.7	24.3	49.6	26.0	60.5	26.2	50.1	23.0
24-30"	43.6	18.2	37.7	17.8	32.9	17.3	39.5	17.1	39.1	18.0
30-36"	34.0	14.2	32.0	15.1	26.6	14.0	34.3	14.8	36.0	16.5
36"+	63.0	26.3	57.2	27.0	53.5	28.2	61.6	26.7	59.9	27.6
Total	239.5	100.0	212.2	100.0	190.0	100.0	230.9	100.0	217.4	100.0

Table 4.9. Distribution of cutting volume by length and edging category for No.2 Shop boards sawn with the two-stage process

boards' clear edges until they match the longest cutting length of 38 inches. It seems logical that the best edging practice should lie within this range.

The effect of edging practice on width is shown in Tables 4.10 through 4.15. Once again, the larger production of cutting parts from the unedged boards is mainly due to increased numbers of narrower cuttings. Tables 4.11, 4.13, 4.15 show the distribution of cutting volume by width.

Cutting Widths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	#	%	#	%	#	%	#	%	#	%
1.5"	451	54.2	312	46.5	283	44.4	346	46.8	340	48.2
2.0"	165	20.0	158	23.5	134	21.0	209	28.2	179	25.4
2.5"	126	15.2	121	18.0	138	21.6	105	14.2	107	15.2
3.0"	85	10.3	80	11.9	83	13.0	80	10.8	83	11.8
Total	827	100.0	671	100.0	638	100.0	740	100.0	709	100.0

Table 4.10. Distribution of the number of cuttings by width and edging category for Select boards sawn with the two-stage process

Cutting Widths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%
1.5"	113.4	39.0	88.2	34.7	79.0	32.0	93.8	33.9	95.4	35.9
2.0"	64.6	22.2	63.3	24.9	54.5	22.1	82.9	30.0	69.4	26.1
2.5"	63.5	21.9	57.0	22.4	66.1	26.8	51.6	18.7	50.9	19.1
3.0	49.0	16.9	45.6	18.0	47.1	19.1	48.2	17.4	50.2	18.9
Total	290.5	100.0	254.1	100.0	246.6	100.0	276.5	100.0	265.9	100.0

Table 4.11. Distribution of cutting volume by width and edging category for Select boards sawn with the two-stage process

Cutting Widths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	#	%	#	%	#	%	#	%	#	%
1.5"	543	63.8	324	48.1	311	49.8	469	60.4	371	51.8
2.0"	195	22.9	188	27.9	233	37.3	186	24.0	204	28.5
2.5"	86	10.1	115	17.1	47	7.5	90	11.6	108	15.1
3.0"	27	3.2	47	7.0	34	5.4	31	4.0	33	4.6
Total	851	100	674	100	625	100	776	100	716	100

Table 4.12. Distribution of the number of cuttings by width and edging category for No. 1 Shop boards sawn with the two-stage process

Cutting Widths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%
1.5"	131.8	51.5	86.0	38.0	85.3	41.7	124.5	50.9	98.6	41.9
2.0"	68.8	26.9	67.8	29.9	81.6	39.9	64.7	26.5	72.5	30.8
2.5"	41.1	16.1	49.8	22.0	22.1	10.8	39.1	16.0	47.2	20.1
3.0	14.1	5.5	22.8	10.1	15.6	7.6	16.3	6.7	17.1	7.2
Total	255.7	100.0	226.4	100.0	204.6	100.0	244.6	100.0	235.4	100.0

Table 4.13. Distribution of cutting volume by width and edging category for No. 1 Shop boards sawn with the two-stage process

Cutting Widths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	#	%	#	%	#	%	#	%	#	%
1.5"	646	72	466	62.3	387	59.2	552	66.6	437	58.4
2.0"	167	18.6	178	23.8	184	28.1	196	23.6	210	28.1
2.5"	68	7.6	84	11.2	51	7.8	57	6.9	74	9.9
3.0"	16	1.8	20	2.7	32	4.9	24	2.9	27	3.6
Total	897	100	748	100	654	100	829	100	748	100

Table 4.14. Distribution of the number of cuttings by width and edging category for No.2 Shop boards sawn with the two-stage process

Cutting Widths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%
1.5"	151.5	63.2	112.8	53.2	96.9	51.0	130.5	56.5	105.2	48.4
2.0"	55.2	23.1	59.1	27.9	61.1	32.1	64.8	28.1	68.6	31.6
2.5"	26.8	11.2	32.5	15.3	17.6	9.3	23.9	10.4	31.0	14.3
3.0	6.11	2.5	7.78	3.6	14.4	7.6	11.7	5.1	12.5	5.8
Total	239.5	100.0	212.2	100.0	190.0	100.0	230.9	100.0	217.4	100.0

