1745

Optimization of Edging and Trimming Operations for Red Oak Lumber

by

Carmen de Castro Regalado

Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Master of Science

in

Forestry and Forest Products

APPROVED:

D. Earl Kline

D. Earl Kline, Chairperson

Eugene Wengert

Eugene M. Wengert

R. L. Youngs

Robert L. Youngs

Philip A. Araman

Philip A. Araman

January, 1991

Blacksburg, Virginia

c.2

LD
5655
V855
1991
R453
c.2

Optimization of Edging and Trimming Operations for Red Oak Lumber

by

Carmen de Castro Regalado
D. Earl Kline, Chairperson
Wood Science and Forest Products

(ABSTRACT)

This research project investigated the upgrading of edging and trimming operations for red oak lumber through computer-aided optimization. The main objective was to evaluate how lumber value recovered by actual hardwood operations compare with the maximum value obtainable through the optimization of edging and trimming.

An optimization procedure was developed involving the use of an iterative computer program for finding optimum edging and trimming solutions. The hardwood lumber grading program developed by Klinkhachorn et.al. [1988] was incorporated into the procedure. Comparison of results with actual values indicated that only 63% to 80%, approximately, of the maximum theoretical value was obtained in the sawmills studied.

Edging and trimming optimizing systems equipped with scanners that provide only wane information have been successfully applied in softwood lumber manufacturing. The second part of this study investigated the lumber value recovery that can be expected if a similar system were applied to hardwood edging and trimmming, i.e., if optimization were based only on wane input. Based on the output of a computer optimization program that maximizes volume yield subject to wane limitations, it was found that for red oak boards, an average value of approximately 80% of the optimum can be recovered through the application of this procedure.

Acknowledgements

Many thanks go to the following:

The members of my committee: Dr. Eugene Wengert, Dr. Robert Youngs, and Philip Araman for their very valuable advice;

Janice Wiedenbeck, Wenjie Lin, and Kenny Albert for their help in the data collection.

My advisor, Dr. D. Earl Kline, for his patience, support, and constant guidance from the start to the completion of this project;

My family: my parents and sister, and most especially my husband Levi, who, for being so supportive and understanding, deserves half the credit in everything I accomplish;

The Lord, for things too many to enumerate.

Table of Contents

List of Illustrations

List of Tables

Chapter 1

INTRODUCTION

The increasing cost and limited supply of high quality logs has been making lumber manufacturers realize the need to optimize the utilization of this raw material. According to Williston [1979], processing areas where the opportunity exists to increase profits through optimization are harvesting, log trimming, sawing at the headrig, board edging and trimming, and kiln-drying. Studies have revealed that in some mills, at least 45% of a log's original volume are converted to chips from slabs and edgings [Williston, 1979], and that possible losses in lumber value due to overedging could be as much as 30% [Bousquet, 1989]. Findings such as these identified the edging operation as a high-potential opportunity area. Upgrading the edging operation would also involve optimization of a closely-related lumber processing operation, i.e., board trimming.

Optimization in most industrial applications involves some degree of automation. While computer automation in processing is not new in the softwood lumber industry, the same can not be said of most hardwood mills. One reason often cited for the lack of adoption in hardwood mills is that unlike softwood, the volume of production in a typical hardwood mill is not large enough to economically justify the investment entailed by automation. Recent studies, however, show a consistent upward trend in the volume of hardwood lumber production within the last eight or nine years [Araman,1990]. Whether or not this trend continues, getting the most value out of a limited resource is of utmost importance for an industry where raw material has the highest contribution to manufacturing cost.

This research project focuses on the optimization of edging and trimming operations in hardwood sawmills. The main question addressed is "Are present edging and trimming practices in hardwood sawmills close to the optimum or can substantial gains in value be made through edging and trimming optimization?" The approach of this research is to evaluate the performance of actual edging and trimming by determining the difference between maximum obtainable lumber value and actual sawmill output. In other words, how much room for improvement is there in hardwood edging and trimming operations?

Since the development of a new optimization system would involve substantial investment, it is worthwhile to investigate if benefits can be obtained from an already existing system. Edger and trimmer optimizing systems have been commercially available for over 10 years and are successfully applied in many softwood mills. However, unlike softwood construction lumber manufacturing where value is often synonymous with volume, hardwood lumber value is a balance between volume and grade. Thus, an edger/trimmer optimizing system for hardwood lumber processing may conceivably differ from that for softwood. Another relevant task, therefore, is to determine if and how well can the present level of optimizing technology (as represented by edger/trimmer optimizers used in softwood manufacturing) upgrade hardwood edging and trimming operations. The evaluation of such a system is the second problem addressed in this project.

Chapter 2

OBJECTIVES AND LIMITATIONS

Before the development and adoption of an automatic system for upgrading hardwood edging and trimming operations, the capability of present conventional systems must be evaluated. This evaluation, which would serve to establish the potential improvement in lumber value obtainable through edging and trimming optimization, is the primary objective of this research. The general approach taken to accomplish this objective was to obtain a sample of unedged and untrimmed boards from hardwood mills, use a computer procedure to estimate optimum edging and trimming solutions for the sample, and compare the lumber value yielded by the optimization procedure to that actually recovered by the sawmills from the same boards.

OBJECTIVES:

The specific objectives of the research project are:

A. To develop a general procedure for estimating the optimum edging and trimming solutions for unedged and untrimmed boards.

B. To determine the difference between lumber value obtained with optimal edging and trimming of boards, and that obtained in actual sawmill operations. Along with this objective, it is also the aim of this research to determine what edging and trimming errors mainly contribute to the difference between optimum and actual lumber values.

C. To compare lumber value obtainable from the optimization of edging only to that resulting from a procedure in which only trimming is optimized.

D. To determine the difference between lumber value obtained with optimal edging and trimming, and lumber value obtained using a procedure in which edging and trimming solutions are based only on estimates of potential grade and wane measured at three-inch intervals. Wane-based cutting solutions represent the capability of currently available edger/trimmer optimizing systems.

LIMITATIONS AND GENERAL ASSUMPTIONS:

The following define the limits of the study. Results and conclusions have to be interpreted within the context of these assumptions and limitations:

A. The study was limited to 4/4 red oak.

B. The three sawmills from which data for the study were collected are all in the Virginia Appalachian area and may or may not be representative of all hardwood mills in the U.S..

C. The grading rules of the National Hardwood Lumber Association (NHLA), especially with regard to wane, were strictly followed whether or not the amount of wane permitted by these rules is acceptable from a merchandising standpoint.

D. Because the sawmills in the study use the Firsts and Seconds One Face (FAS 1 Face) grade, this grade was used in the analysis instead of the alternate grade of Selects.

E. The 50-50% wane rule recommended for well-manufactured lumber [Malcolm, 196 ;Petro, 1982] was used to define the maximum permissible amount of wane for Common grade boards.

Chapter 3

LITERATURE REVIEW

CURRENT EDGER AND TRIMMER OPTIMIZING SYSTEMS

As mentioned in the introduction, edger and trimmer optimizers are already in use in the softwood lumber industry. The following are the three basic components of an edger/trimmer optimizing system:

A. the scanner for flitch data acquisition

B. the decision-making portion

C. the mechanical means to carry out the solution

A. The scanner

There are two general types of scanning mechanisms used in today's modern mills: optical and mechanical. A simplified discussion of each type follows:

Optical Systems:

The simplest optical sensing mechanism is the interruption of the light path between a source and a detector to detect the position of the edge of an object [Browne and Norton-Wayne,1986]. In sawmill applications, this is referred to as the crossed-beam technique,shown in figure 1 [Source: Maxey,1979]. As the piece moves through the system, the forward edge of the wider face blocks one beam. Subsequently, the other beam is broken by one edge of the narrow face. With encoders synchronized with the movement of the conveyor, the width of both faces of the flitch are determined by using a mathematical relationship among the following variables: 1) the distance the board has travelled within the time between interruptions of the two light beams, 2) the angle of the beams, and 3) board thickness [Maxey,1979;Price, 1979].

Another optical scanning method applied in the sawmill is optical proximity scanning technique. Thes system employs a light source, light pipe and photodetector assembly to provide proximity information by transmission and reflectance [Dessy,1983]. Light beams are broken by the scanned object and the resulting scattered light is then received by the detector. The signals received diminish as the light spot on the piece moves away from the view of the detector [Browne and Norton-Wayne,1986]. Thus a cross-section of the waney-edged flitch is traced as it moves though the beam since the distance of the light spot from the detector is a function of the shape of the surface interrupting the light beam. Edger optimizers use either a pair or two pairs of beams for this scanning technique. Two pairs of beams at each scan line result in a two-plane scan which also yields thickness data. In the two-beam approach, thickness information is required from some other source [Grove, 1983].

A third type of optical scanning method applied in edging and trimming optimizers is the camera technique in which an image of the scene being scanned is formed within the optoelectronic converter. The basic elements are a light source, an array of sensors, and a lens system for imaging the scene being scanned onto the sensor array [Browne,1986;Price,1979]. Figure 2 shows a schematic diagram of the system. The light sensitive element of the sensor is a photodiode array. The system works through illumination contrast. Two sets of lights on each side of the flitch are

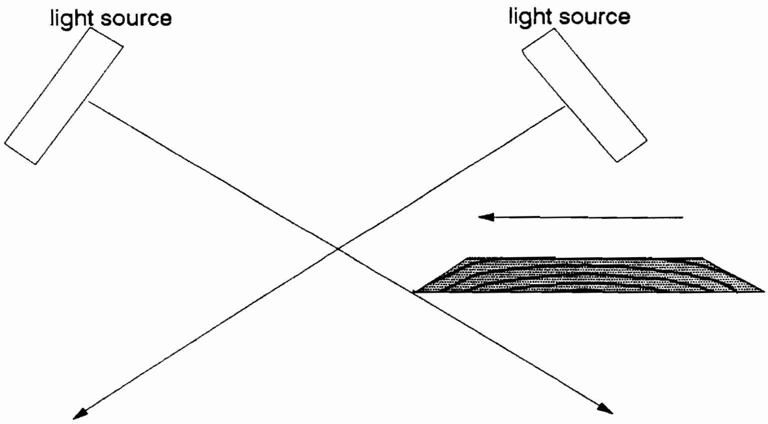


Fig. 1. Schematic diagram of crossed-beam technique for board scanning.

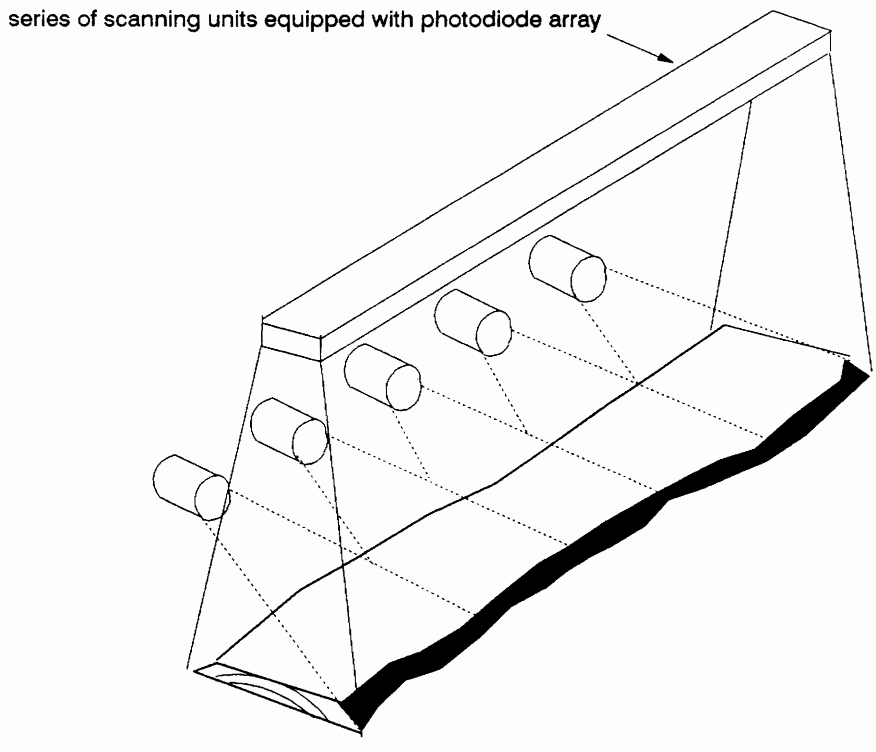


Fig. 2. Shadowing technique for wane detection.

mounted at low angles with respect to the plane of the board. When one set of lights comes on, the top of the flitch and the waney edge nearest the piece are brightly illuminated, contrasting with the opposite edge which is in shadow. Each linear scan across a flitch section provides a binary form of information based on light intensity reflected from the flitch. In other words, the information is simplified to a two-level gray scale: the illuminated part vs. the shadowed portion. The mirror in the scanner is then stepped so that the photodiode array is exposed to the flitch image at a regularly spaced interval, four to six inches typically. In this system, the board is stationary while being scanned. Top and bottom profiles are obtained but thickness has to be measured by other means.

Mechanical System:

The mechanical scanning system most commonly used is the pneumatic proximity scanner [Price, 1979]. The principle behind this technique has some similarities with optical proximity scanning. Instead of reflected light indicating the position of the scanned piece, the pneumatic scanner detects the nearness of the piece by changes in air pressure. The main elements of this scanning system are two concentric pressure tubes. When a board passes beneath the sensor, the pressure relationship between the two tubes changes, depending on the nearness of the surface of the board.Thus the exact width of the top surface is determined. An identical sensor has to be located at the bottom face of the flitch to get a complete description of cross-section profile. One pair of top and bottom sensors is needed for each scan line. Distance between scan lines may be as close as four inches [Price,1979;Browne and Norton-Wayne,1986].

One thing the above scanners have in common is that they only provide board dimension and wane information. This level of scanning capability has been available since the 1970's and is still the kind currently used in the lumber industry. Other scanning methods that are being studied for use in log and lumber processing include ultrasonic, x-ray, microwave and computer vision techniques [Szymani and McDonald, 1981;Conners et. al.,1989].

B. The Decision Model

The part of an optimizing system that processes information to arrive at the optimum decision is typically in the form of a computer program written for the specific requirements of the given problem. Examples are the the Best-Opening-Face (BOF) program for log breakdown [Hallock and Lewis,1971] and OPTYLD for maximizing cutting yields in the rough mill [Giese and McDonald,1982]. For edging and trimming, the software may be programmed to maximize yield recovery or to maximize lumber value in dollars. If the latter is the objective of optimization, information other than flitch data are required: grading rules and prevalent market prices have to be incorporated into the program. Most if not all available software use heuristic methods in arriving at the optimum solution [Price, 1979]. A number of potential solutions are generated and the one that yields the maximum volume (or value) is the optimum.

C. Mechanical Actuators of the Optimum Solution

Computerized optimizing systems can be limited in the effectiveness of their application by the capabilities at the machine centers to accurately execute the optimum solution. This problem is overcome in sawmilling operations by the development of hydraulic linear positioners [Grove,1983;Franklin and Koenigsberg,1982]. The device combines the precision of computer control and the speed and power of hydraulic cylinder positioners. Franklin and Koenigsberg estimate the precision of these setworks to be 0.005" at worst.

Programmable controllers have found wide application as an interface between the computer and the machine center [Grove, 1983]. Instead of totally relying on computer software for machine control logic, some functions such as sequencing of operations, timing of gates, and setworks control may be assigned to the programmable controller.

To summarize, several parameters determine the usefulness and effectiveness of each of the above optimizing system components. For the scanner, it is the accuracy and quantity of information provided. For the decision model, it is the number of relevant factors it takes into consideration when deciding on the best solution. If the optimization routine is heuristic in nature, the capability to generate a large number of potential solutions from which to select the optimum and to execute the same at a reasonable speed are an advantage. How well the entire system performs in current applications is discussed in the next section.

APPLICATIONS IN SOFTWOOD LUMBER MANUFACTURING: Manual vs. Optimized Edging and Trimming

Yield studies in softwood mills have indicated the need to increase recovery through better processing methods. A study in a Pacific Northwest fir mill showed that only 40% of the original log volume was converted to finished kiln-dried lumber, 46% went to chips from slabs and edgings [Williston, 1979]. In another mill processing small southern yellow pine logs, chips constituted 49% of the total production output. Of this 49%, 44% came from slabs and edgings [Williston,1979]. Such figures indicate that the headrig and the edger are areas where the opportunity exists to upgrade profits by increasing lumber recovery and reducing the production of chips, a low value product. The headrig opportunity is already widely recognized. In more recent years the attention of softwood lumber manufacturers has turned to the optimization of edging and trimming.

Values of 65% and 85% were cited when referring to the lumber recovery capability of manually operated edgers [Pease,1980; Price,1979; Grove,1983]. Under normal mill operating pressures, recovery fell as low as 65%. The higher value was attributed to test data obtained under controlled conditions when the edger operator was aware of the testing procedure.

Before installing an edger optimizing system in a stud mill in British Columbia, Pease and Co. [Pease,1980] made their own estimate of potential loss incurred by manual edging as compared to maximum theoretical recovery. Each unedged flitch was evaluated by making a judgement, based on the mill's cutting patterns, of the piece's likelihood of being misedged and the probable consequence of misedging. The estimates were applied to two log distribution samples. Results indicated that an average loss of 17% (or a recovery of 83%) could be expected from manual edging in this particular mill.

As for manual trimming, a study made in a southern yellow pine mill revealed a 92.5% recovery given correct edging [Grove, 1983].

The following are some of the factors believed to influence the relatively poor performance of manually operated edgers and trimmers [Bennett,1978].