Table 4.15. Distribution of cutting volume by width and edging category for No. 2 Shop boards sawn with the two-stage process

B. STATISTICAL ANALYSIS

Analysis of variance and Duncan's multiple range tests (alpha=0.05) were used to establish the relative significance of each edging procedure. Yields were derived on a board-by-board basis using the cutting volume for each edging regime and the corresponding board volume of the actual edging regime. The results of the multiple range tests are shown below for each grade. The means sharing the same Duncan grouping letter are not significantly different.

B.1. Select Boards

The results of the multiple range test on the Select board data (Table 4.16) show that the difference between the actual and severe edging procedures is insignificant. This lack of significance suggests that actual edging is probably excessive and unnecessarily reduces the yield of cut stock.

Edge Type	Mean Yield	N	Duncan grpg.
Unedged	83.25	85	A
Actual	73.06	85	D
Severe	71.87	85	D
Light	79.49	85	C
Conventional	76.63	85	B

Table 4.16. Multiple range test on edging treatments for Select boards

B.2. No 1 Shop

Table 4.17 shows that all of the edging categories are significantly different for the No. 1 Shop boards.

Edge Type	Mean Yield	N	Duncan grpg.
Unedged	79.48	85	A
Actual	70.28	85	D
Severe	64.09	85	E
Light	76.08	85	B
Conventional	73.26	85	C

Table 4.17. Multiple range test on edging treatments for No. 1 Shop boards

B.3. No. 2 Shop

Table 4.18 shows that there are no significant differnces between the actual and conventional treatments edging treatments for the No. 2 Shop boards.

Edge type	Mean Yield	N	Duncan grpg.
Unedged	75.53	85	A
Actual	66.24	85	C
Severe	60.02	85	D
Light	72.39	85	B
Conventional	68.22	85	C

Table 4.18. Multiple range test on edging treatments for No.2 Shop boards

Based on this data, it appears the edger operator removes too much of the Select board in an effort to ensure the proper percent clear area required in the grading rules while he is more permissive with the No.2 Shop boards because the required percent of clear area is more likely to be met. In other words, the operator, perhaps due to the higher value of the Select boards, is liable to edge more to make sure that the board does not fall into the No. 1 Shop grade and lose value.

C. COST ANALYSIS

The cost analysis, as outlined in the methodology section, estimates the differential income related to the changes in drying, handling, and transporting costs and compares them to the changes in cut stock and pulp chip revenue. These costs will differ between mills and should be taken as estimates only.

C.1. Differential Revenue

C.1a. Change in Cut-Stock Revenue

Tables 4.19, 4.20 and 4.21 show the value of the cuttings produced from Select, No.1 Shop, and No.2 Shop boards. Totals for the sample and adjusted totals per Mbf are shown. Adjusted totals for these tables as well as in the cost analysis are based on the volume of the unedged sample.

Cutting Length	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
<9"	4.44	2.44	2.25	2.39	2.58
9-24"	188.18	154.81	152.32	171.40	160.06
24-35"	150.88	139.53	122.93	149.67	135.93
35"+	359.92	323.34	325.86	350.98	351.51
Total	703.42	620.12	603.36	674.44	650.08
Total/Mbf	1313.50	1157.96	1126.66	1259.39	1213.90
ΔCutting Revenue per Mbf	155.54	0.00	(31.30)	101.43	55.94

Table 4.19. Total dollar value of cuttings by length and edging category for Select boards sawn with the two-stage process

Cutting Length	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
<9"	5.39	3.44	3.18	4.01	3.42
9-24"	177.90	148.11	132.56	161.03	148.87
24-35"	197.53	190.79	160.90	197.95	197.55
35"+	223.34	198.96	191.51	218.55	207.26
Total	604.16	541.30	488.15	581.54	557.10
Total/Mbf	1238.13	1109.31	1000.39	1191.78	1141.69
ΔCutting Revenue per Mbf	128.82	0.00	(108.92)	82.47	32.38

Table 4.20. Total dollar value of cuttings by length and edging category for No.1 Shop boards sawn with the two-stage process

Cutting Length	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
<9"	7.62	5.72	4.58	5.69	5.74
9-24"	195.79	171.13	156.36	193.10	164.88
24-35"	170.23	154.96	127.56	159.65	156.80
35"+	180.95	162.63	156.23	179.73	182.38
Total	554.59	494.44	444.73	538.17	509.80
Total/Mbf	1149.60	1020.68	921.87	1115.56	1056.76
ΔCutting Revenue per Mbf	128.92	0.00	(98.81)	94.88	36.08

Table 4.21. Total dollar value of cuttings by length and edging category for No. 2 Shop boards sawn with the two-stage process

C.1b. Change in Residue Revenue

The following changes in revenue associated with losses in chip volume in $/Mbf were estimated using the value estimate of $52/2400 lbs as described in the methodology section:

	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
Select	($14.97)	$ 0.00	$ .23	($6.54)	($3.22)
No. 1	($14.23)	$ 0.00	$3.46	($6.08)	($1.90)
No. 2	($14.31)	$ 0.00	$3.40	($6.15)	($1.74)

Table 4.22. Changes in pulp chip revenue (dollars/Mbf).

C.2. Differential Costs

The differential costs as well as the bundle volume ratios are shown in Table 4.23.

	Edging Practices				
	Unedged	Actual	Severe	Light	Conven.
Volume Ratio	1.7	1.0	0.9	1.2	1.1
Drying Costs	$93.50/Mbf ($38.50/Mbf)	$55.00/Mbf --------	$49.50/Mbf $5.50/Mbf	$66.00/Mbf ($11.00/Mbf)	$60.50/Mbf ($5.50/Mbf)
Trucking Costs	$102.00/Mbf ($42.00/Mbf)	$60.00/Mbf --------	$54.00/Mbf $6.00/Mbf	$72.00/Mbf ($12.00/Mbf)	$66.00/Mbf ($11.00/Mbf)
Handling Costs	$53.75/Mbf ($10.75/Mbf)	$43.00/Mbf --------	$43.00/Mbf --------	$43.00/Mbf --------	$43.00/Mbf -------

Table 4.23. Costs/Mbf, differential costs (small font, second line) and volume ratio for five edging practices

C.2a. Drying Costs

The increase in drying costs is due to decreased kiln capacity. This decrease is the result of air gaps in the bundles formed by irregularly shaped flitches. To accurately estimate the increase in dry-kiln cost, therefore, the flitches and boards for each edging practice had to be stacked. Using the bounding box, and a procedure described in the methodology section, the relative values were derived. These ratios, based on the bundle volume of the actual edging category, are shown with the adjusted drying cost figures in Table 4.23.

If the mill is dry-kiln bound, restrictions in kiln throughput will drastically affect production figures. If the assumption that unedged material is 1.7 times greater in volume is correct, then production will be reduced 70% unless additional kilns are erected, or custom facilities are employed.

C.2b.Trucking Costs

An average interstate trucking cost of $60/mbf was provided by the contributing mill. Because the limiting factor in trucking dry lumber is volume and not weight, the costs were determined by multiplying the average cost by the bundle volume ratio. The values are shown in Table 4.23. Obviously, if the roughmill was at the same location as the sawmill, these costs would not apply. They are included so that costs for non-vertically integrated operations can be estimated.

C.2c. Handling Costs

To allow for the cost of handling unedged flitches to be quantified, and continue in the vein of conservatism, the estimates for the handling cost of $43/mbf will be increased by 25%, as in Kline's study, for the unedged practice. The costs are shown in Table 4.23.

C.3. Differential Income

When using a two-stage procedure for the breakdown of red alder lumber, a light edging procedure is recommended as indicated by the results shown in Tables 4.24, 4.25 and 4.26.

	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
Gain in yield	$155.54	$ 0.00	($31.30)	$101.42	$55.94
Drying costs	($ 38.50)	$ 0.00	$ 5.50	($ 11.00)	($ 5.50)
Trucking costs	($ 42.00)	$ 0.00	$ 6.00	($ 12.00)	($ 6.00)
Handling costs	($ 10.75)	--------	--------	--------	--------
Loss in chip volume	($ 14.97)	$ 0.00	$ .23	($ 6.54)	($ 3.22)
Diff. Income	$ 49.32	$ 0.00	($19.57)	$ 71.88	$41.22

Table 4.24. Differential costs and revenue ($/Mbf) for Select boards sawn with the two-stage process

This cost analysis serves to demonstrate the effect of using unedged or partially edged material. As mentioned earlier, these numbers are estimates only and are based on very conservative assumptions. It should be further noted that even if the trucking costs were eliminated, and the stacking volume ratios less conservative, the light-edging practice would remain the most viable.