1. Operator skill
2. Operator fatigue
3. Machine variables (type, maintenance condition)
4. Quality of raw material
5. Processing rate

The last two factors also directly affect the operator. It is not humanly possible to make the best cutting decisions 100% of the time on low quality wood at a high production rate.

Whether in the testing stage or used in actual operation, currently installed edger and trimmer optimizers have been reported to get a high percentage of maximum theoretical recovery. Maximum theoretical recovery is that value obtainable from a board through careful analysis by an experienced grader using a template and given unlimited time. Price [1979] gave an estimate of 90% to 97 % recovery for an edger optimizer. In a series of tests conducted by the Swedish Wood Research Institute, the generalized results indicate that minimum average recovery obtained with optimized edging was 95% of the optimum [Pease,1980].

An article published in the July,1977 issue of World Wood [Anon.,1978] reported on a test run of an edger optimizer installation in one of the larger forest products companies in Sweden. The system employed the crossed-beam technique of optical scanning using infra-red light . The computer could be instructed to either maximize yield or maximize revenue. Processing rate was high --- scanning, computing and giving instructions to the mechanical alignment system was all completed in less than 2 seconds. When boards were randomly selected and checked for results, an average of 94% of theoretical recovery was obtained when the system was programmed for yield maximization.

An even more encouraging result was found when a similar test was performed in a Weyerhauser mill [Bennett,1978]. The mill's automated edging system employed the shadowing technique of optical scanning technique discussed in earlier. All feed systems were computer-controlled. With 200 test boards, it was found that the edging system was able to capture 100% of the theoretical maximum yield.

The performance of a semi-automated trimmer optimizer was discussed by Ailport [1983]. In this system, one end of a board was manually trimmed while the trim line for the other end was computer-determined. A 2-ft. scanning interval was used. Aside from a 5% increase in lumber recovery, a faster rate of processing was achieved at the trimmer. The optimizer system also provided information for quality control purposes.

DEVELOPMENTS IN HARDWOOD EDGING AND TRIMMING

For various reasons, the hardwood lumber industry has been slow to adopt computer and automation technology in its operations. However, the need to keep up with increasing demands in productivity and lumber recovery and the success of computer applications in the softwood industry necessitate a review of current manufacturing practices.

Bousquet [1989] emphasized some important points on the subject of hardwood edging. Table 1 shows the result of his study conducted in a northeastern hardwood mill producing 2.5 million board ft. annually. Two hundred unedged and untrimmed 4/4 boards were pulled from the production line. Each board was manually analyzed and the maximum potential lumber value and footage for each was determined. Finding the optimum edging and trimming cuts allowed for ripping and cross-cutting where these could further increase the board's value. Calculation of results shows that actual value recovered was only 83% of maximum potential, a difference of 17%. In this mill, approximately 42% of all lumber being sawn at the time of the study was edged.

In another study, the effect of different edging practices on the value of hard maple boards was investigated [Flann and Lamb, 1966; Bousquet,1989]. Edging was categorized into four classes: 1) severe, the practice of edging away too much wood; 2) wide or underedging; 3) conventional,

Table 1. Potential dollar increase obtainable from correct edging and trimming.

Volume	Potential Recovery	Actual Recovery
Total	1,200 b.f.	1,040 b.f.
Face and Better	410	210
Common Grade	790	830
Revenue	$ 396	$330

Source: Bousquet [1989].

Table 2. Effect of edging practice on the value of hard maple boards.

Edging Practice	No. of Boards	Ave. Surface Measure	Total $ Value
Conventional	390	5.9	778
Severe	390	4.6	598
Wide	390	6.2	537
Optimum	450	4.8	858

Source: Bousquet [1989]; Flann and Lamb [1966].

which follows the 50-50% edging rule[1]; and 4) optimum. The last category allowed for ripping and cross-cutting. All test boards graded No.1 Common if edged and trimmed the "conventional" way. Values of these same boards if edged according to the other edging categories are shown in Table 2. None of the boards actually went through the edger and trimmer. The price of No.1 Common hard maple used in these calculations was $340. Bousquet [1989] noted that the usual practice in many hardwood mills is closer to the severe approach. Thus, using the results obtained in this study as the basis, the loss in dollar value for hard maple could be as much as 30%. Bousquet attributed this loss to the following edging errors:

1. Overedging, the most commonly observed error;
2. Underedging;
3. Incorrect edging for grade;
4. Improper alignment of board through edger saws;
5. Errors in tradeoff decisions between width and length;
6. Failing to inspect both faces of a board prior to edging.

Recognizing the need for improvement, a few hardwood mills have taken steps from training operators to installing computer-controlled equipment. One example is a sawmill in Louisiana which recently upgraded its equipment starting from an optimization package at the headrig to an automated lumber stacker at the end of the manufacturing sequence [Griffin,1989]. The new edging optimizer system starts with an optical laser scanner scanning at three-inch intervals. Solutions are run by a 32-bit microcomputer and control functions are handled by a programmable controller. Since the scanner provides only wane data, operator input is required to arrive at the complete

---

1 Refer to Flann and Lamb, 1966.

sawing solution. The amount of permissible wane for each lumber grade serves as the decision parameter for setting the two outside saws of the four-saw edger. The position of the middle saws are determined by the operator should he/she decide to make a two- or three-piece solution. Trimming decisions are still manually determined.

As illustrated in the above sawmill example, there is still a very limited degree of automation in hardwood edging and trimming operations. Thus, errors associated with human limitations are still present even in the more modern hardwood mills. Such will be the case until an optimizing system tailored to the particular requirements of hardwood lumber manufacturing becomes available. Current research efforts are directed towards this goal.

The development of a computer vision system for defect detection is underway [Conners,Cho and Araman,1989]. The aim is to identify the type and locate the boundaries of all defects pertinent to lumber grading. Unlike softwood edging and trimming problems, finding the optimum cutting solution for hardwood boards requires more than wane and dimension information.

A computer program for grading boards based on National Hardwood Lumber Association (NHLA) rules was developed by Klinkhachorn et. al. [1988]. The program accepts data in the form of rectangular coordinates enclosing the defects periphery. This program provides improvement over previously written grading programs in at least two aspects: 1) exceptions to the standard grading rules (e.g. species-related exceptions) are more easily accomodated into the program code, and 2) both faces of a flitch are considered in assigning the grade, as is done in actual lumber grading [Klinkhachorn et. al.,1988]. Currently, the program's industrial applicability is being enhanced further by increasing processing speed and making defect presentation more accurate than the current rectangular shape [Araman,1990].

Aside from automatic grading of processed lumber, another application of a computer grading program is as a component of an optimization software for maximizing board value. HaRem, an expert systems program developed by Schwehm et. al. [1990] is one such software. The program name is an acronym for Hardwood Lumber Remanufacturing. Using grade and current market prices as parameters, the program determines if a processed board's dollar value can be increased by further edging and trimming. Program logic for finding the optimum amount of wood to edge and trim follows heuristic rules involving current grade and defect size and location. The grading program by Klinkhachorn is used for determining board grades.

Due to technological and economic limitations, it may be that the actual application in the hardwood industry of a fully developed edger/trimmer optimizing system will not be in the near future. A fully developed system in this context refers to one that has the ability to obtain and utilize **all** relevant input information, generate the **true** optimum solution, and execute these at **production speeds**. Meanwhile, other simpler and more feasible systems have to be considered. Prior to evaluating these alternative systems, it is first important to determine the maximum potential improvement that can be expected in upgrading current hardwood edging and trimming operations.

Chapter 4

METHODS AND MATERIALS

DATA COLLECTION

Three sawmills in the southwestern part of Virginia were selected for the study. Sawmill A is a family-owned mill producing 3 to 5 million board feet per year. Sawmill B is one of the mills of a comparatively large lumber corporation. This particular mill has an annual production of between 5 to 10 million board feet. In sawmill C, 2 to 3 million board feet per year is produced, including a significant volume of pine lumber. Red oak is a major species in all three sawmills.

Data collection was divided into the following phases: 1) obtaining board samples from the sawmills, and 2) digitizing the board images collected.

A. **Data Collection at the Sawmill**

The first phase consisted of pulling 40 unedged/untrimmed boards from the production line, tracing the image of each board on a transparent polyethylene plastic sheet, and returning these boards into the production line to be edged and trimmed. Boards included in the sample were 4/4 red oak pieces of varying lengths and with at least one unedged side. For the purposes of this study, data giving a complete description of the appearance of each board was required. This included board cross-section profile and the size, location, and type of all defects present.

One problem usually encountered when using green boards as specimens is that drying, which occurs during prolonged exposure, is usually accompanied by the appearance of new defects such as checks and end splits. Obtaining the required data directly off the boards could take a considerable amount of time during which board degradation due to drying could occur. This problem was circumvented by tracing the image of the board on clear plastic sheets without measuring dimensions and coordinates. This procedure considerably shortened the time between getting the board from the headrig and returning it to the production line for edging and trimming. Figure 3a shows a diagram of the procedure. A sheet of 1.5' x 13' clear plastic was laid over each board, supported by a 3/8" thick glass sheet. Defects appearing on the face of the board were traced, as well as the outline of the top and bottom edges. Defects were labelled according to the following code:

1 - Stain	6 - Split or shake
2 - Check	7 - Pith
3 - Sound knot	8 - Hole
4 - Unsound knot	9 - Decay
5 - Wane	

The above coding system was based on the codes used in Klinkhachorn's [1988] lumber grading program. Bark pocket, a type of defect frequently encountered with the boards tested, was classified under decay. Both the wide and narrow faces of a board were traced on the same plastic sheet. Defects on the opposite face were drawn as if looking through a transparent board. The result was a two-dimensional image in which defects in the narrow face were distinguished from those on the opposite face by color-coding. The board was then labelled with an identification number, with a corresponding identification number on the plastic sheet.

After completion of a drawing, each board was returned to be edged and trimmed. After these processing steps, the board was again retrieved and the place where it was actually cut was marked on the plastic sheet. A diagram showing an example of a completed drawing is shown in figure 3b.

DATA COLLECTION:

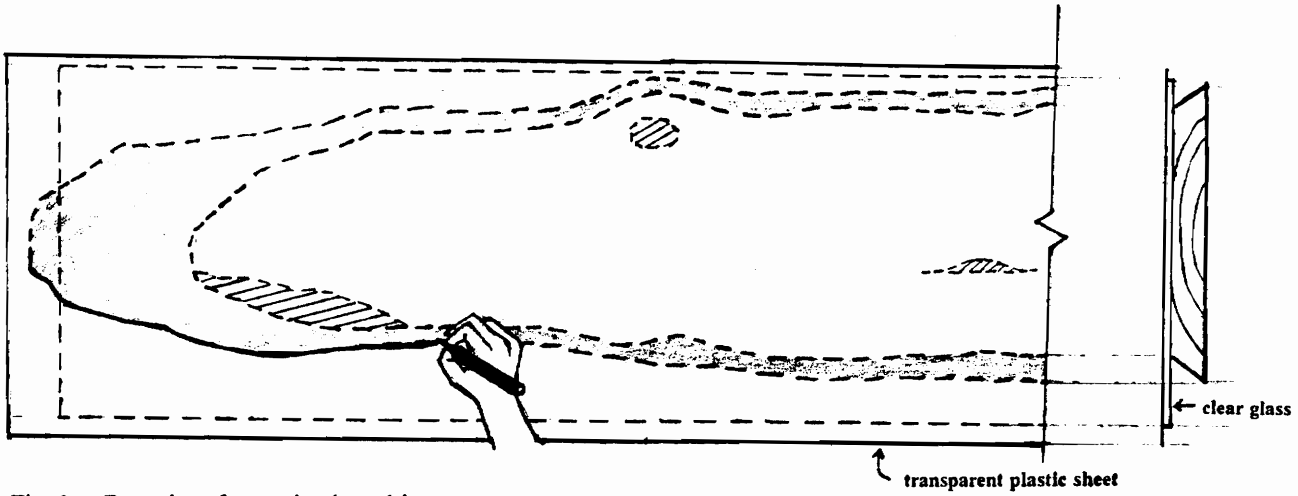


Fig. 3a. Procedure for tracing board image.

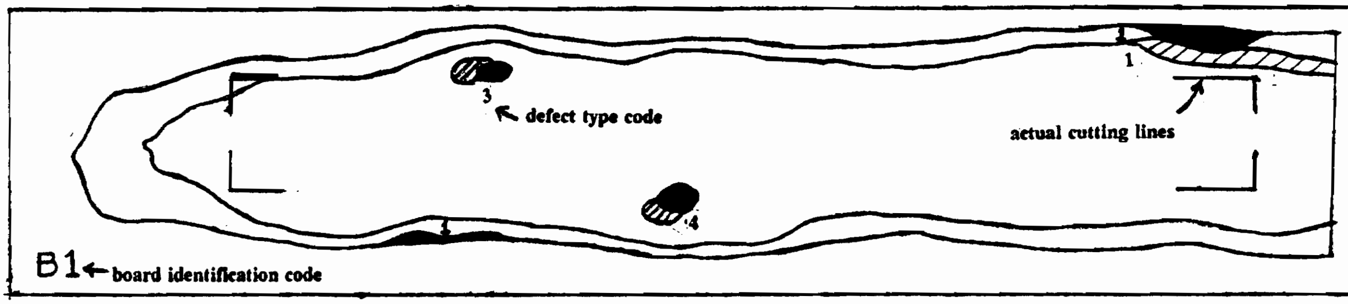


Fig. 3b. Completed board diagram. Darkly-shaded defects are those on the back face of the board (Face 1).

B. Digitizing Board Images

Measuring and recording the coordinates defining the outline of the edges of a board and all defects on it was the second phase of data collection. Each drawing was laid over a calibrated grid with the lower left corner designated as (0,0). The coordinates of the sides of the rectangular box enclosing each defect were recorded, as well as the defect type and the face of the board on which it appeared. The narrow (or waney) face of the board was coded as Face 0 and the wider face as Face 1. These data correspond to the required input information to Klinkhachorn's [1988] lumber grading computer program which was used later in optimization. Dimensions were rounded off to the nearest quarter inch. Inconspicuous pin knots were ignored unless there were several clustered together.

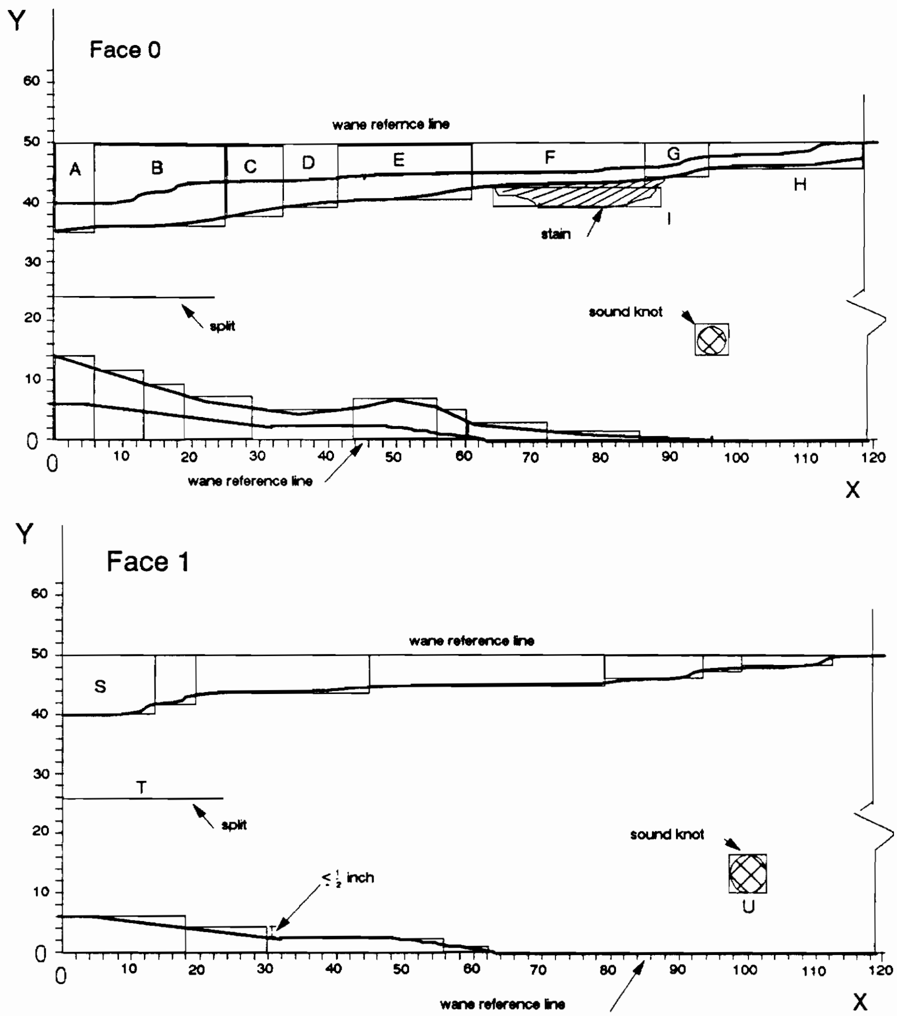
Wane (or board edge) coordinates required special handling. Lines parallel to the longitudinal axis of a board and running through the outermost points of the wider face served as temporary reference lines and defined the outer side of the rectangles enclosing wane regions. Thus, wane width was measured as the distance between a board edge and the nearest reference line. Later in the analysis, edging lines were substituted in place of these reference lines as the outside boundaries of the rectangular areas enclosing wane. As with other large defects, several rectangles were used to define the shape of wane. These rectangles were made as close as possible to the actual wane outline, i.e., as close as the quarter inch resolution would allow. In regions of sloping wane, no point of the enclosing rectangle was allowed to deviate from the actual edge outline by more than 1/2 inch. (Note: No adjustment was made for wane that would be eliminated when surfacing to standard thickness).