	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
Gain in yield	$128.78	$ 0.00	($108.91)	$82.46	$32.38
Drying costs	($ 38.50)	$ 0.00	$ 5.50	($11.00)	($ 5.50)
Trucking costs	($ 42.00)	$ 0.00	$ 6.00	($12.00)	($ 6.00)
Handling costs	($ 10.75)	------	------	------	------
Loss in chip volume	($ 14.23)	$ 0.00	$ 3.46	($ 6.08)	($ 1.90)
Diff. Income	$ 23.30	$ 0.00	($ 93.95)	$53.38	$18.98

Table 4.25. Differential costs and revenue ($/Mbf) for No. 1 Shop boards sawn with the two-stage process

	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
Gain in yield	$124.72	$ 0.00	($103.06)	$90.65	$31.84
Drying costs	($ 38.50)	$ 0.00	$ 5.50	($11.00)	($ 5.50)
Trucking costs	($ 42.00)	$ 0.00	$ 6.00	($12.00)	($ 6.00)
Handling costs	($ 10.75)	------	------	------	------
Loss in chip volume	($ 14.31)	$ 0.00	$ 3.40	($ 6.15)	($ 1.74)
Diff. Income	$ 19.16	$ 0.00	($ 88.16)	$61.50	$18.60

Table 4.26. Differential costs and revenue ($/Mbf) for No. 2 Shop boards sawn with the two-stage process

The low value of the less-than-9 inch cuttings coupled with the high stacked volume jeopardized the cost effectiveness of the unedged practice. The increases in cutting volume and number of cuttings shown by the unedged practice were derived from the crooks and flares which allowed for mostly small cuttings. These less-than-9 inch cuttings had very little value in comparison to the 9 to 24 inch category. This drastic reduction in value did not help to offset the large increase in stacked volume and the inherent volume related costs.

D. THREE-STAGE SAWING PROCESS ANALYSIS

It has been reported that substantial increases in yield can be obtained with the addition of a third stage in the cut-up process (Anderson *et al.*, 1992). Furthermore, it was apparent, because of the irregular shape of the alder flitches and the inherent opportunities for re-ripping, that increases in yield above the two-stage process were possible. A preliminary investigation was made by holding all other experimental variables constant and changing the CORY model from a two-stage to a three-stage version.

The three-stage analysis presented here follows the form of the two-stage analysis. However, the reader should consider carefully any economic comparisons between the two- and the three-stage results as it was assumed that the facilities for both types of operations already existed.

The added capital and operating expense associated with the three-stage sawing process was, therefore, irrelevant and not considered. However, the estimated cutting volumes and revenues may be used to develop a full economic comparison if desired.

For the three-stage analysis, the total unedged cutting volume presented in Table 4.27 was 23.1% greater than severe, 13.8% greater than actual, 3% greater than light-edged, and 9.6% greater than conventional. These figures are similar to the results of Flann *et al.* (1967) and Kline *et al.* (1993).

Lumber Grade	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
Select	289.74	251.33	238.17	280.97	265.08
No.1	258.22	222.96	191.76	251.69	233.23
No.2	247.19	211.11	181.53	239.15	220.57

Table 4.27. Cutting volume (bd.ft.) by edging category and lumber grade sawn with the three-stage process

Table 4.28 shows that the total number of cuttings from the unedged boards was 31.3% greater than severe, 23.9% greater than actual, 8.87% greater than light-edged, and 20.4% greater than conventional. The percent volume yields are presented in Table 4.38 and show significant increases with the lighter edging practices.

Lumber Grade	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
Select	1066	777	764	969	857
No.1	1074	829	714	970	852
No.2	1129	865	750	1037	893

Table 4.28. Number of cuttings by edging category and lumber grade sawn with the three-stage process

Lumber Grade	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
Select	95.10	82.19	79.78	92.35	87.48
No.1	91.64	78.65	68.57	89.28	82.76
No.2	88.93	75.19	65.72	85.83	79.10

Table 4.29. Cut-stock yields (percent) based on the volume of actual-edged boards sawn with the three-stage process

The high number of cuttings produced by the unedged treatment is due to a large increase in the number of cuttings in the shorter categories in all three grades (Tables 4.30, 4.32, 4.34). These tables are accompanied by Tables 4.31, 4.33, and 4.35 which show the volume of the cuttings in board feet as well as percent of total.