Figure 4 illustrates the digitization procedure used. A sample segment of a board with both faces shown are accompanied by a table containing the data describing the board segment. For this sample board, wane reference lines are the horizontal lines y = 50 and y = 0 (the X-axis). Wane regions are represented by a series of rectangles. The variables defining rectangular defect regions are X1 and X2, the x-coordinates of the left and right sides, respectively, of the rectangle; and Y1 and Y2, the y-coordinates of the bottom and top sides of the rectangular defect region. Wane is the space between a reference line and the adjacent wood. Thus, the first wane region on Face 0 labelled as defect A has a wane width of 15 quarter inches (Y2 - Y1), and is directly opposite wane segment S on Face 1, which has a wane width of 10 quarter inches. This method of wane width measurement was used used only for raw data collection to describe the unprocessed board. To illustrate how wane was measured during analysis, the placement of an edging line with a y-coordinate of 38 would leave a 3-quarter inch wane on the upper edge of Face 0 in the region x = 0 to x = 6, while cutting away all wane on the same region on Face 1.

OPTIMIZATION PROCEDURE

A. General Procedure

The task of finding the optimum edging and trimming solution for an unprocessed board was accomplished in earlier studies by visual examination of the board by an experienced grader. In this study, the optimization procedure was executed by a computer. The use of a computer for this task had the advantages of accuracy and consistency. Decisions were always based on the same guidelines, so that variation in the factors affecting optimum decisions which might be expected from one human grader to another (or from the same grader at different times) were



Data:

Defect Label	X1	Y1	X2	Y2	Defect Code	Face
A	0	35	6	50	5	0
B	6	36	25	50	5	0
C	25	38	33	50	5	0
D	33	40	42	50	5	0
E	42	41	60	50	5	0
F	60	42	86	50	5	0
G	86	43	95	50	5	0
H	95	45	119	50	5	0
I	64	39	38	42	1	0
.						
.						
.						
S	0	40	14	50	5	1
T	0	26	24	26	6	1
U	98	11	103	16	3	1

1 unit = 0.25 inch

Fig. 4. Procedure for digitizing board image.

avoided. Another advantage was the computer's ability to consider numerous cutting options from which to choose the optimum.

The algorithm for finding the optimum cutting solution was an iterative one in which the cutting line for each of the four sides of a board was made to vary within specified limits. The general algorithm is summarized in Fig. 5. Variables in the flowchart shown in Fig. 5 are defined in Table 3.

The procedure started with information input. Two types of data were required: 1) data describing the unprocessed board and 2) the coordinates of the limits for varying edging and trimming lines. Guidelines for determining these limits are discussed in the next section. These data were were fed into a computer program (program name: CUTCOMB.EXE, language: Microsoft FORTRAN)[2] whose function was to decide, for each cutting combination, which defects had been edged or trimmed away, which defects remained on the board, and the new coordinates of each remaining defect relative to the current edging and trimming lines. Edging and trimming line coordinates were initially set at the lowest values in the range of cutting line variation. Edging lines were varied using quarter inch increments. For trimming variation, half-foot increments were used. Thus, if there were n_i increments between the cutting limits on side i of a board, there would be a total of (n_1 x n_2 x n_3 x n_4) cutting combinations considered. The output of the iteration program CUTCOMB was data describing the lumber produced by each cutting combination. This output was saved in a file using the format accepted by Klinkhachorn's [1988] lumber grading program. The latter program yielded surface measure and lumber grade for each iteration. The set of cutting lines producing the combination of grade and volume with the highest dollar value was the optimum

---

2 See Appendix A.

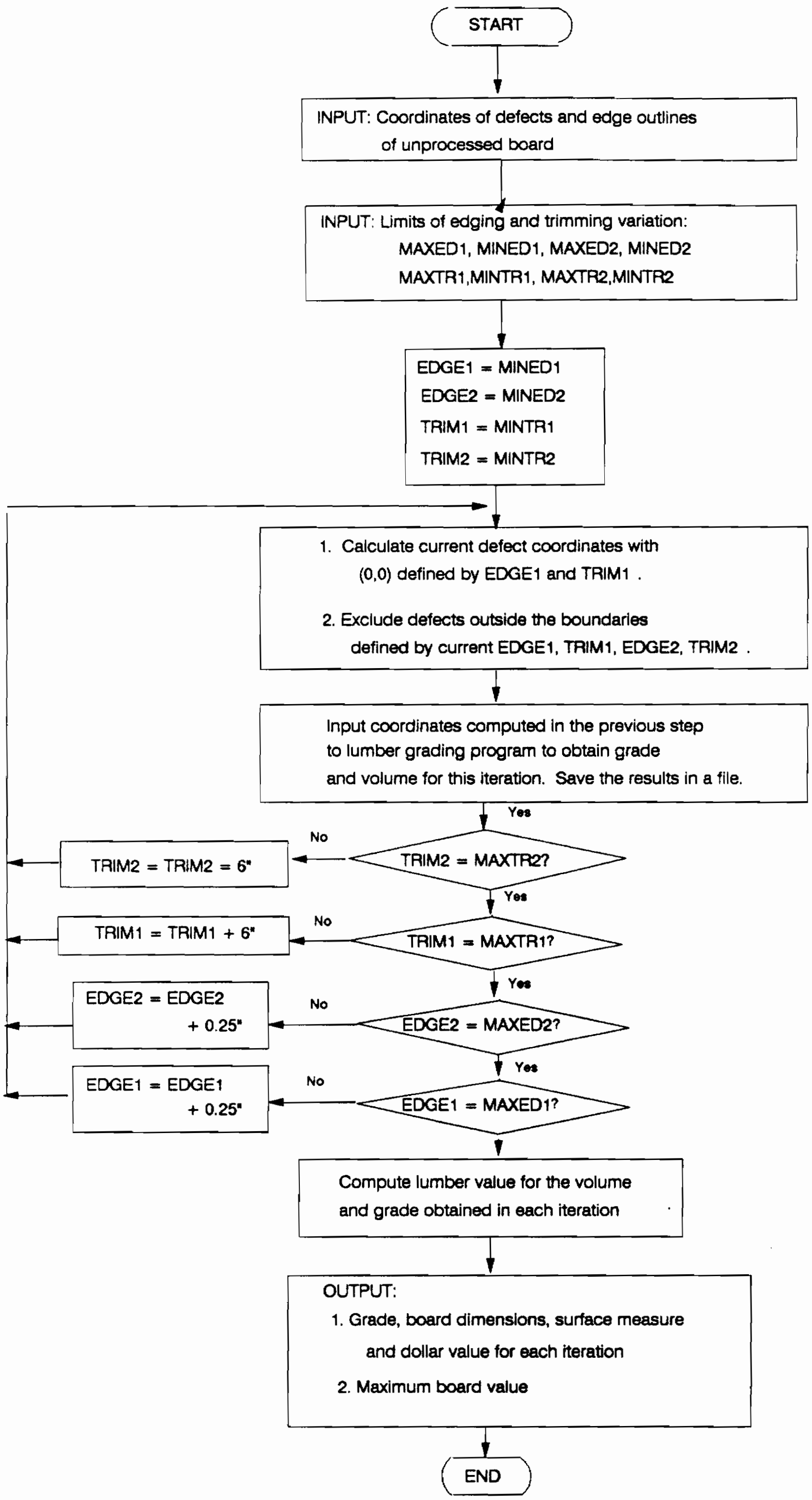


Figure 5. Algorithm for finding optimum cutting solution.

Table 3. Definition of variables in the optimization algorithm.

EDGE1	=	Y-coordinate of lower edging line currently under investigation
EDGE2	=	Y-coordinate of current upper edging line.
MAXED1	=	inner limit of edging variation for EDGE1.
MINED1	=	outer limit of edging variation for EDGE1.
MAXED2	=	outer limit of edging variation for EDGE2.
MINED2	=	inner limit of edging variation for EDGE2.
TRIM1	=	X-coordinate of current left trimming line.
TRIM2	=	X-coordinate of current right trimming line.
MAXTR1	=	inner limit of trimming variation for TRIM1.
MINTR2	=	outer limit of trimming variation for TRIM1.
MAXTR2	=	outer limit of trimming variation for TRIM2.
MINTR2	=	inner limit of trimming variation for TRIM2.

cutting solution. It should be noted that although there was a unique combination of optimum grade and volume for each board, there could be more than one set of cutting lines that could result in this particular grade/volume combination.

B. Guidelines for Determining Limits of Cutting Variation

Figure 6 shows the limits of variation in the edging and trimming lines. Several guidelines were used in setting these limits:

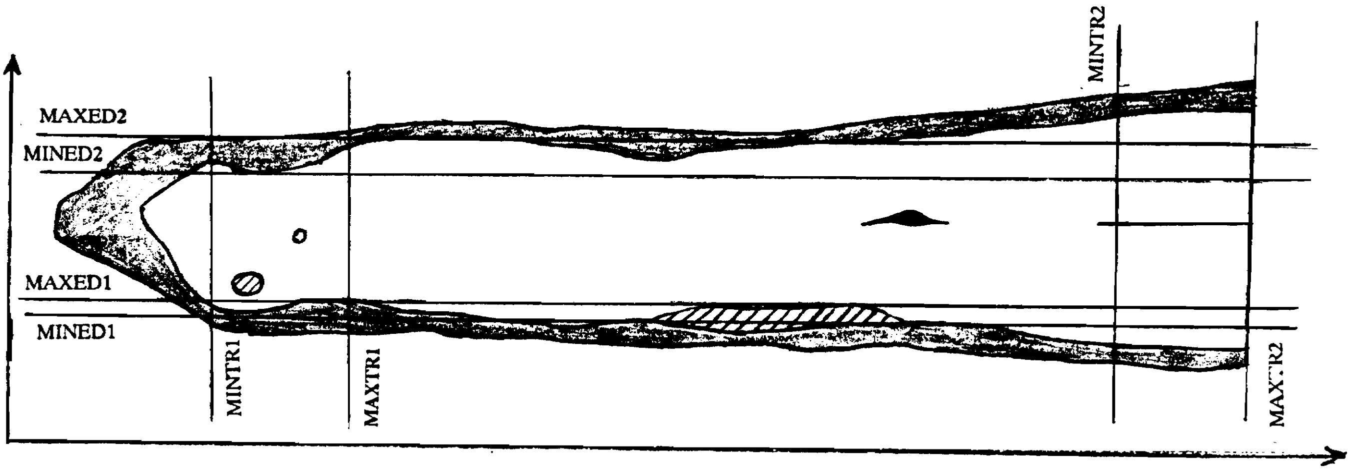
1. Outer edging limits (MINED1 and MAXED2) were determined by the so-called 50-50% edging rule for proper lumber manufacturing [F.J. Petro, 1982]. With this rule, sawlines were located such that the area of wane left on the board was approximately equal to the area of clear wood edged away. In a few cases where such placement of edging lines left wane on the board that was less than the maximum permissible amount for the FAS grade, the maximum wane rule for this grade was used in setting the outer edging line.

2. Some degree of subjectivity and judgement were involved in setting MAXED1 and MINED2 (i.e. the inner edging limits). For flitches which could potentially yield FAS or FAS one-face lumber based on their appearance, inner edging limits were placed such that edge defects (commonly wane and stain) were largely eliminated. More defects were allowed to remain in lower quality boards. For some boards, following the above guidelines could result to an extremely large number of iterations which would have greatly increased computing time. In these cases, if the only edge defect was wane, the inner edging limit was set so that the wane left on the board was just enough to satisfy the maximum allowable amount for the FAS grade.

3. At each end of a board, the outermost trim line MINTR1 or MAXTR2 was set at the farthest section where a full width square end could be produced if the board were trimmed at this section.

4. Inner limits for trimming line variation (MAXTR1 and MINTR2) depended on the location and size of splits, stain, decay areas, and other defects that typically appear within the vicinity of the ends of an untrimmed board. These limits were placed so as to trim off all end defects. However, regardless of end defects present, it was decided that inner trim lines were not to be

Fig. 6. Limits for varying edging and trimming lines to search for optimum cutting solution.



allowed to vary from the outer trim limits by more than 3 feet. The latter was a rule of thumb adopted to cut down the number of iterations. In all cases encountered, the ranges of trimming variation required to cover all end defects were less than this 3 feet limit.

The edging and trimming boundaries discussed above were determined visually from board diagrams on plastic sheets. These were supplied to the iteration program CUTCOMB along with data describing the unprocessed board. The purpose of setting such limits was to minimize the number of iterations while covering the range where the optimum solution was most likely to be found. Although it was not actually done in the optimization procedure, it is possible to incorporate the above guidelines into the program CUTCOMB so that the cutting limits are determined within the program.

C. Cross-cutting and Ripping

Cross-cutting and ripping were allowed in cases where these operations were thought to possibly improve lumber value beyond that obtainable from the general iterative procedure discussed earlier. The extent to which cross-cutting or ripping were done was such that at most two lumber pieces were produced from one waney-edged board. In general, these operations were applied to boards with sufficient width and/or length to yield two pieces, and with an uneven distribution of defects that one piece was most likely to grade higher than the other. In such cases, the iterative algorithm used in finding the optimum edging and trimming lines was applied separately to each piece. It should be pointed out that although the general procedure accomodated cross-cutting and ripping, the decision to perform these operations was not inherent in the program CUTCOMB. These decisions were controlled through the edging and trimming limits supplied to the program. Thus, for finding the position of the middle cut in a solution involving ripping, the limits for varying EDGE2 for one piece could be the same limits for varying EDGE1 for the other piece.

D. FAS 1 Face Vs. Selects

Klinkhachorn's [1988] lumber grading program used the more commonly utilized Selects as the second highest lumber grade. However, in the Appalachian region where the sawmills studied are located, the FAS 1 Face grade is traditionally used instead of Selects. Therefore, a few modifications had to be made on some statements and parameters in the grading program. The two grades are identical in most aspects with the following exceptions:

	FAS 1 Face	
Minimum dimensions	6" x 8'	4" x 6'
Maximum wane dimensions on No. 1 Common side	0.33W x 0.5L*	4' SM and higher: 0.33W x 0.5L* or 0.25W x 0.5L* < 4' SM: 0.33W x 0.5L*

* Aggregate wane length

In the above dimensions for allowable wane, the expressions W, L, and SM refer to width, length, and surface measure of the board, respectively. From the above table, it can be seen that all FAS 1 Face boards qualify as Selects, whereas not all Selects can grade as FAS 1 Face.

E. Calculation of Lumber Value

Lumber value of each board was computed as the product of price per board foot and surface measure (equivalent to board footage since all were 4/4 pieces). The following prices were used [Source: Weekly Hardwood Review, Sept. 15, 1989]:

FAS	$990/mbf
FAS 1 Face	980
No.1 Common	520
No.2 Common	255
No.3 Common	195

Although prices change from time to time, the rates of change are never drastic and the relative proportions of prices from one grade to another are essentially constant. It should be noted that the lumber price and grading rules used in this study for No.2 Common are those for the No.2A Common grade, while No.3 Common is equivalent to No.3A Common. The grades No.2B and No.3B Common were not considered.

The procedure recommended by the NHLA manual for tallying board footage is to round off computed values to the nearest board foot, i.e., values with a fraction component higher than the half-foot mark are to be raised to the next higher board foot, while those below the half-mark should be dropped to the next lower value. For pieces with exactly a 0.5 board foot fraction, it is recommended that in counting the total board footage, these boards be rounded off alternately. Thus, if the first board with the half-board foot measure were dropped to the lower board foot, the next such board should be raised to the next higher board foot. For this study, each board was considered individually. There had to be consistency in the comparison of lumber value produced by each cutting combination for every board. Therefore, the alternate rounding off procedure was not followed. Instead, all computed values falling on the half board foot mark were counted as the lower board foot.

EVALUATION OF ACTUAL YIELD

Actual lumber values were evaluated using the same computer programs used in optimization. Coordinates of actual edging and trimming lines were fed to the program CUTCOMB[3] along with data describing the unedged/untrimmed board. Since no iterative search for a solution was involved, both inner and outer limits for varying cutting lines were equal to the actula edging and trimming coordinates. As with the optimization procedure, results were input to the lumber grading program which computed the grade and volume of each board resulting from the edger and trimmer operators' decision. The procedure for tallying board footage was as described in the preceding section.

---

[3] See Appendix A.

Chapter 5

RESULTS AND DISCUSSION

Optimum cutting solutions and corresponding lumber values were determined using the procedure discussed in the preceding chapter. This chapter consists of the following main topics:

I. Comparison of optimum lumber values and actual sawmill output.

II. Results from independent optimization of edging and trimming compared to actual sawmill output. The first part of this topic discusses the outcome of optimizing edging only, followed by a discussion of the results of the procedure in which only trimming was optimized.

OPTIMUM VS. ACTUAL LUMBER VALUE

The overall difference between optimal and actual lumber values for each sawmill was expressed as the percentage of optimum value actually recovered in the sawmill, i.e.,

$$V=\frac{A}{O}x100\%$$

where O = total optimum value
A = total lumber value actually obtained in the sawmill
V = value recovery

Tables 4a to 4c show the optimum vs. actual comparisons for the three sawmills in the study. These results are summarized in Figure 7. Comparing lumber values among the three sawmills, the recovery of 80.01% for A is noticeably larger than the 64.75% and 62.47% for mills B and C, respectively. This fact was most probably attributable to edger operator performance. It was evident that the edger operator at mill A was knowledgeable about NHLA grading rules, whereas the same was not observed at mills B and C.

A. Difference Between Optimum and Actual Values as a Function of Potential Grade

To investigate how board quality affected the difference between optimum and actual values, boards were grouped according to potential (optimum) grade and the contribution of each group to the overall value difference was computed. Up to this point, optimum-versus-actual comparisons were expressed as percentage value recovery, i.e. the percentage of optimum value actually obtained. For the particular analysis discussed in this sub-section, it is more meaningful to express optimum-versus-actual comparisons in terms of value difference rather than percentage value recovery. The value difference for each lumber grade group was expressed as a percentage of the optimum value for the particular grouping. As an illustration, if the total optimum value for all FAS boards was $48 and the total actual value for the same boards was $32, then the value difference for the FAS group was the ratio of the quantity (48 - 32) to the optimum value of 48. This value difference per group was multipled by the ratio of the group size to the total number of boards from each mill, a procedure analogous to the computation of weighted average. Thus, the product of these two quantities gave the relative magnitude of the contribution of each grade to the overall value difference between the optimum and actual lumber values: the higher the product, the greater the contribution. Results of this analysis are shown in Table 5. Note that in the context of this analysis, the phrase "overall value difference" was equivalent to (1 - V)100%, where V is value recovery as defined earlier.

Table 4a. Optimum vs. actual values, Sawmill A.

OPTIMIZED EDGING AND TRIMMING DATA					ACTUAL DATA FROM SAWMILL				
BOARD LABEL	OPT.GRADE	$/BD.FT	VOLUME	VALUE	ACTUAL GRADE	$/BD.FT	VOLUME	VALUE	DIFFERENCE
A1	FAS 1-face	0.980	8	$7.84	No.1 COMMON	0.520	8	$4.16	$3.68
A2	No.3 COMMON	0.195	4	$0.78	No.3 COMMON	0.195	4	$0.78	$0.00
A3	FAS 1-face	0.980	7	$6.86	No.1 COMMON	0.520	9	$4.68	$2.18
A4	No.1 COMMON	0.520	5	$2.60	No.2 COMMON	0.255	5	$1.28	$1.33
A5	No.1 COMMON	0.520	7	$3.64	No.2 COMMON	0.255	7	$1.79	$1.86
A6	No.1 COMMON	0.520	11	$5.72	No.1 COMMON	0.520	11	$5.72	$0.00
A7	No.2 COMMON	0.255	10	$2.55	No.2 COMMON	0.255	9	$2.30	$0.25
A8	FAS 1-face	0.980	7	$6.86	No.1 COMMON	0.520	8	$4.16	$2.70
A9	FAS 1-face	0.980	6	$5.88	No.1 COMMON	0.520	8	$4.16	$1.72
A10	No.1 COMMON	0.520	4	$2.08	No.2 COMMON	0.255	5	$1.28	$0.81
A11	No.1 COMMON	0.520	7	$3.64	No.1 COMMON	0.520	7	$3.64	$0.00
A12	No.1 COMMON	0.520	6	$3.12	No.2 COMMON	0.255	9	$2.30	$0.83
A13	No.1 COMMON	0.520	6	$3.12	No.1 COMMON	0.520	6	$3.12	$0.00
A14	No.2 COMMON	0.255	9	$2.30	No.2 COMMON	0.255	9	$2.30	$0.00
A15	No.2 COMMON	0.255	7	$1.79	No.2 COMMON	0.255	7	$1.79	$0.00
A16	No.2 COMMON	0.255	11	$2.81	No.2 COMMON	0.255	10	$2.55	$0.26
A17	FAS 1-face	0.980	5	$4.90	No.2 COMMON	0.255	6	$1.53	$3.37
A18	FAS 1-face	0.980	10	$9.80	FAS 1-face	0.980	10	$9.80	$0.00
A19	FAS 1-face	0.980	7	$6.86	No.1 COMMON	0.520	7	$3.64	$3.22
A20	No.1 COMMON	0.520	9	$4.68	No.1 COMMON	0.520	8	$4.16	$0.52
A21	No.1 COMMON	0.520	4	$2.08	No.2 COMMON	0.255	4	$1.02	$1.06
A22	No.3 COMMON	0.195	5	$0.98	Below Grade	0.000	5	$0.00	$0.98
A23I	No.1 COMMON	0.520	5	$2.60	No.2 COMMON	0.255	7	$1.79	$1.40
A23II	No.3 COMMON	0.195	3	$0.59					
A24	No.1 COMMON	0.520	12	$6.24	No.1 COMMON	0.520	10	$5.20	$1.04
A25	FAS	0.990	9	$8.91	FAS	0.990	9	$8.91	$0.00
A26	NO.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	6	$1.17	$0.00
A27	No.1 COMMON	0.520	3	$1.56	No.1 COMMON	0.520	3	$1.56	$0.00
A29	FAS 1-face	0.980	7	$6.86	No.1 COMMON	0.520	8	$4.16	$2.70
A30	FAS 1-face	0.980	8	$7.84	FAS 1-face	0.980	7	$6.86	$0.98
A31I*	NO.1 COMMON	0.520	8	$4.16	No.2 COMMON	0.255	4	$1.02	$1.06
A31II*					No.1 COMMON	0.520	4	$2.08	
A32	No.2 COMMON	0.255	5	$1.28	No.3 COMMON	0.195	5	$0.98	$0.30
A33	No.3 COMMON	0.195	5	$0.98	No.3 COMMON	0.195	5	$0.98	$0.00
A34	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
A35	FAS 1-face	0.980	7	$6.86	FAS 1-face	0.980	6	$5.88	$0.98
A36I*	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
A36II*	Below Grade			$0.00	Below Grade				
A37	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	4	$1.02	$0.00
A38	FAS	0.990	12	$11.88	FAS	0.990	12	$11.88	$0.00
A39	FAS 1-face	0.980	7	$6.86	FAS 1-face	0.980	7	$6.86	$0.00
A40	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
A41	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	5	$0.98	$0.19
			274	$167.08			276	$133.68	

$$\text{Value recovery} = \frac{\$\ 133.68}{\$\ 167.08} \times 100\% = 80.01\%$$

* Ripped or cross-cut

Table 4b. Optimum vs. actual values, Sawmill B.

OPTIMIZED EDGING AND TRIMMING DATA					ACTUAL VALUES OBTAINED FROM SAWMILL				
BOARD LABEL	OPT. GRADE	$/BDFT	VOLUME	VALUE	ACT. GRADE	$/BDFT	VOLUME	VALUE	DIFFERENCE
B2	No.3 COMMON	0.195	9	$1.76	No.3 COMMON	0.195	7	$1.37	$0.39
B3	No.2 COMMON	0.255	12	$3.06	No.2 COMMON	0.255	10	$2.55	$0.51
B4	No.1 COMMON	0.52	5	$2.60	No.2 COMMON	0.255	5	$1.28	$1.33
B5	FAS 1-face	0.98	6	$5.88	No.2 COMMON	0.255	4	$1.02	$4.86
B6	No.2 COMMON	0.255	14	$3.57	No.2 COMMON	0.255	10	$2.55	$1.02
B7	FAS 1-face	0.98	5	$4.90	No.1 COMMON	0.52	4	$2.08	$2.82
B8	FAS 1-face	0.98	14	$13.72	No.1 COMMON	0.52	13	$6.76	$6.96
B9	FAS 1-face	0.98	12	$11.76	No.1 COMMON	0.52	11	$5.72	$6.04
B10	No.2 COMMON	0.255	7	$1.79	No.3 COMMON	0.195	5	$0.98	$0.81
B11	No.2 COMMON	0.255	11	$2.81	No.2 COMMON	0.255	7	$1.79	$1.02
B12	FAS 1-face	0.98	5	$4.90	No.1 COMMON	0.52	5	$2.60	$2.30
B13	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	5	$1.28	$0.26
B14	No.1 COMMON	0.52	9	$4.68	No.2 COMMON	0.255	8	$2.04	$2.64
B15	No.1 COMMON	0.52	16	$8.32	No.2 COMMON	0.255	12	$3.06	$5.26
B16	No.1 COMMON	0.52	14	$7.28	No.1 COMMON	0.52	13	$6.76	$0.52
B17	FAS 1-face	0.98	4	$3.92	No.1 COMMON	0.52	4	$2.08	$1.84
B18	FAS	0.99	6	$5.94	FAS	0.99	5	$4.95	$0.99
B19	FAS	0.99	12	$11.88	FAS	0.99	10	$9.90	$1.98
B20	FAS 1-face	0.98	6	$5.88	No.2 COMMON	0.255	7	$1.79	$4.10
B21	FAS 1-face	0.98	6	$5.88	No.1 COMMON	0.52	5	$2.60	$3.28
B22	FAS 1-face	0.98	11	$10.78	FAS 1-face	0.98	8	$7.84	$2.94
B23	No.1 COMMON	0.52	5	$2.60	No.1 COMMON	0.52	5	$2.60	$0.00
B24I*	No.1 COMMON	0.52	6	$3.12	No.2 COMMON	0.255	10	$2.55	$1.55
B24II*	No.3 COMMON	0.195	5	$0.98					
B25	No.1 COMMON	0.52	5	$2.60	No.2 COMMON	0.255	3	$0.77	$1.84
B26	No.2 COMMON	0.255	9	$2.30	No.3 COMMON	0.195	7	$1.37	$0.93
B27	FAS 1-face	0.98	7	$6.86	FAS 1-face	0.98	5	$4.90	$1.96
B28	No.1 COMMON	0.52	6	$3.12	No.2 COMMON	0.255	7	$1.79	$1.34
B29	No.1 COMMON	0.52	15	$7.80	No.1 COMMON	0.52	13	$6.76	$1.04
B30	FAS 1-face	0.98	6	$5.88	No.1 COMMON	0.52	5	$2.60	$3.28
B31	FAS 1-face	0.98	12	$11.76	FAS 1-face	0.98	10	$9.80	$1.96
B32	FAS 1-face	0.98	7	$6.86	FAS 1-face	0.98	6	$5.88	$0.98
B33I*	No.2 COMMON	0.255	7	$1.79	No.1 COMMON	0.52	12	$6.24	$1.43
B33II*	FAS 1-face	0.98	6	$5.88					
B34	FAS 1-face	0.98	7	$6.86	FAS 1-face	0.98	6	$5.88	$0.98
B35I*	No.2 COMMON	0.255	7	$1.79	No.2 COMMON	0.255	11	$2.81	$3.88
B35II*	FAS 1-face	0.98	5	$4.90					
B36	No.1 COMMON	0.52	10	$5.20	No.1 COMMON	0.52	9	$4.68	$0.52
B37	No.1 COMMON	0.52	4	$2.08	No.2 COMMON	0.255	4	$1.02	$1.06
B38	No.1 COMMON	0.52	9	$4.68	No.1 COMMON	0.52	8	$4.16	$0.52
B39	No.1 COMMON	0.52	8	$4.16	No.1 COMMON	0.52	7	$3.64	$0.52
B40	FAS 1-face	0.98	10	$9.80	FAS 1-face	0.98	9	$8.82	$0.98
B41	FAS 1-face	0.98	11	$10.78	No.1 COMMON	0.52	9	$4.68	$6.10
			357	$234.61			304	$151.90	

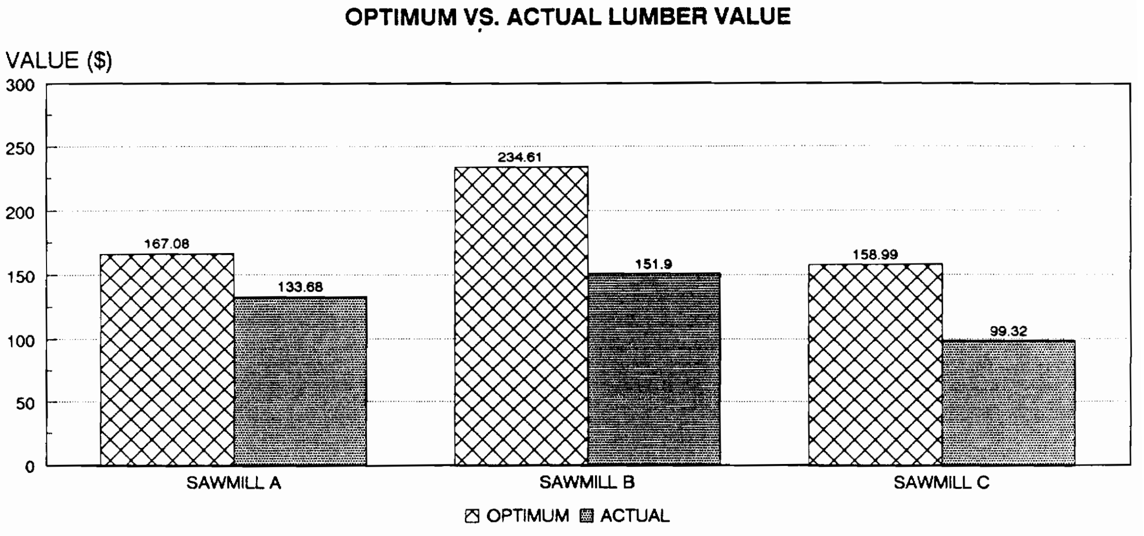
$$\text{Value recovery} = \frac{\$\ 151.90}{\$\ 234.61} \times 100\% = 64.75\%$$

*Ripped or cross-cut

Table 4c. Optimum vs. actual values, Sawmill C.

OPTIMIZED EDGING AND TRIMMING DATA					ACTUAL DATA FROM SAWMILL				
BOARD LABEL	OPT. GRADE	$/BDFT.	VOLUME	VALUE	ACT. GRADE	$/BDFT.	VOLUME	VALUE	DIFFERENCE
C1	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	4	$1.02	$0.00
C2	No.1 COMMON	0.520	2	$1.04	No.2 COMMON	0.255	3	$0.77	$0.28
C3	No.2 COMMON	0.255	4	$1.02	No.3 COMMON	0.195	2	$0.39	$0.63
C4	No.1 COMMON	0.520	6	$3.12	No.1 COMMON	0.520	2	$1.04	$2.08
C5	No.1 COMMON	0.520	5	$2.60	No.1 COMMON	0.520	4	$2.08	$0.52
C7	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	4	$0.78	$0.39
C8	FAS 1-face	0.980	6	$5.88	No.1 COMMON	0.520	4	$2.08	$3.80
C9	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	2	$0.51	$0.51
C11	FAS 1-face	0.980	5	$4.90	No.1 COMMON	0.520	6	$3.12	$1.78
C12	FAS 1-face	0.980	6	$5.88	No.2 COMMON	0.255	5	$1.28	$4.61
C13	FAS 1-face	0.980	6	$5.88	FAS 1-face	0.980	6	$5.88	$0.00
C14	No.1 COMMON	0.520	2	$1.04	No.1 COMMON	0.520	2	$1.04	$0.00
C15	FAS 1-face	0.980	8	$7.84	FAS 1-face	0.980	6	$5.88	$1.96
C16	FAS 1-face	0.980	6	$5.88	FAS	0.990	4	$3.96	$1.92
C17	No.1 COMMON	0.520	2	$1.04	No.1 COMMON	0.520	2	$1.04	$0.00
C18	FAS 1-face	0.980	4	$3.92	No.1 COMMON	0.520	3	$1.56	$2.36
C19	FAS 1-face	0.980	5	$4.90	No.1 COMMON	0.520	4	$2.08	$2.82
C20	FAS 1-face	0.980	4	$3.92	FAS 1-face	0.980	4	$3.92	$0.00
C21	No.1 COMMON	0.520	5	$2.60	No.1 COMMON	0.520	5	$2.60	$0.00
C22	FAS 1-face	0.980	4	$3.92	No.2 COMMON	0.255	5	$1.28	$2.65
C23	No.1 COMMON	0.520	4	$2.08	No.2 COMMON	0.255	4	$1.02	$1.06
C24	FAS 1-face	0.980	5	$4.90	No.2 COMMON	0.255	4	$1.02	$3.88
C25	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	4	$1.02	$0.51
C26	FAS 1-face	0.980	4	$3.92	No.1 COMMON	0.520	3	$1.56	$2.36
C27	No.1 COMMON	0.520	3	$1.56	No.1 COMMON	0.520	3	$1.56	$0.00
C28	FAS 1-face	0.980	4	$3.92	No.1 COMMON	0.520	3	$1.56	$2.36
C29	No.3 COMMON	0.195	5	$0.98	No.3 COMMON	0.195	3	$0.59	$0.39
C30	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	6	$1.17	$0.00
C31	No.2 COMMON	0.255	10	$2.55	No.2 COMMON	0.255	9	$2.30	$0.25
C32	No.2 COMMON	0.255	9	$2.30	No.3 COMMON	0.195	7	$1.37	$0.93
C33	FAS	0.99	4	$3.96	No.1 COMMON	0.520	4	$2.08	$1.88
C34	FAS 1-face	0.980	9	$8.82	FAS 1-face	0.980	8	$7.84	$0.98
C35	No.1 COMMON	0.520	7	$3.64	No.1 COMMON	0.520	7	$3.64	$0.00
C36	FAS 1-face	0.980	11	$10.78	FAS	0.990	9	$8.91	$1.87
C37	No.1 COMMON	0.520	3	$1.56	No.2 COMMON	0.255	2	$0.51	$1.05
C38	No.2 COMMON	0.255	8	$2.04	No.2 COMMON	0.255	6	$1.53	$0.51
C39	FAS 1-face	0.98	12	$11.76	No.1 COMMON	0.52	9	$4.68	$7.08
C40	No.1 COMMON	0.520	10	$5.20	No.1 COMMON	0.520	8	$4.16	$1.04
C41	FAS	0.990	10	$9.90	FAS	0.990	8	$7.92	$1.98
C42	FAS 1-face	0.980	8	$7.84	No.1 COMMON	0.520	5	$2.60	$5.24
			232	$158.99			189	$99.32	

$$\text{Value recovery} = \frac{\$\ 99.32}{\$\ 158.99} \times 100\% = 62.47\%$$



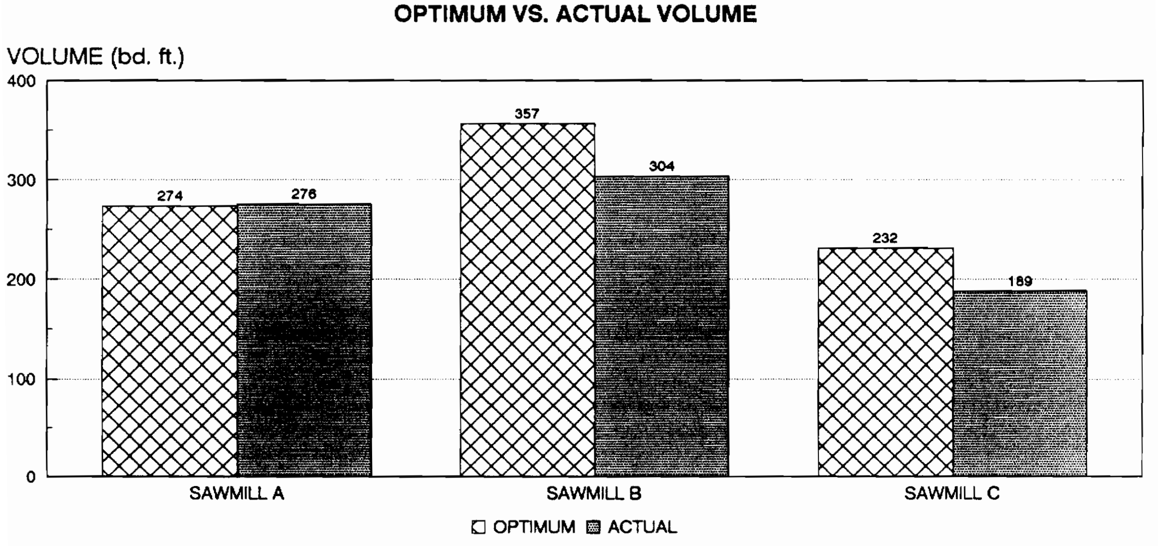


Fig. 7. Comparison of optimum and actual values.