Lengths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	#	%	#	%	#	%	#	%	#	%
6-12"	332	31.1	161	20.3	148	19.4	255	26.2	205	23.9
12-18"	189	17.7	81	14.9	81	10.6	146	15.0	123	14.4
18-24"	211	19.8	194	21.6	194	25.4	228	23.5	175	20.4
24-30"	111	10.4	82	12.0	82	10.5	119	12.2	85	9.9
30-36"	96	9.0	82	9.8	82	10.5	82	8.4	101	11.8
36"+	127	11.9	177	21.3	177	23.2	139	14.3	168	19.6
Total	1066	100	777	100	764	100	969	100	857	100

Table 4.30. Distribution of the number of cuttings by length and edging category for Select boards sawn with the three-stage process

Lengths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%
6-12"	42.2	12.8	20.4	7.1	17.5	6.4	32.7	10.2	25.6	8.5
12-18"	43.1	13.1	26.4	9.2	20.2	7.4	33.7	10.5	27.8	9.2
18-24"	69.6	21.1	56.8	19.8	59.1	21.8	74.7	23.3	57.6	19.1
24-30"	47.2	14.3	38.9	13.6	32.4	11.9	51.3	16.1	36.0	11.9
30-36"	48.8	14.8	40.7	14.2	39.7	14.6	42.0	13.1	52.2	17.3
36"+	79.0	14.8	103.1	36.0	102.6	37.8	85.6	26.8	102.9	34.1
Total	329.9	100.0	286.3	100.0	271.5	100.0	320.0	100.0	302.1	100.0

Table 4.31. Distribution of cutting volume by length and edging category for Select boards sawn with the three-stage process

Lengths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	#	%	#	%	#	%	#	%	#	%
6-12"	398	37.1	203	24.5	120	16.8	314	32.4	225	26.4
12-18"	204	19.0	119	14.4	71	9.9	163	16.8	118	13.8
18-24"	217	20.2	195	23.5	184	25.8	231	23.8	211	24.8
24-30"	107	10.0	118	14.2	131	18.3	105	10.8	120	14.1
30-36"	71	6.6	87	10.5	88	12.3	76	7.8	74	8.7
36"+	77	7.2	107	12.9	120	16.8	81	8.4	104	12.2
Total	1074	100	829	100	714	100	970	100	852	100

Table 4.32. Distribution of the number of cuttings by length and edging category for No. 1 Shop boards sawn with the three-stage process

Lengths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%
6-12"	50.8	17.3	24.8	9.8	13.5	6.2	40.4	14.1	29.3	11.0
12-18"	46.7	15.9	25.0	9.8	13.5	6.2	37.3	13.0	26.4	9.9
18-24"	70.1	23.9	59.9	23.6	48.8	22.3	76.8	26.8	65.6	24.7
24-30"	44.6	15.2	44.6	17.6	46.2	21.1	43.3	15.1	46.9	17.7
30-36"	34.4	11.7	42.1	16.6	38.3	17.5	38.2	13.3	35.3	13.3
36"+	47.0	16.0	57.5	22.6	58.2	26.6	50.5	17.6	62.0	23.3
Total	293.6	100.0	253.9	100.0	218.5	100.0	286.5	100.0	265.5	100.0

Table 4.33. Distribution of cutting volume by length and edging category for No.1 Shop boards sawn with the three-stage process

Lengths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	#	%	#	%	#	%	#	%	#	%
6-12"	443	39.2	252	29.1	157	20.9	361	34.8	283	31.7
12-18"	243	21.5	182	21.0	133	17.7	207	20.0	159	17.8
18-24"	208	18.4	183	21.2	176	23.5	234	22.6	170	19.0
24-30"	107	9.5	101	11.7	107	14.3	95	9.2	100	11.2
30-36"	68	6.0	58	6.7	74	9.9	67	6.5	80	9.0
36"+	60	5.3	89	10.3	103	13.7	73	7.0	101	11.3
Total	1129	100	865	100	750	100	1037	100	893	100

Table 4.34. Distribution of the number of cuttings by length and edging category for No. 2 Shop boards sawn with the three-stage process

Lengths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%
6-12"	54.3	19.3	31.4	13.1	17.7	8.6	43.2	15.9	34.4	13.7
12-18"	52.0	18.5	39.8	16.6	25.7	12.4	43.9	16.1	33.6	13.4
18-24"	66.7	23.7	55.0	23.0	47.0	22.7	74.7	27.5	52.5	20.9
24-30"	42.2	15.0	37.9	15.8	37.2	18.0	36.9	13.6	38.4	15.3
30-36"	32.5	11.6	27.6	11.5	31.2	15.1	34.1	12.5	37.6	15.0
36"+	33.3	11.9	48.5	20.2	48.0	23.2	39.2	14.4	54.6	21.7
Total	281.0	100.0	240.2	100.0	206.8	100.0	272.0	100.0	251.1	100.0

Table 4.35. Distribution of cutting volume by length and edging category for No. 2 Shop sawn with the three-stage process

The distribution of widths showed an overall drop in the number of cuttings in the 1.5 inch category, but large increases in the number of cuttings in the other three widths. See Tables 4.36, 4.37, 4.38, 4.39, 4.40, 4.41.

Cutting Widths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	#	%	#	%	#	%	#	%	#	%
1.5"	254	23.8	199	25.1	253	32.4	230	23.7	206	24.0
2.0"	310	29.1	240	30.3	258	33.1	303	31.2	272	31.7
2.5"	296	27.8	184	23.2	38	21.9	236	24.3	196	22.9
3.0"	206	19.3	169	21.3	31	12.6	203	20.9	183	21.4
Total	1066	100	792	100	580	100	972	100	857	100

Table 4.36. Distribution of the number of cuttings by width and edging category for Select boards sawn with the three-stage process

Cutting Widths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%
1.5"	47.8	14.5	42.5	14.8	56.8	20.9	44.5	13.9	41.9	13.9
2.0"	81.3	24.7	77.9	27.2	83.2	30.7	88.7	27.7	83.9	27.8
2.5"	103.5	31.4	72.8	25.4	75.7	27.9	82.6	25.8	77.1	25.5
3.0	97.1	29.5	93.3	32.6	55.7	20.5	104.1	32.5	99.1	32.8
Total	329.7	100.0	286.5	100.0	271.4	100.0	319.9	100.0	302.0	100.0

Table 4.37. Distribution of cutting volume by width and edging category for Select boards sawn with the three-stage process

Cutting Widths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	#	%	#	%	#	%	#	%	#	%
1.5"	286	26.6	271	32.7	322	45.1	228	23.5	242	28.4
2.0"	305	28.4	296	35.7	317	44.4	298	30.7	274	32.2
2.5"	287	26.7	175	21.1	45	6.3	257	26.5	211	24.8
3.0"	196	18.2	87	10.5	30	4.2	187	19.3	125	14.7
Total	1074	100	829	100	714	100	970	100	852	100

Table 4.38. Distribution of the number of cuttings by width and edging category for No. 1 Shop boards sawn with the three-stage process

Cutting Widths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%
1.5"	51.4	17.5	59.5	23.4	80.6	36.9	40.6	14.3	51.7	19.5
2.0"	73.3	25.0	88.1	34.7	104.8	48.0	75.3	26.3	79.0	29.7
2.5"	87.7	29.9	65.2	25.7	16.8	7.7	89.3	31.2	77.7	29.3
3.0	81.3	27.7	41.1	16.2	16.3	7.4	80.8	28.2	57.1	21.5
Total	293.7	100	253.9	100.0	218.5	100.0	286.4	100.0	265.5	100.0

Table 4.39. Distribution of cutting volume by width and edging category for No. 1 Shop boards sawn with the three-stage process

Cutting Widths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	#	%	#	%	#	%	#	%	#	%
1.5"	358	31.7	267	30.9	380	50.7	327	31.5	327	36.6
2.0"	352	31.2	325	37.6	293	39.1	361	34.8	265	29.7
2.5"	263	23.3	170	19.7	40	5.3	222	21.4	199	22.3
3.0"	156	13.8	103	11.9	37	4.9	127	12.2	102	11.4
Total	1129	100	865	100	750	100	1037	100	893	100

Table 4.40. Distribution of the number of cuttings by width and edging category for No. 2 Shop boards sawn with the three-stage process

Cutting Widths	Edging Practice									
	Unedged		Actual		Severe		Light		Conven.	
	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%	Vol. (bf)	%
1.5"	61.6	21.9	53.3	22.2	86.8	42.0	57.5	21.1	64.0	25.5
2.0"	81.6	29.0	89.3	37.2	90.3	43.7	88.3	32.5	75.9	30.2
2.5"	77.1	27.4	54.1	22.5	11.6	5.6	70.4	25.9	67.2	26.8
3.0	60.8	21.6	43.4	18.1	18.1	8.8	55.8	20.5	43.9	17.5
Total	281.1	100.0	240.1	100.0	206.8	100.0	272.0	100.0	251.0	100.0

Table 4.41. Distribution of cutting volume by width and edging category for No. 2 Shop boards sawn with the three-stage process

A cost analysis estimating the differential income related to the changes in drying, handling, and transporting costs and comparing them to the changes in cut stock and residue revenue was completed for the three-stage sawing process investigation. The differential costs and revenue are the same as in the two-stage sawing process investigation, with the exception of the revenue derived from the cut stock. The addition of the third stage resulted in an average of 8.42% increase in total cutting value. See Tables 4.42, 4.43, 4.44.