Table 5. Contribution of each grade to overall difference between optimum and actual lumber values.

SAWMILL A:

OPTIMUM GRADE (A)	VALUE DIFFERENCE (B)	NUMBER OF BOARDS (C)	(B)X(C) / 40
FAS	0 %	2	0 %
FAS 1-face	25.60	11	7.04
No.1 Common	18.99	16	7.60
No.2 Common	4.88	6	.73
No.3 Common	19.88	5	2.49

SAWMILL B:

OPTIMUM GRADE (A)	VALUE DIFFERENCE (B)	NUMBER OF BOARDS (C)	(B)X(C) / 40
FAS	16.67 %	2	.83 %
FAS 1-face	40.27	18	18.12
No.1 Common	30.60	13	9.95
No.2 Common	30.23	6	4.53
No.3 Common	22.22	1	.56

SAWMILL C:

OPTIMUM GRADE (A)	VALUE DIFFERENCE (B)	NUMBER OF BOARDS (C)	(B)X(C) / 40
FAS	27.85 %	2	1.39 %
FAS 1-face	43.54	17	18.51
No.1 Common	23.63	11	6.50
No.2 Common	29.18	7	5.11
No.3 Common	23.49	3	1.76

The last column in Table 5 gives the computed values of the weighted contribution of each lumber grade group. Since the computed quantity represents a difference between the lumber value that should have been obtained and that actually recovered, the grades having the largest quantities in the last column of table 5 were the grades where optimization made the most difference. For all three mills, it is shown that the greatest opportunity for upgrading lumber value was with boards which have the potential to grade as FAs 1 Face and No.1 Common.

B. Value Maximization vs. Volume

Results of this study showed that a significant number of boards were actually degraded by excessive loss of volume. To analyze volume/grade interaction with lumber value, boards with non-zero differences between optimum and actual value were grouped according to the following categories:

Group 1: Boards where value difference between optimum and actual was due only to a higher optimum grade.

Group 2: Those where the increase in lumber value was due only to volume increase.

Group 3: Those where value difference was the combined effect of greater volume and higher lumber grade from the optimum solution.

Results of the above analysis are summarized in Table 6. The procedure for the computation of value difference for each group was as explained in the previous section. The last column in Table 6 shows the weighted contribution of each group category to the overall value difference.

Due to the substantial gap between lumber grade prices, the largest value differences were those involving grade increase from actual to optimum. The last column of Table 6 shows that for

Table 6. Difference in lumber value as determined by grade and volume. (Refer to text for explanation of board group categories).

SAWMILL A:

	VALUE % DIFFERENCE (A)	NUMBER OF BOARDS (B)	(A) X (B) / 40
Group 1	42.08 %	15	15.78 %
Group 2	13.15	7	2.30
Group 3	43.89	1	1.10

SAWMILL B:

	VALUE % DIFFERENCE (A)	NUMBER OF BOARDS (B)	(A) X (B) / 40
Group 1	53.11 %	6	7.97 %
Group 2	15.52	18	6.98
Group 3	53.31	15	19.99

SAWMILL C:

	VALUE % DIFFERENCE (A)	NUMBER OF BOARDS (B)	(A) X (B) / 40
Group 1	48.05 %	5	6.01 %
Group 2	23.52	14	8.23
Group 3	64.22	12	19.27

mills B and C, most of the difference between optimum and actual values were accounted for by Group 3 boards. This observation and the large volume difference shown in Fig. 7 for these two mills imply that much of the loss in dollar value was due to severe cutting which not only reduced volume but also lowered the grade for a significant number of boards. Sawmill A, however did a relatively adequate job in edging for volume, and as such, the loss was primarily due to the type of edging/trimming error that characterize Group 1 boards.

The following are cases where volume loss could result to a lower lumber grade:

1. Severe edging or trimming of a potential FAS or FAS 1 Face may reduce board dimensions such that minimum width and length requirements are not satisfied.

2. In the hardwood lumber grading system, the maximum allowable number of clear cuttings is a function of surface measure. Thus, in some cases, with a lower surface measure, the required amount of clear area will have to be met with fewer cuttings. An example of this case will be discussed later in the sub-section "Specific Board Cases."

3. With severe edging or trimming, clear areas are cut away which could have increased the size of clear cuttings, particularly when the clear area in the edging strip is greater than the defective area.

To summarize, edging and trimming a board to exclude defective areas may raise the board's grade. However, excessive cutting can produce the opposite effect.

C. Boards with One Straight Edge

Sample boards used in the study included those where wane on one edge was removed at the heardrig. Boards which fit this category include the following:

	SAWMILL A:	SAWMILL B:			SAWMILL C:
	A23	B3	B16	B27	C1
	A38	B4	B19	B29	C39
	A40	B9	B21	B31	
		B11	B22	B35	
		B41			
Value recovery	91.84%	67.54%			44.61%

While the number of boards of this type in the sample from mills A and C was small enough not to have significantly affected the computed value recovery for these mills, thirteen of the total forty boards from mill B belong to this category. It was important to determine whether value recovery for boards of this type differ from those with two waney edges, and if the inclusion of a significant number of such boards affected the overall results for mill B. Computation of average value recovery for boards with one straight edge in mill B gave a value of 67.54%, which was comparable to the overall value recovery for this mill (64.75%). Therefore, for the sample used in this study, it was concluded that the difference between optimum and actual lumber values was not affected by the boards' having one or two waney edges.

An observation was made about actual edging cuts on a number of boards with one straight edge. In ten of the thirteen such boards from sawmill B, the actual edging line was not oriented parallel to the other straight edge, thus producing a tapered board. The difference in width between the narrow and wide ends was typically 1 inch. Volume measurements for these boards followed the procedure required by the National Hardwood Lumber Association handbook for lumber grading and measurement. For tapered boards, surface measure was based on the width of the board one third of the length from the narrow end. An example case will be discussed in the next sub-section.

C. Specific Board Cases

The following boards exemplify how actual cutting solutions typically differed from the optimum for boards with a large difference between optimum and actual values. Illustrations for the discussion below are shown in Figures 8a-f. The board diagrams shown in these illustrations are based on actual measurements. Shaded areas represent wane while other defects are denoted by rectangular areas.

Board label: C33

Optimum: Grade = FAS, Surface Measure = 4
Actual : Grade = No.1 Common, Surface Measure = 4

The misorientation of actual edging lines on this board resulted to the inclusion of a large wane area on the upper edge at the right end, and wasted a substantial usable clear area at the lower part of the same end of the board. The large defect at the left end further degraded the actual board.

Board label: B25

Optimum: Grade = No.1 Common, Surface Measure = 5
Actual : Grade = No.2 Common, Surface Measure = 3

This board illustrated the effect of cutting severely on the resulting board grade. The poor or grading face is Face 1. Actual cutting lines produced a board with a surface measure of 3. Based on this surface measure, the board had to have at least 66.67% clear area in one clear cutting or 75% clear area in two cuttings in order to be graded as No.1 Common. An inspection of the actual board in Fig. 8b would show that the above are not possible with the location of defects on Face 1. On the other hand, a surface measure of 5 was obtained with the optimum cutting solution. This surface measure allowed 2 cuttings to comprise the 66.67% clear area requirement, or 3 cuttings to make up a 75% clear area for a No.1 Common grade. With the number of allowed cuttings, the board graded No.1 Common.

Board label: B21

Optimum: Grade = FAS 1-face, Surface Measure = 6
Actual : Grade = No.1 Common, Surface Measure = 5

An erroneous trimming decision lowered the actual grade of this board. A significant area of clear wood at the right end was excluded, while at the opposite end, the trimming line resulted to a non-optimal location of the cluster of defects shown in Fig. 8c. The board also illustrates the non-parallel edging lines mentioned in an earlier section concerning boards with one straight edge. The width at the right end was actually 1 inch less than than that at the other end, resulting to a loss in volume.

Board label: B20

Optimum: Grade = FAS 1-face, Surface Measure = 6
Actual : Grade = No.2 Common, Surface Measure = 7

Board B20 is an example showing how the removal of defects could raise a board's grade. With a large defect-free area on Face 1, this board had the potential to grade as FAS 1-face if the poorer face (Face 0) could satisfy the requirements of the No.1 Common grade. However, the placement of actual cuts produced a No.2 Common face on Face 0. Two factors contributed to the failure of Face 0 to grade as No.1 Common. The first was the presence of large defect areas at the left end. With the optimum cutting solution, these areas of wane and stain were substantially edged away. The second reason concerned the the percent clear area requirement. The optimum and actual surface measure, 6 and 7 respectively, both allowed a maximum of 2 cuttings to comprise the required 66.67% clear area. With the same number of clear cuttings, the total clear area of the actual board was only slightly greater than that produced by the optimum cutting lines. On the other hand, the overall face area of the actual board was a full board foot greater than the optimum. Thus, when the ratio of clear area to total face area was computed, the percentage clear area for the actual board was only 65%, compared to the required 66.67%, and 73% for the optimum. Given the structure of the grading rules, the larger volume of the actual board became a disadvantage in this particular case.

Board label: B24

The added dollar value due to ripping is illustrated by this board. The size of the board and the distribution of defects allowed an optimum cutting solution producing one No.1 Common (the top board in Fig. 8e) and one No.3 Common board. The total value of these boards was greater than the No.2 Common lumber that was actually produced.

Large differences between optimum and actual lumber values are typically represented by one of the above cases.

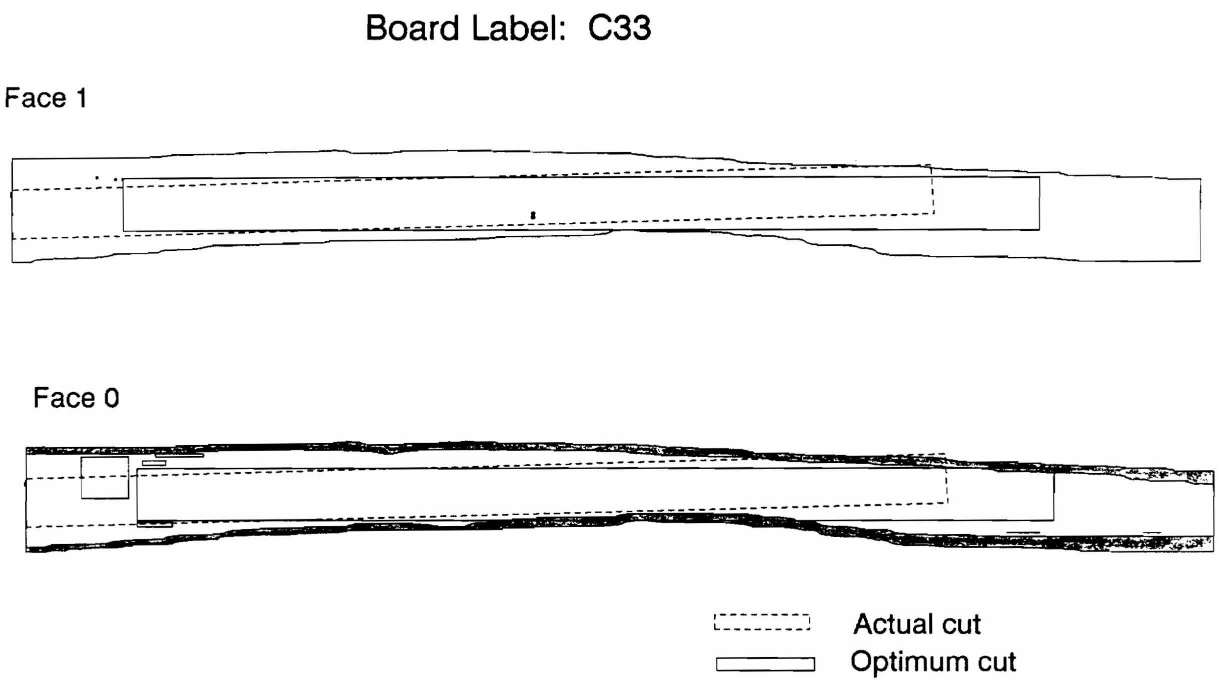


Fig. 8. Sample board showing misoriented edging lines.

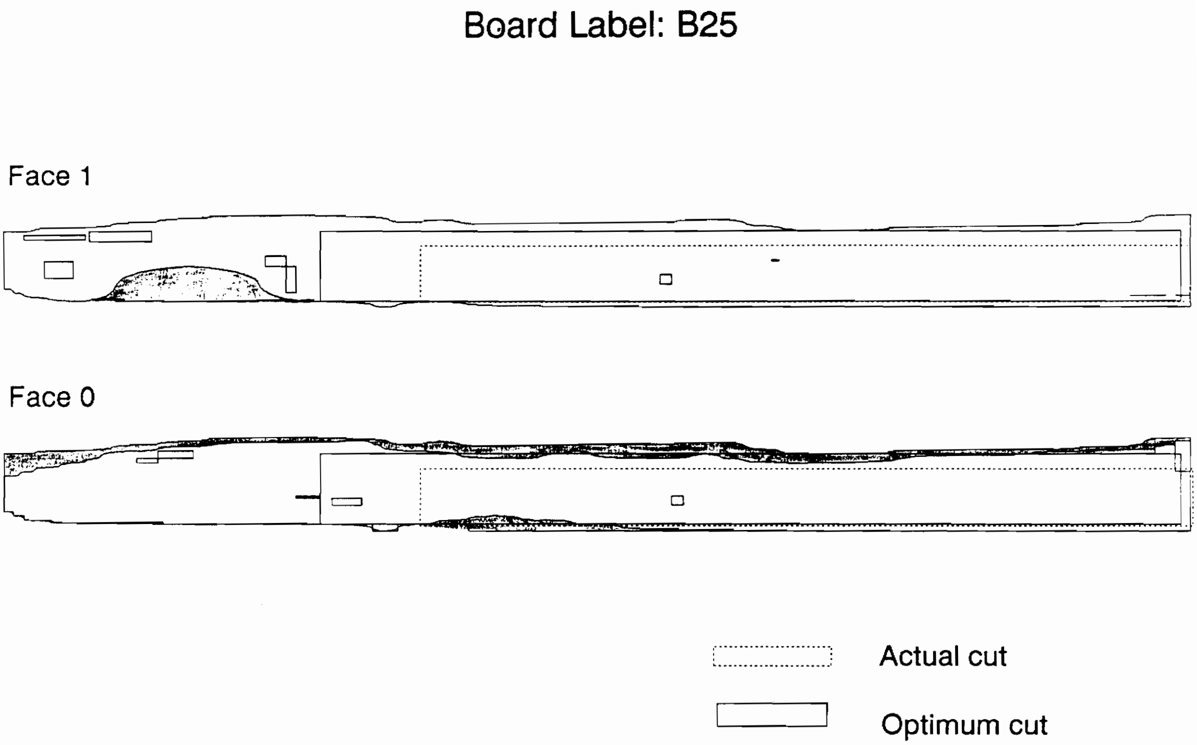


Fig. 8b. Illustration of severe edging and trimming at the sawmill.