	Edging Practice				
Length	Unedged	Actual	Severe	Light	Conven.
<9"	19.60	6.59	6.99	12.80	23.33
9-24"	293.59	211.54	194.24	279.46	187.86
24-35"	218.33	178.36	161.89	213.44	202.99
35"+	226.64	289.98	285.02	241.77	285.61
Total	757.06	686.47	648.14	747.47	699.79
Total/Mbf	1413.66	1281.85	1210.28	1395.75	1306.72
Δcutting revenue per Mbf	131.81	0.00	(71.57)	113.90	24.87

Table 4.42. Dollar value of cuttings by length and edging category for Select boards sawn with the three-stage process

Length	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
<9"	23.52	10.80	6.33	16.25	11.93
9-24"	312.01	214.12	149.45	300.76	237.50
24-35"	180.83	197.85	184.00	184.50	184.28
35"+	136.46	163.59	173.05	148.29	179.88
Total	652.82	586.36	512.83	649.80	613.59
Total/Mbf	1337.86	1201.66	1050.97	1331.67	1257.46
Δcutting revenue per Mbf	136.20	0.00	(150.69)	130.01	55.80

Table 4.43. Dollar value of cuttings by length and edging category for No.1 Shop boards sawn with the three-stage process

Length	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
<9"	24.29	12.59	6.62	19.00	14.29
9-24"	318.61	246.01	180.12	308.67	229.29
24-35"	172.67	146.52	154.78	169.48	173.15
35"+	96.79	140.65	136.08	106.09	155.29
Total	612.36	545.77	470.98	603.24	572.02
Total/Mbf	1269.35	1131.32	976.29	1250.45	1185.73
Δcutting revenue per Mbf	138.03	0.00	(155.03)	119.13	54.41

Table 4.44. Dollar value of cuttings by length and edging category for No. 2 Shop boards sawn with the three-stage process

As was the case in the two-stage sawing process investigation, the light-edging practice displayed the highest differential income. See Tables 4.45, 4.46, 4.47.

	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
Gain in yield	131.80	0.00	(75.57)	113.91	21.85
Drying costs	(38.50)	0.00	5.50	(11.00)	(5.50)
Trucking costs	(42.00)	0.00	6.00	(12.00)	(6.00)
Handling costs	(10.75)	------	------	------	------
Loss in chip volume	(15.24)	0.00	(0.05)	(6.95)	(3.35)
Diff. Income	25.31	0.00	(64.12)	83.96	7.00

Table 4.45. Differential costs and revenue ($/Mbf) for Select boards sawn with the three-stage process

	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
Gain in yield	136.18	0.00	(150.68)	130.00	55.80
Drying costs	(38.50)	0.00	5.50	(11.00)	(5.50)
Trucking costs	(42.00)	0.00	6.00	(12.00)	(6.00)
Handling costs	(10.75)	------	------	------	------
Loss in chip volume	(14.62)	0.00	2.97	(6.60)	(2.00)
Diff. Income	30.31	0.00	(136.21)	100.40	42.30

Table 4.46. Differential costs and revenue ($/Mbf) for No. 1 Shop boards sawn with the three-stage process

	Edging Practice				
	Unedged	Actual	Severe	Light	Conven.
Gain in yield	138.04	0.00	(155.06)	119.04	54.42
Drying costs	(38.50)	0.00	5.50	(11.00)	(5.50)
Trucking costs	(42.00)	0.00	6.00	(12.00)	(6.00)
Handling costs	(10.75)	------	------	------	------
Loss in chip volume	(14.81)	0.00	2.98	(6.63)	(1.93)
Diff. Income	31.98	0.00	(140.58)	89.41	40.99

Table 4.47. Differential costs and revenue ($/Mbf) for No. 2 Shop boards sawn with the three-stage process

The results of the three-stage cost analysis are similar to the two-stage cost analysis in that the light-edging procedure is the most viable. The differential income from the light-edging practice with the three-stage sawing process is $83.96/Mbf to $100.40/Mbf as compared to the differential income range from the two-stage sawing process of $54.68/Mbf to $73.48/Mbf. As in the two-stage analysis, the difference in total value of the cuttings between the unedged and the light-edging was too small to offset the cost increases due to stacked volume.

It was assumed for the cost analysis that the operation already had a third-stage machine center. The cost of adding a machine center, and employing another worker was not considered.