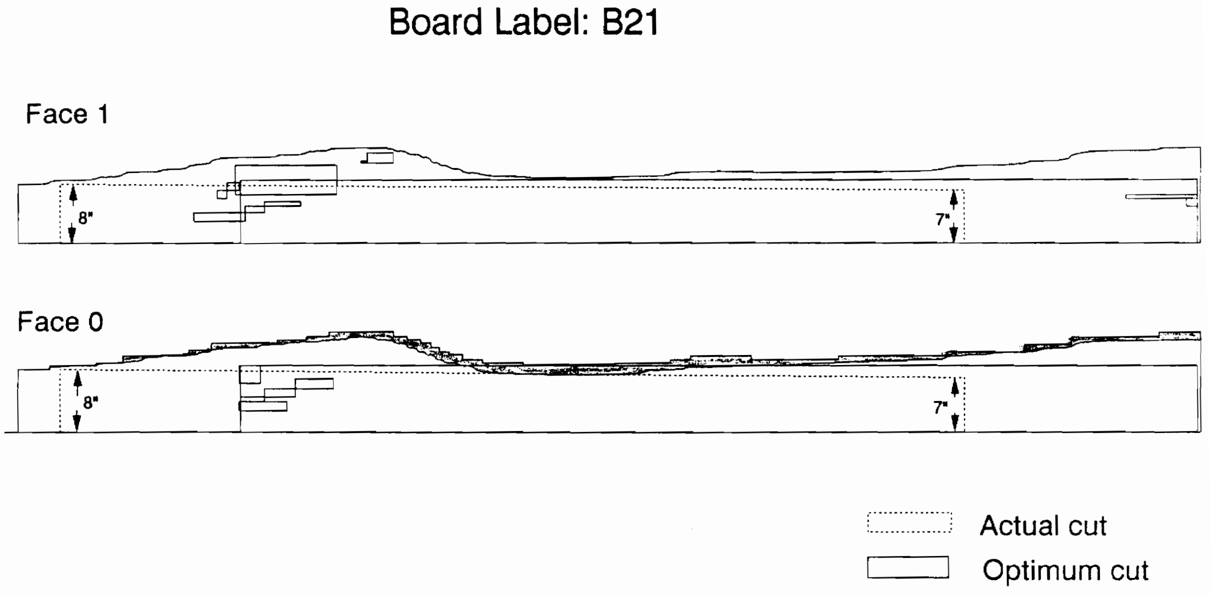


Fig. 8c. Sample board showing erroneous trimming decision and non-parallel edges.

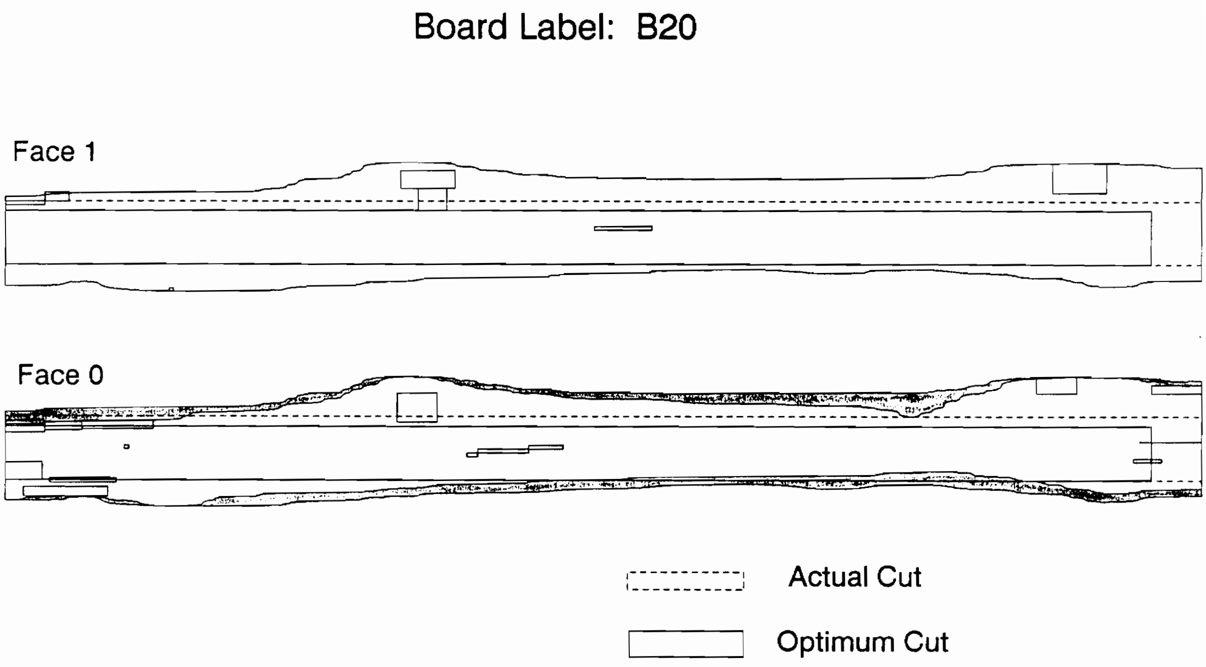
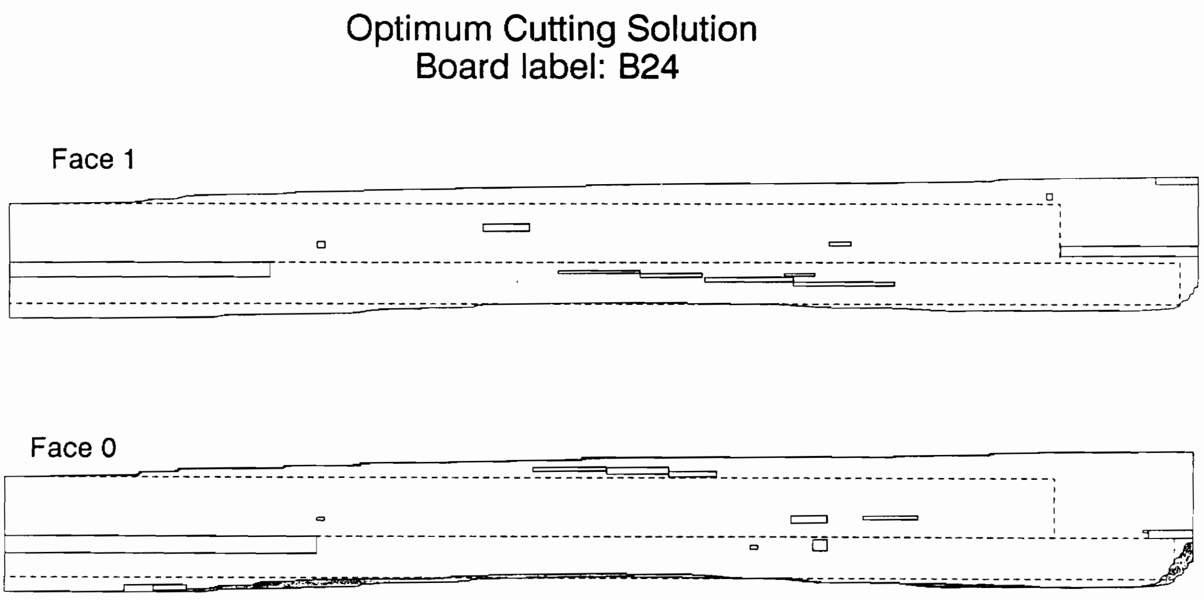


Fig. 8d. Illustration of raising lumber grade by edging and trimming off larger areas of defect.



Board 1
Grade: No.1 COMMON
Volume: 6 bd.ft.
Value: $3.12

Board 2
Grade:No.2 COMMON
Volume: 5 bd. ft.
Value: $.98

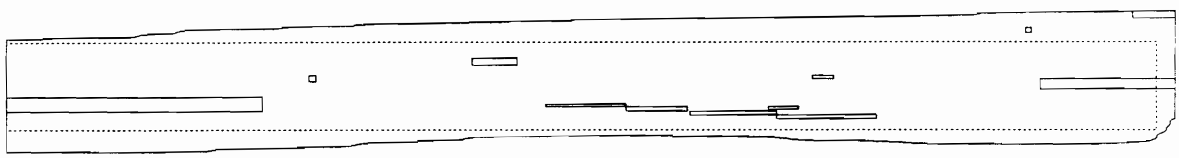
Total Value = $4.10

Fig. 8e. Illustration of upgrading board value through ripping.

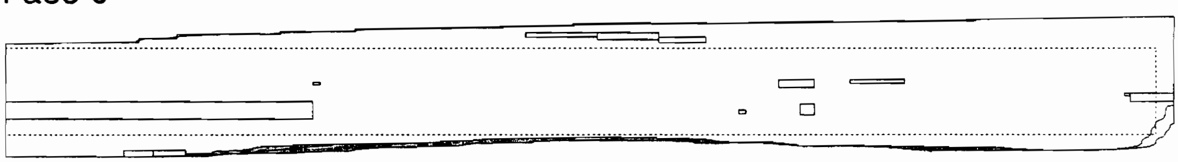
Actual cutting solution

Board label: B24

Face 1



Face 0



Grade: No.2 Common
Volume: 10 bd. ft.
Value: $2.55

Fig. 8f. Actual cutting solution at the sawmill for a board that could be upgraded through ripping.

INDEPENDENT OPTIMIZATION OF EDGING AND TRIMMING

True optimization of hardwood flitch processing to produce rough graded lumber involves the interactive optimization of edging and trimming. Whether or not the placement of edging lines is optimal for a given board can not be ascertained until the subsequent trimming decision; and vice versa if trimming was done prior to edging in the processing sequence. It is therefore ideal to have these two operations within one integrated optimizing system.

However, since edging and trimming operations occur independently, it is of interest to analyze how much improvement in lumber value can be achieved if only one of these operations were "optimized". The purpose of such analysis is to assess the relative impact on lumber value of each operation and how the sub-optimum values resulting from such a procedure compare with the true optimum.

A. Optimization of Edging.

As noted previously, lumber value from a flitch is determined by the interactive combination of edging and trimming cuts. In the following analysis, the objectives were to find the best location of edging lines given a predetermined (non-optimal) trimming solution and to evaluate the improvement in lumber value from this procedure over the observed lumber value.

The method used to calculate edging solution followed the same algorithm as that described in Chapter 4 with one exception: the iterative search for the best cutting solution involved only the variation of edging lines. Coordinates of trimming lines at both ends of the board were kept constant and equal to the coordinates of the actual trimming lines. Thus, the overall cutting solution consisted of a computer-determined edging solution based on manual trimming decision. Detailed results are shown in Tables 7a-c and summarized in Fig. 9.

B. Optimization of Trimming

For this analysis, the objective was to locate the trimming lines that would maximize lumber value given the coordinates of actual edging lines. The same limits for trimming line variation as in the complete input optimization (refer to Chapter 4) were used, while edging line coordinates were kept constant. Results are shown in Tables 8a-c and Figure 10.

C. Comparison of Results of Edging vs. Trimming Optimization

Several conclusions can be made from the results of the above analysis. Based on the computed value recovery from each optimization procedure, higher lumber values than the actual are obtainable even if only one operation were optimized. The results also indicate that edging decisions have a greater impact on lumber value than trimming, as shown by value recovery ranging from 90.31% to 95.28% from edging optimization compared to 89.31%, 70.87%, and 64.87% from the optimization of trimming.

Earlier analyses revealed that the loss in lumber value in sawmills B and C were mostly attributable to severe volume loss. Comparing the volume charts in Figs. 9 and 10, it can be seen that higher volume recovery was obtained from edging optimization than from the optimization of trimming in sawmills B and C. The fact that greater volume increases were attained through the optimization of edging indicates that for these mills, much of the volume loss occured at the edger.

Table 7a. Comparison of true optimum values vs. results of edging optimization, Sawmill A.

OPTIMIZED EDGING AND TRIMMING DATA					OPTIMIZED EDGING DATA				
BOARD LABEL	OPT.GRADE	$/BD.FT	VOLUME	VALUE	GRADE	$/BDFT.	VOLUME	VALUE	DIFFERENCE
A1	FAS 1-face	0.980	8	$7.84	No.1 COMMON	0.520	8	$4.16	$3.68
A2	No.3 COMMON	0.195	4	$0.78	No.3 COMMON	0.195	4	$0.78	$0.00
A3	FAS 1-face	0.980	7	$6.86	No.1 COMMON	0.520	10	$5.20	$1.66
A4	No.1 COMMON	0.520	5	$2.60	No.2 COMMON	0.255	6	$1.53	$1.07
A5	No.1 COMMON	0.520	7	$3.64	No.1 COMMON	0.520	7	$3.64	$0.00
A6	No.1 COMMON	0.520	11	$5.72	No.1 COMMON	0.520	11	$5.72	$0.00
A7	No.2 COMMON	0.255	10	$2.55	No.2 COMMON	0.255	10	$2.55	$0.00
A8	FAS 1-face	0.980	7	$6.86	FAS 1-face	0.980	7	$6.86	$0.00
A9	FAS 1-face	0.980	6	$5.88	No.1 COMMON	0.520	9	$4.68	$1.20
A10	No.1 COMMON	0.520	4	$2.08	No.2 COMMON	0.255	5	$1.28	$0.81
A11	No.1 COMMON	0.520	7	$3.64	No.1 COMMON	0.520	7	$3.64	$0.00
A12	No.1 COMMON	0.520	6	$3.12	No.2 COMMON	0.255	9	$2.30	$0.83
A13	No.1 COMMON	0.520	6	$3.12	No.1 COMMON	0.520	6	$3.12	$0.00
A14	No.2 COMMON	0.255	9	$2.30	No.2 COMMON	0.255	9	$2.30	$0.00
A15	No.2 COMMON	0.255	7	$1.79	No.2 COMMON	0.255	7	$1.79	$0.00
A16	No.2 COMMON	0.255	11	$2.81	No.2 COMMON	0.255	11	$2.81	$0.00
A17	FAS 1-face	0.980	5	$4.90	FAS 1-face	0.980	5	$4.90	$0.00
A18	FAS 1-face	0.980	10	$9.80	FAS 1-face	0.980	10	$9.80	$0.00
A19	FAS 1-face	0.980	7	$6.86	No.1 COMMON	0.520	8	$4.16	$2.70
A20	No.1 COMMON	0.520	9	$4.68	No.1 COMMON	0.520	9	$4.68	$0.00
A21	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
A22	No.3 COMMON	0.195	5	$0.98	No.3 COMMON	0.195	5	$0.98	$0.00
A23I	No.1 COMMON	0.520	5	$2.60	No.2 COMMON	0.255	7	$1.79	$0.82
A23II	No.3 COMMON	0.195	3	$0.59					
A24	No.1 COMMON	0.520	12	$6.24	No.1 COMMON	0.520	12	$6.24	$0.00
A25	FAS	0.990	9	$8.91	FAS	0.990	9	$8.91	$0.00
A26	No.3 COMMON	0.195	6	$1.17	NO.3 COMMON	0.195	6	$1.17	$0.00
A27	No.1 COMMON	0.520	3	$1.56	No.1 COMMON	0.520	3	$1.56	$0.00
A29	FAS 1-face	0.980	7	$6.86	No.1 COMMON	0.520	8	$4.16	$2.70
A30	FAS 1-face	0.980	8	$7.84	FAS 1-face	0.980	8	$7.84	$0.00
A31	No.1 COMMON	0.520	8	$4.16	No.1 COMMON	0.520	8	$4.16	$0.00
A32	No.2 COMMON	0.255	5	$1.28	No.2 COMMON	0.255	5	$1.28	$0.00
A33	No.3 COMMON	0.195	5	$0.98	No.3 COMMON	0.195	5	$0.98	$0.00
A34	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
A35	FAS 1-face	0.980	7	$6.86	FAS 1-face	0.980	7	$6.86	$0.00
A36I*	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
A36II*	Below Grade			$0.00	Below Grade				
A37	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	4	$1.02	$0.00
A38	FAS	0.990	12	$11.88	FAS	0.990	12	$11.88	$0.00
A39	FAS 1-face	0.980	7	$6.86	FAS 1-face	0.980	7	$6.86	$0.00
A40	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
A41	No.3 COMMON	0.195	6	$1.17	No.2 COMMON	0.255	4	$1.02	$0.15
			274	$167.08			284	$150.89	

$$\text{Value recovery} = \frac{\$150.89}{\$167.08} \times 100\% = 90.31\%$$

* Ripped or cross-cut

Table 7b. Comparison of true optimum values vs. results of edging optimization, Sawmill B.

OPTIMIZED EDGING AND TRIMMING DATA					OPTIMIZED EDGING DATA				
BOARD LABEL	OPT. GRADE	$/BDFT	VOLUME	VALUE	GRADE	$/BDFT.	VOLUME	VALUE	DIFFERENCE
B2	No.3 COMMON	0.195	9	$1.76	No.3 COMMON	0.195	8	$1.56	$0.20
B3	No.2 COMMON	0.255	12	$3.06	No.2 COMMON	0.255	12	$3.06	$0.00
B4	No.1 COMMON	0.52	5	$2.60	No.1 COMMON	0.52	5	$2.60	$0.00
B5	FAS 1-face	0.98	6	$5.88	FAS 1-face	0.98	6	$5.88	$0.00
B6	No.2 COMMON	0.255	14	$3.57	No.2 COMMON	0.255	14	$3.57	$0.00
B7	FAS 1-face	0.98	5	$4.90	FAS 1-face	0.98	5	$4.90	$0.00
B8	FAS 1-face	0.98	14	$13.72	FAS 1-face	0.98	14	$13.72	$0.00
B9	FAS 1-face	0.98	12	$11.76	FAS 1-face	0.98	12	$11.76	$0.00
B10	No.2 COMMON	0.255	7	$1.79	No.2 COMMON	0.255	5	$1.28	$0.51
B11	No.2 COMMON	0.255	11	$2.81	No.2 COMMON	0.255	11	$2.81	$0.00
B12	FAS 1-face	0.98	5	$4.90	FAS 1-face	0.98	5	$4.90	$0.00
B13	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	6	$1.53	$0.00
B14	No.1 COMMON	0.52	9	$4.68	No.1 COMMON	0.52	9	$4.68	$0.00
B15	No.1 COMMON	0.52	16	$8.32	No.1 COMMON	0.52	13	$6.76	$1.56
B16	No.1 COMMON	0.52	14	$7.28	No.1 COMMON	0.52	14	$7.28	$0.00
B17	FAS 1-face	0.98	4	$3.92	FAS 1-face	0.98	4	$3.92	$0.00
B18	FAS	0.99	6	$5.94	FAS	0.99	6	$5.94	$0.00
B19	FAS	0.99	12	$11.88	FAS	0.99	12	$11.88	$0.00
B20	FAS 1-face	0.98	6	$5.88	FAS 1-face	0.98	6	$5.88	$0.00
B21	FAS 1-face	0.98	6	$5.88	No.1 COMMON	0.52	5	$2.60	$3.28
B22	FAS 1-face	0.98	11	$10.78	FAS 1-face	0.98	11	$10.78	$0.00
B23	No.1 COMMON	0.52	5	$2.60	No.1 COMMON	0.52	5	$2.60	$0.00
B24I*	No.1 COMMON	0.52	6	$3.12	No.2 COMMON	0.255	12	$3.06	$1.04
B24II*	No.3 COMMON	0.195	5	$0.98					
B25	No.1 COMMON	0.52	5	$2.60	No.2 COMMON	0.255	4	$1.02	$1.58
B26	No.2 COMMON	0.255	9	$2.30	No.2 COMMON	0.255	9	$2.30	$0.00
B27	FAS 1-face	0.98	7	$6.86	FAS 1-face	0.98	7	$6.86	$0.00
B28	No.1 COMMON	0.52	6	$3.12	No.1 COMMON	0.52	6	$3.12	$0.00
B29	No.1 COMMON	0.52	15	$7.80	No.1 COMMON	0.52	15	$7.80	$0.00
B30	FAS 1-face	0.98	6	$5.88	FAS 1-face	0.98	6	$5.88	$0.00
B31	FAS 1-face	0.98	12	$11.76	FAS 1-face	0.98	12	$11.76	$0.00
B32	FAS 1-face	0.98	7	$6.86	FAS 1-face	0.98	6	$5.88	$0.98
B33I*	No.2 COMMON	0.255	7	$1.79	No.2 COMMON	0.255	7	$1.79	$0.00
B33II*	FAS 1-face	0.98	6	$5.88	FAS 1-face	0.98	6	$5.88	
B34	FAS 1-face	0.98	7	$6.86	FAS 1-face	0.98	6	$5.88	$0.98
B35I*	No.2 COMMON	0.255	7	$1.79	No.2 COMMON	0.255	7	$1.79	$0.00
B35II*	FAS 1-face	0.98	5	$4.90	FAS 1-face	0.98	5	$4.90	
B36	No.1 COMMON	0.52	10	$5.20	No.1 COMMON	0.52	10	$5.20	$0.00
B37	No.1 COMMON	0.52	4	$2.08	No.2 COMMON	0.255	5	$1.28	$0.81
B38	No.1 COMMON	0.52	9	$4.68	No.1 COMMON	0.52	9	$4.68	$0.00
B39	No.1 COMMON	0.52	8	$4.16	No.1 COMMON	0.52	8	$4.16	$0.00
B40	FAS 1-face	0.98	10	$9.80	FAS 1-face	0.98	10	$9.80	$0.00
B41	FAS 1-face	0.98	11	$10.78	FAS 1-face	0.98	11	$10.78	$0.00
			357	$234.61			349	$223.68	

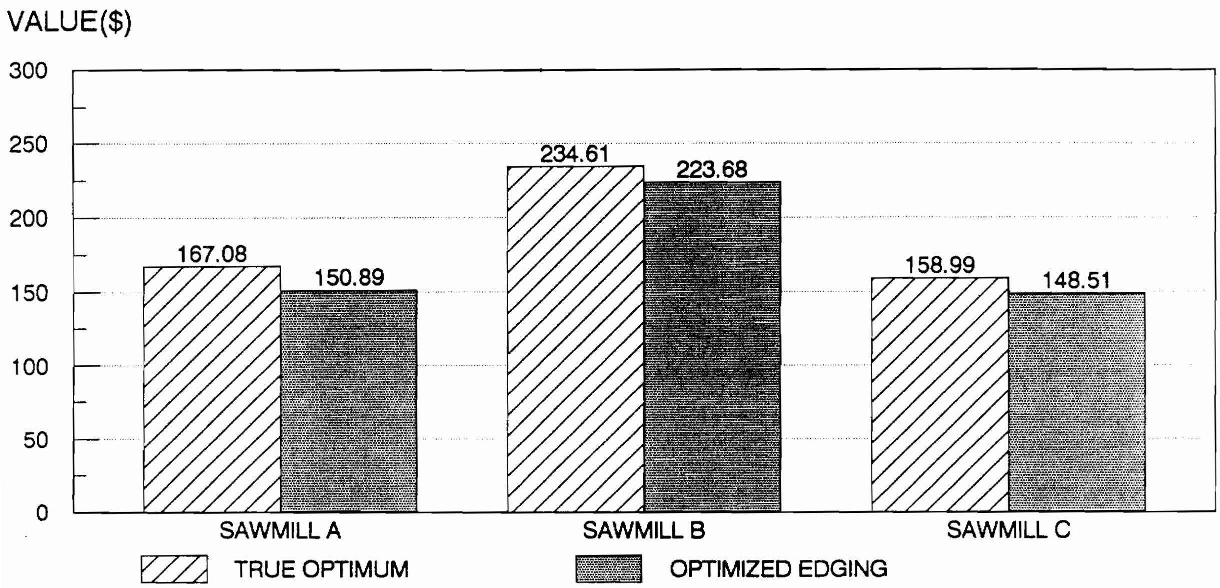
$$\text{Value recovery} = \frac{\$\ 223.68}{\$\ 234.61} \times 100\% = 95.34\%$$

* Ripped or cross-cut

Table 7c. Comparison of true optimum values vs. results of edging optimization, Sawmill C.

OPTIMIZED EDGING AND TRIMMING DATA					OPTIMIZED EDGING DATA				
BOARD LABEL	OPT. GRADE	$/BDFT.	VOLUME	VALUE	GRADE	$/BDFT.	VOLUME	VALUE	DIFFERENCE
C1	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	4	$1.02	$0.00
C2	No.1 COMMON	0.520	2	$1.04	No.2 COMMON	0.255	3	$0.77	$0.28
C3	No.2 COMMON	0.255	4	$1.02	No.3 COMMON	0.195	3	$0.59	$0.44
C4	No.1 COMMON	0.520	6	$3.12	No.1 COMMON	0.520	6	$3.12	$0.00
C5	No.1 COMMON	0.520	5	$2.60	No.1 COMMON	0.520	5	$2.60	$0.00
C7	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	5	$0.98	$0.19
C8	FAS 1-face	0.980	6	$5.88	FAS 1-face	0.980	5	$4.90	$0.98
C9	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	4	$1.02	$0.00
C11	FAS 1-face	0.980	5	$4.90	No.1 COMMON	0.520	7	$3.64	$1.26
C12	FAS 1-face	0.980	6	$5.88	FAS 1-face	0.980	6	$5.88	$0.00
C13	FAS 1-face	0.980	6	$5.88	FAS 1-face	0.980	6	$5.88	$0.00
C14	No.1 COMMON	0.520	2	$1.04	No.1 COMMON	0.520	2	$1.04	$0.00
C15	FAS 1-face	0.980	8	$7.84	FAS 1-face	0.980	8	$7.84	$0.00
C16	FAS 1-face	0.980	6	$5.88	FAS 1-face	0.980	6	$5.88	$0.00
C17	No.1 COMMON	0.520	2	$1.04	No.1 COMMON	0.520	2	$1.04	$0.00
C18	FAS 1-face	0.980	4	$3.92	FAS 1-face	0.980	4	$3.92	$0.00
C19	FAS 1-face	0.980	5	$4.90	FAS 1-face	0.980	5	$4.90	$0.00
C20	FAS 1-face	0.980	4	$3.92	FAS 1-face	0.980	4	$3.92	$0.00
C21	No.1 COMMON	0.520	5	$2.60	No.1 COMMON	0.520	5	$2.60	$0.00
C22	FAS 1-face	0.980	4	$3.92	FAS 1-face	0.980	4	$3.92	$0.00
C23	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
C24	FAS 1-face	0.980	5	$4.90	No.1 COMMON	0.520	5	$2.60	$2.30
C25	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	6	$1.53	$0.00
C26	FAS 1-face	0.980	4	$3.92	No.1 COMMON	0.520	4	$2.08	$1.84
C27	No.1 COMMON	0.520	3	$1.56	No.1 COMMON	0.520	3	$1.56	$0.00
C28	FAS 1-face	0.980	4	$3.92	No.1 COMMON	0.520	4	$2.08	$1.84
C29	No.3 COMMON	0.195	5	$0.98	No.3 COMMON	0.195	5	$0.98	$0.00
C30	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	6	$1.17	$0.00
C31	No.2 COMMON	0.255	10	$2.55	No.2 COMMON	0.255	10	$2.55	$0.00
C32	No.2 COMMON	0.255	9	$2.30	No.2 COMMON	0.255	9	$2.30	$0.00
C33	FAS	0.99	4	$3.96	No.1 COMMON	0.520	5	$2.60	$1.36
C34	FAS 1-face	0.980	9	$8.82	FAS 1-face	0.980	9	$8.82	$0.00
C35	No.1 COMMON	0.520	7	$3.64	No.1 COMMON	0.520	7	$3.64	$0.00
C36	FAS 1-face	0.980	11	$10.78	FAS 1-face	0.980	11	$10.78	$0.00
C37	No.1 COMMON	0.520	3	$1.56	No.1 COMMON	0.520	3	$1.56	$0.00
C38	No.2 COMMON	0.255	8	$2.04	No.2 COMMON	0.255	8	$2.04	$0.00
C39	FAS 1-face	0.98	12	$11.76	FAS 1-face	0.980	12	$11.76	$0.00
C40	No.1 COMMON	0.520	10	$5.20	No.1 COMMON	0.520	10	$5.20	$0.00
C41	FAS	0.990	10	$9.90	FAS	0.990	10	$9.90	$0.00
C42	FAS 1-face	0.980	8	$7.84	FAS 1-face	0.980	8	$7.84	$0.00
			232	$158.99			233	$148.51	

$$\text{Value recovery} = \frac{\$\ 148.51}{\$\ 158.99} \times 100\% = 93.41\%$$



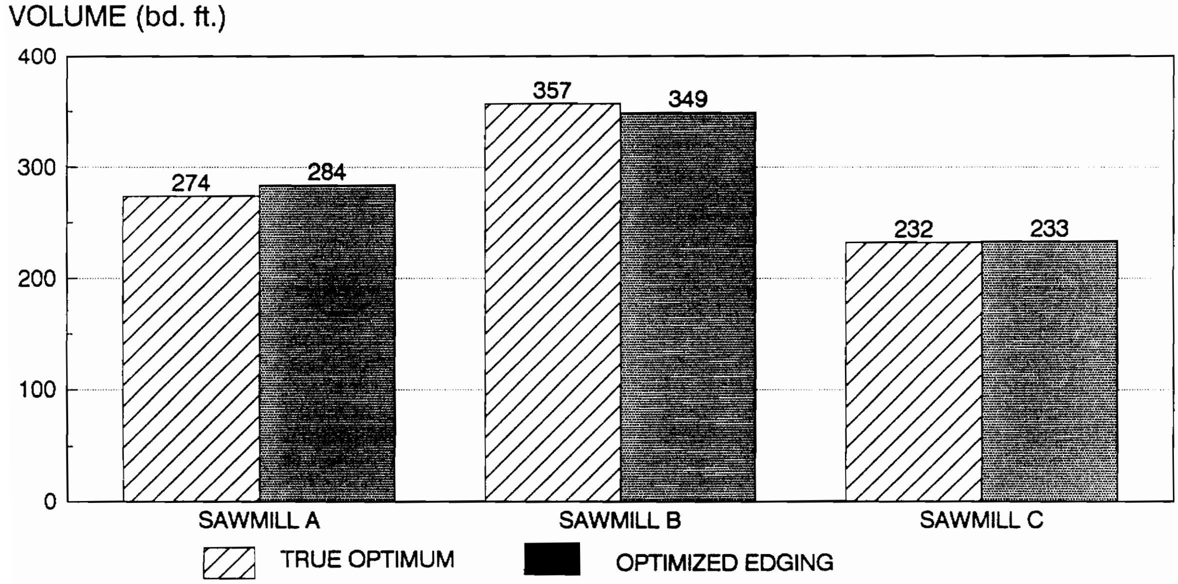


Fig. 9. Values under optimized edging vs. true optimum values.

Table 8a. Comparison of true optimum values vs. results of trimming optimization, Sawmill A.

OPTIMIZED EDGING AND TRIMMING DATA					OPTIMIZED TRIMMING DATA				
BOARD LABEL	OPT.GRADE	$/BD.FT	VOLUME	VALUE	GRADE	$/BDFT.	VOLUME	VALUE	DIFFERENCE
A1	FAS 1-face	0.980	8	$7.84	FAS 1-face	0.980	7	$6.86	$0.98
A2	No.3 COMMON	0.195	4	$0.78	No.3 COMMON	0.195	4	$0.78	$0.00
A3	FAS 1-face	0.980	7	$6.86	FAS 1-face	0.980	7	$6.86	$0.00
A4	No.1 COMMON	0.520	5	$2.60	No.1 COMMON	0.520	5	$2.60	$0.00
A5	No.1 COMMON	0.520	7	$3.64	No.1 COMMON	0.520	7	$3.64	$0.00
A6	No.1 COMMON	0.520	11	$5.72	No.1 COMMON	0.520	11	$5.72	$0.00
A7	No.2 COMMON	0.255	10	$2.55	No.2 COMMON	0.255	9	$2.30	$0.25
A8	FAS 1-face	0.980	7	$6.86	No.1 COMMON	0.520	8	$4.16	$2.70
A9	FAS 1-face	0.980	6	$5.88	FAS 1-face	0.980	6	$5.88	$0.00
A10	No.1 COMMON	0.520	4	$2.08	No.2 COMMON	0.255	5	$1.28	$0.81
A11	No.1 COMMON	0.520	7	$3.64	No.1 COMMON	0.520	7	$3.64	$0.00
A12	No.1 COMMON	0.520	6	$3.12	No.1 COMMON	0.520	6	$3.12	$0.00
A13	No.1 COMMON	0.520	6	$3.12	No.1 COMMON	0.520	6	$3.12	$0.00
A14	No.2 COMMON	0.255	9	$2.30	No.2 COMMON	0.255	9	$2.30	$0.00
A15	No.2 COMMON	0.255	7	$1.79	No.2 COMMON	0.255	7	$1.79	$0.00
A16	No.2 COMMON	0.255	11	$2.81	No.2 COMMON	0.255	10	$2.55	$0.26
A17	FAS 1-face	0.980	5	$4.90	No.2 COMMON	0.255	6	$1.53	$3.37
A18	FAS 1-face	0.980	10	$9.80	FAS 1-face	0.980	10	$9.80	$0.00
A19	FAS 1-face	0.980	7	$6.86	FAS 1-face	0.980	6	$5.88	$0.98
A20	No.1 COMMON	0.520	9	$4.68	No.1 COMMON	0.520	8	$4.16	$0.52
A21	No.1 COMMON	0.520	4	$2.08	No.2 COMMON	0.255	4	$1.02	$1.06
A22	No.3 COMMON	0.195	5	$0.98	Below Grade	0.000	5	$0.00	$0.98
A23I	No.1 COMMON	0.520	5	$2.60	No.2 COMMON	0.255	7	$1.79	$0.82
A23II	No.3 COMMON	0.195	3	$0.59					
A24	No.1 COMMON	0.520	12	$6.24	No.1 COMMON	0.520	10	$5.20	$1.04
A25	FAS	0.990	9	$8.91	FAS	0.990	9	$8.91	$0.00
A26	No.3 COMMON	0.195	6	$1.17	NO.3 COMMON	0.195	6	$1.17	$0.00
A27	No.1 COMMON	0.520	3	$1.56	No.1 COMMON	0.520	3	$1.56	$0.00
A29	FAS 1-face	0.980	7	$6.86	FAS 1-face	0.980	7	$6.86	$0.00
A30	FAS 1-face	0.980	8	$7.84	FAS 1-face	0.980	7	$6.86	$0.98
A31I*	No.1 COMMON	0.520	8	$4.16	No.2 COMMON	0.255	4	$1.02	$1.06
A31II*					No.1 COMMON	0.520	4	$2.08	
A32	No.2 COMMON	0.255	5	$1.28	No.3 COMMON	0.195	5	$0.98	$0.30
A33	No.3 COMMON	0.195	5	$0.98	No.3 COMMON	0.195	5	$0.98	$0.00
A34	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
A35	FAS 1-face	0.980	7	$6.86	FAS 1-face	0.980	6	$5.88	$0.98
A36I*	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
A36II*	Below Grade			$0.00	Below Grade				$0.00
A37	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	4	$1.02	$0.00
A38	FAS	0.990	12	$11.88	FAS	0.990	12	$11.88	$0.00
A39	FAS 1-face	0.980	7	$6.86	FAS 1-face	0.980	7	$6.86	$0.00
A40	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
A41	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	5	$0.98	$0.19
			274	$167.08			266	$149.22	

$$\text{Value recovery} = \frac{\$\,149.22}{\$\,167.08} \times 100\% = 89.31\%$$

* Ripped or cross-cut

Table 8b. Comparison of true optimum values vs. results of trimming optimization, Sawmill B