5. CONCLUSIONS AND RECOMMENDATIONS

The main objective of this study was to determine the effect of edging on the yield of cut stock from red alder boards and to evaluate the effect of edging on the profitability of a vertically-integrated cut-stock producer. Five edging scenarios were simulated; Unedged, Actual, Severe, Light, and Conventional. Volume yields determined by the cut-up program CORY showed that the unedged material produced 18% more volume that severe, 12% more volume than actual, 9% more volume than conventional, and 4% more volume than the light. Economic evaluation shows that although the use of the unedged material was more profitable than the actual, the light-edging procedure was the most profitable. The light-edging procedure shows a differential income over actual that ranges from $54.68/Mbf to $73.48/Mbf depending on grade even when considering the additional costs of drying, trucking, and handling partially edged material.

An additional investigation was undertaken to evaluate the effect of edging on the yield of cut stock derived from the same database of red alder boards sawn with a three-stage cut-up process. The results were comparable to the two-stage analysis in that the yield of volume of the unedged material was 23.1% greater than severe, 13.8% greater than actual, 9.6% greater than conventional, and 3.0% greater than light. Economic evaluation showed again that the unedged procedure was more profitable than the actual procedure, but that the light-edging procedure was the most profitable. The light-edging procedure shows differential income over actual that ranges from $83.96/Mbf to $100.40/Mbf. It was also noted that the inclusion of the third-stage resulted in an increase in the number of wide cuttings, and a decrease in the number of long cuttings.

The results of this study show that there is a substantial opportunity for savings in the manufacture of cut stock from red alder boards by reducing the amount of wood removed at the edger station. Unfortunately, this opportunity is limited to those producers who are vertically integrated, or have made special arrangements for lumber transactions. Those companies that buy and sell standard grade lumber are unable to take advantage of the savings in money and wood. Given the present demand for lumber, and its relative scarcity, grading rules may at some point be modified to leave more wood for further processing.

As cited earlier, it has been noted that the current grade systems facilitate transactions between buyers and sellers but may lead to wood being used for less than its optimal economic purpose. To remedy this situation, Kline suggested the use of a "pencil grading" system where the location of the edger lines are marked, and the grade is established based on what the board would have been had it been sent through the edger. This approach may be too time consuming, so perhaps the board's grades should be established based on their highest potential. The boards used for this study were graded on their potential and not their actual characteristics. While this proved taxing on the graders, it seemed to produce accurate results. Further research should be done to evaluate the present grading system and the feasibility of using partially-edged lumber in non-vertically integrated operations.

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APPENDIX

A. Image System Accuracy Test

A random number generator was used to provide the coordinates of 50 points along the span of the track system. The points were located using rulers on the calibration board and an X-shaped target was placed at that point. The program TVIS (Track Vision) was used to measure the world coordinates of the target via the vision system. The coordinates (X_i, Y_i) supplied by TVIS were then compared to the coordinates (x_i, y_i) supplied by the number generator.

The average errors in X and in Y were computed by averaging the pairwise differences between the generated coordinates and those coordinates supplied by TVIS.

$$\overline{dX} = \sum_{n=1}^{50} \frac{(X_i - x_i)}{50} \quad (7.1)$$

$$\overline{dY} = \sum_{i=1}^{50} \frac{(Y_i - y_i)}{50} \quad (7.2)$$

The average errors in X and Y were computed as dX = 0.01 and dY = 0.05, respectively.

The root mean square errors in X and Y were computed by averaging the squares of the pairwise differences between the two coordinates then taking the squareroot of the result.

These RMS errors were $dX_{rms} = 0.03$ and $dY_{rms} = 0.08$.

The mean-adjusted RMS errors for X and Y were also calculated and are 0.03 and 0.07, respectively. The RMS errors were adjusted for the mean because board measurements are relative to one another and their absolute location is not known. To adjust for the mean in RMS, the following formulas were used:

$$dX_{rmsa}=\sqrt{\frac{1}{50}\sum (X_i-x_i-\overline{dX})^2} \quad (7.3)$$

$$dY_{rmsa}=\sqrt{\frac{1}{50}\sum (X_i-x_i-\overline{dY})^2} \quad (7.4)$$

The maximum X error was found to be 0.07 and the maximum Y error was found to be 0.18. The mean adjusted maximum errors for X and Y were 0.08 and 0.13, respectively.

Results from this test show that the accuracy of the track system is approximately 1/10". An approximation of accuracy is all the test will allow given the difficulty in placing the X-shaped target precisely at a specified location. There are no data obtained from this test that would help describe the repeatability of the system. It has been the experience of the researchers, however, that the track system is very repeatable.