OPTIMIZED EDGING AND TRIMMING DATA					OPTIMIZED TRIMMING DATA				
BOARD LABEL	OPT. GRADE	$/BDFT	VOLUME	VALUE	GRADE	$/BDFT	VOLUME	VALUE	DIFFERENCE
B2	No.3 COMMON	0.195	9	$1.76	No.3 COMMON	0.195	7	$1.37	$0.39
B3	No.2 COMMON	0.255	12	$3.06	No.2 COMMON	0.255	10	$2.55	$0.51
B4	No.1 COMMON	0.52	5	$2.60	No.2 COMMON	0.255	5	$1.28	$1.33
B5	FAS 1-face	0.98	6	$5.88	No.2 COMMON	0.255	4	$1.02	$4.86
B6	No.2 COMMON	0.255	14	$3.57	No.2 COMMON	0.255	10	$2.55	$1.02
B7	FAS 1-face	0.98	5	$4.90	No.1 COMMON	0.52	4	$2.08	$2.82
B8	FAS 1-face	0.98	14	$13.72	No.1 COMMON	0.52	13	$6.76	$6.96
B9	FAS 1-face	0.98	12	$11.76	FAS	0.99	9	$8.91	$2.85
B10	No.2 COMMON	0.255	7	$1.79	No.2 COMMON	0.255	7	$1.79	$0.00
B11	No.2 COMMON	0.255	11	$2.81	No.2 COMMON	0.255	7	$1.79	$1.02
B12	FAS 1-face	0.98	5	$4.90	No.1 COMMON	0.52	5	$2.60	$2.30
B13	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	5	$1.28	$0.26
B14	No.1 COMMON	0.52	9	$4.68	No.2 COMMON	0.255	8	$2.04	$2.64
B15	No.1 COMMON	0.52	16	$8.32	No.1 COMMON	0.52	14	$7.28	$1.04
B16	No.1 COMMON	0.52	14	$7.28	No.1 COMMON	0.52	13	$6.76	$0.52
B17	FAS 1-face	0.98	4	$3.92	No.1 COMMON	0.52	4	$2.08	$1.84
B18	FAS	0.99	6	$5.94	FAS	0.99	5	$4.95	$0.99
B19	FAS	0.99	12	$11.88	FAS	0.99	10	$9.90	$1.98
B20	FAS 1-face	0.98	6	$5.88	No.1 COMMON	0.52	7	$3.64	$2.24
B21	FAS 1-face	0.98	6	$5.88	FAS 1-face	0.98	5	$4.90	$0.98
B22	FAS 1-face	0.98	11	$10.78	FAS 1-face	0.98	8	$7.84	$2.94
B23	No.1 COMMON	0.52	5	$2.60	No.1 COMMON	0.52	5	$2.60	$0.00
B24I*	No.1 COMMON	0.52	6	$3.12	No.2 COMMON	0.255	10	$2.55	$1.55
B24II*	No.3 COMMON	0.195	5	$0.98					
B25	No.1 COMMON	0.52	5	$2.60	No.2 COMMON	0.255	4	$1.02	$1.58
B26	No.2 COMMON	0.255	9	$2.30	No.2 COMMON	0.255	7	$1.79	$0.51
B27	FAS 1-face	0.98	7	$6.86	FAS 1-face	0.98	5	$4.90	$1.96
B28	No.1 COMMON	0.52	6	$3.12	No.2 COMMON	0.255	8	$2.04	$1.08
B29	No.1 COMMON	0.52	15	$7.80	No.1 COMMON	0.52	13	$6.76	$1.04
B30	FAS 1-face	0.98	6	$5.88	No.1 COMMON	0.52	5	$2.60	$3.28
B31	FAS 1-face	0.98	12	$11.76	FAS 1-face	0.98	10	$9.80	$1.96
B32	FAS 1-face	0.98	7	$6.86	FAS 1-face	0.98	6	$5.88	$0.98
B33I*	No.2 COMMON	0.255	7	$1.79	No.1 COMMON	0.52	12	$6.24	$1.43
B33II*	FAS 1-face	0.98	6	$5.88					
B34	FAS 1-face	0.98	7	$6.86	FAS 1-face	0.98	6	$5.88	$0.98
B35I*	No.2 COMMON	0.255	7	$1.79	No.2 COMMON	0.255	11	$2.81	$3.88
B35II*	FAS 1-face	0.98	5	$4.90					
B36	No.1 COMMON	0.52	10	$5.20	No.1 COMMON	0.52	9	$4.68	$0.52
B37	No.1 COMMON	0.52	4	$2.08	No.1 COMMON	0.52	4	$2.08	$0.00
B38	No.1 COMMON	0.52	9	$4.68	No.1 COMMON	0.52	8	$4.16	$0.52
B39	No.1 COMMON	0.52	8	$4.16	No.1 COMMON	0.52	7	$3.64	$0.52
B40	FAS 1-face	0.98	10	$9.80	FAS 1-face	0.98	9	$8.82	$0.98
B41	FAS 1-face	0.98	11	$10.78	No.1 COMMON	0.52	9	$4.68	$6.10
			357	$234.61			308	$166.27	

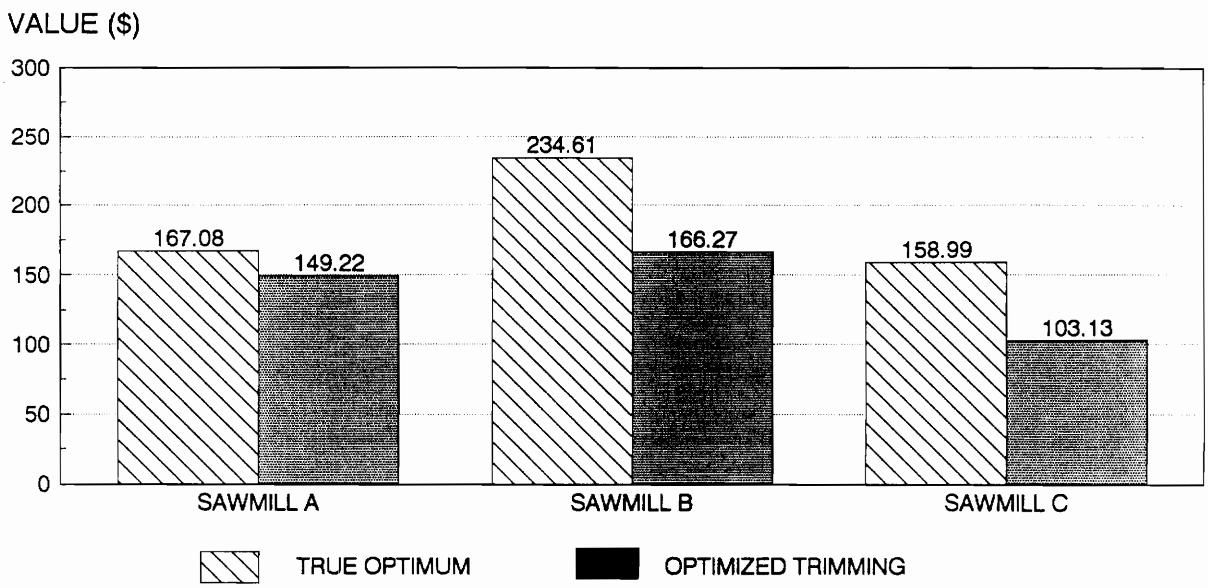
$$\text{Value recovery} = \frac{\$\ 166.27}{\$\ 234.61} \times 100\% = 70.87\%$$

* Ripped or cross-cut

Table 8c. Comparison of true optimum values vs. results of trimming optimization, Sawmill C.

	OPTIMIZED EDGING AND TRIMMING DATA				OPTIMIZED TRIMMING DATA				
BOARD LABEL	OPT. GRADE	$/BDFT.	VOLUME	VALUE	GRADE	$/BDFT.	VOLUME	VALUE	DIFFERENCE
C1	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	4	$1.02	$0.00
C2	No.1 COMMON	0.520	2	$1.04	No.1 COMMON	0.520	2	$1.04	$0.00
C3	No.2 COMMON	0.255	4	$1.02	No.3 COMMON	0.195	3	$0.59	$0.44
C4	No.1 COMMON	0.520	6	$3.12	No.1 COMMON	0.520	2	$1.04	$2.08
C5	No.1 COMMON	0.520	5	$2.60	No.1 COMMON	0.520	4	$2.08	$0.52
C7	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	4	$0.78	$0.39
C8	FAS 1-face	0.980	6	$5.88	No.1 COMMON	0.520	4	$2.08	$3.80
C9	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	2	$0.51	$0.51
C11	FAS 1-face	0.980	5	$4.90	FAS 1-face	0.980	5	$4.90	$0.00
C12	FAS 1-face	0.980	6	$5.88	No.2 COMMON	0.255	5	$1.28	$4.61
C13	FAS 1-face	0.980	6	$5.88	FAS 1-face	0.980	6	$5.88	$0.00
C14	No.1 COMMON	0.520	2	$1.04	No.1 COMMON	0.520	2	$1.04	$0.00
C15	FAS 1-face	0.980	8	$7.84	FAS 1-face	0.980	6	$5.88	$1.96
C16	FAS 1-face	0.980	6	$5.88	FAS	0.990	4	$3.96	$1.92
C17	No.1 COMMON	0.520	2	$1.04	No.1 COMMON	0.520	2	$1.04	$0.00
C18	FAS 1-face	0.980	4	$3.92	No.1 COMMON	0.520	3	$1.56	$2.36
C19	FAS 1-face	0.980	5	$4.90	No.1 COMMON	0.520	4	$2.08	$2.82
C20	FAS 1-face	0.980	4	$3.92	FAS 1-face	0.980	4	$3.92	$0.00
C21	No.1 COMMON	0.520	5	$2.60	No.1 COMMON	0.520	5	$2.60	$0.00
C22	FAS 1-face	0.980	4	$3.92	No.2 COMMON	0.255	5	$1.28	$2.65
C23	No.1 COMMON	0.520	4	$2.08	No.2 COMMON	0.255	4	$1.02	$1.06
C24	FAS 1-face	0.980	5	$4.90	No.1 COMMON	0.520	3	$1.56	$3.34
C25	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	4	$1.02	$0.51
C26	FAS 1-face	0.980	4	$3.92	No.1 COMMON	0.520	3	$1.56	$2.36
C27	No.1 COMMON	0.520	3	$1.56	No.1 COMMON	0.520	3	$1.56	$0.00
C28	FAS 1-face	0.980	4	$3.92	No.1 COMMON	0.520	4	$2.08	$1.84
C29	No.3 COMMON	0.195	5	$0.98	No.3 COMMON	0.195	3	$0.59	$0.39
C30	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	6	$1.17	$0.00
C31	No.2 COMMON	0.255	10	$2.55	No.2 COMMON	0.255	9	$2.30	$0.25
C32	No.2 COMMON	0.255	9	$2.30	No.2 COMMON	0.255	6	$1.53	$0.77
C33	FAS	0.99	4	$3.96	No.1 COMMON	0.52	4	$2.08	$1.88
C34	FAS 1-face	0.980	9	$8.82	FAS 1-face	0.980	8	$7.84	$0.98
C35	No.1 COMMON	0.520	7	$3.64	No.1 COMMON	0.520	7	$3.64	$0.00
C36	FAS 1-face	0.980	11	$10.78	FAS	0.990	9	$8.91	$1.87
C37	No.1 COMMON	0.520	3	$1.56	No.3 COMMON	0.195	3	$0.59	$0.98
C38	No.2 COMMON	0.255	8	$2.04	No.2 COMMON	0.255	7	$1.79	$0.25
C39	FAS 1-face	0.98	12	$11.76	No.1 COMMON	0.52	9	$4.68	$7.08
C40	No.1 COMMON	0.520	10	$5.20	No.1 COMMON	0.520	8	$4.16	$1.04
C41	FAS	0.990	10	$9.90	FAS	0.990	8	$7.92	$1.98
C42	FAS 1-face	0.980	8	$7.84	No.1 COMMON	0.520	5	$2.60	$5.24
			232	$158.99			189	$103.13	

$$\text{Value recovery} = \frac{\$\ 103.13}{\$\ 158.99} \times 100\% = 64.87\%$$



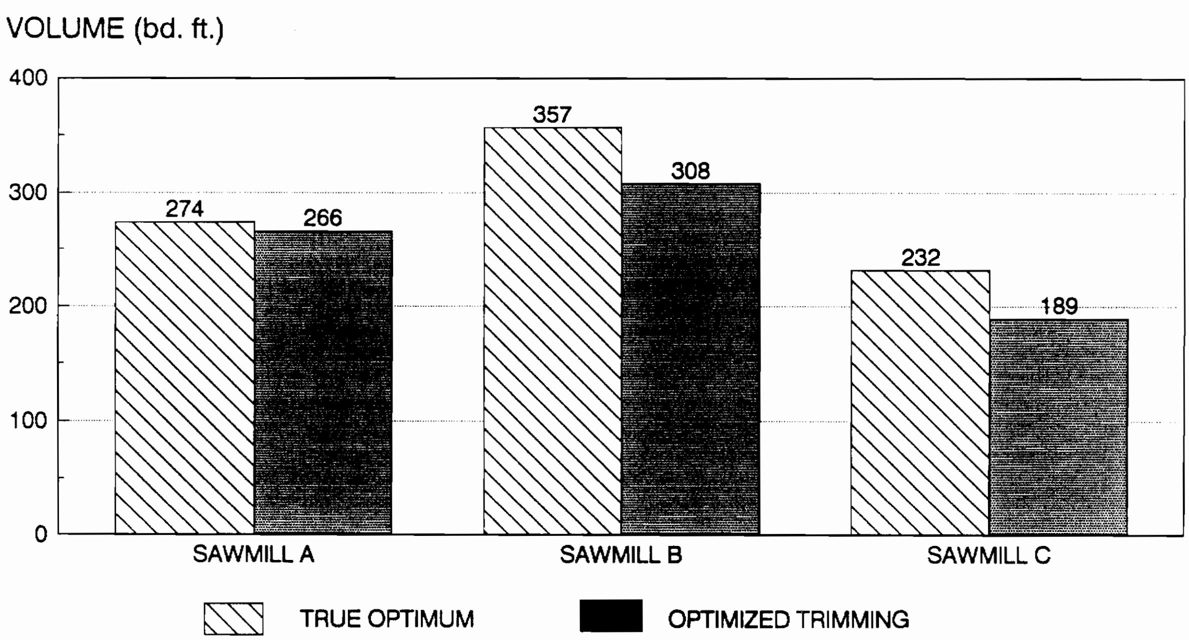


Fig. 10. Values under optimized trimming vs. true optimum values.

Furthermore, since trimming solutions in the trimming optimization procedure were based on predetermined **actual edging decisions**, the fact that a relatively lower value recovery was obtained from trimming optimization for mills B and C implies that trimming optimization can not substantially upgrade value once an erroneous edging decision has been made. The latter observation, in particular, applied to overedged boards.

Chapter 6

EDGING AND TRIMMING SOLUTIONS BASED ON WANE DATA

Optimization of edging and trimming for hardwood lumber ideally requires complete board defect information. As seen from results comparing lumber values obtained from optimized solutions to actual sawmill output, substantial increases in lumber value are possible. However, the scanning technology that could provide the information required by the optimization procedure used at arriving at the above results are not currently available.

The phase of the research discussed in this section investigated the potential lumber value recovery from a model in which edging and trimming solutions are based only on wane data. As discussed in Chapter 2, this type of board input data represents the capability of scanners currently utilized in softwood edging and trimming optimization.

DESCRIPTION OF WANE-BASED OPTIMIZATION MODEL

The model for the wane-based edging and trimming optimization may be summarized by the following:

Objective: Maximize volume

Constraint: NHLA wane restrictions for each lumber grade and the 50/50% wane rule for well-manufactured lumber

Input: i) Board cross-section data at every three-inch interval
ii) Edger operator's estimate of potential grade

The absence of complete board defect data precluded lumber grade evaluation, and consequently the determination of value. Thus, in contrast with the optimization procedure described in Chapter 4 where the objective was lumber value maximization, the aim of the wane-based model was to maximize volume without exceeding the amount of wane permitted by the potential grade as estimated by the edger operator. Board scanners currently used in industry are able to yield cross-section data at regular intervals along the length of the board. The three-inch interval selected for this study is within the capability of these scanners.

A computer program was used (program name: MAINWANE.EXE, language: Microsoft FORTRAN),.[4] for finding the wane-based edging and trimming solution. The algorithm for the program is summarized in Fig.11. Variable names used in the flowchart in Fig. 11 follow the same definition as those enumerated in Table 3 of the previous chapter.

Prior to actual edging and trimming of each board in the sample, the edger operator was asked to estimate the grade potentially obtainable from the unprocessed board. This information was used in the wane-based optimization model as an indicator of the board's appearance in lieu of actual defect data. To describe the board's shape, y-coordinates of the four edges of the board at every three-inch interval were used. Figure 12 shows a sample board with the corresponding cross-section data. The above information, i.e. grade estimate and cross-section data were used as initial input to the program MAINWANE.

As with the procedure for finding the optimum cutting solution, the algorithm used in MAINWANE was an iterative variation of edging and trimming lines, with cutting line variation starting

---

[4] See Appendix B.

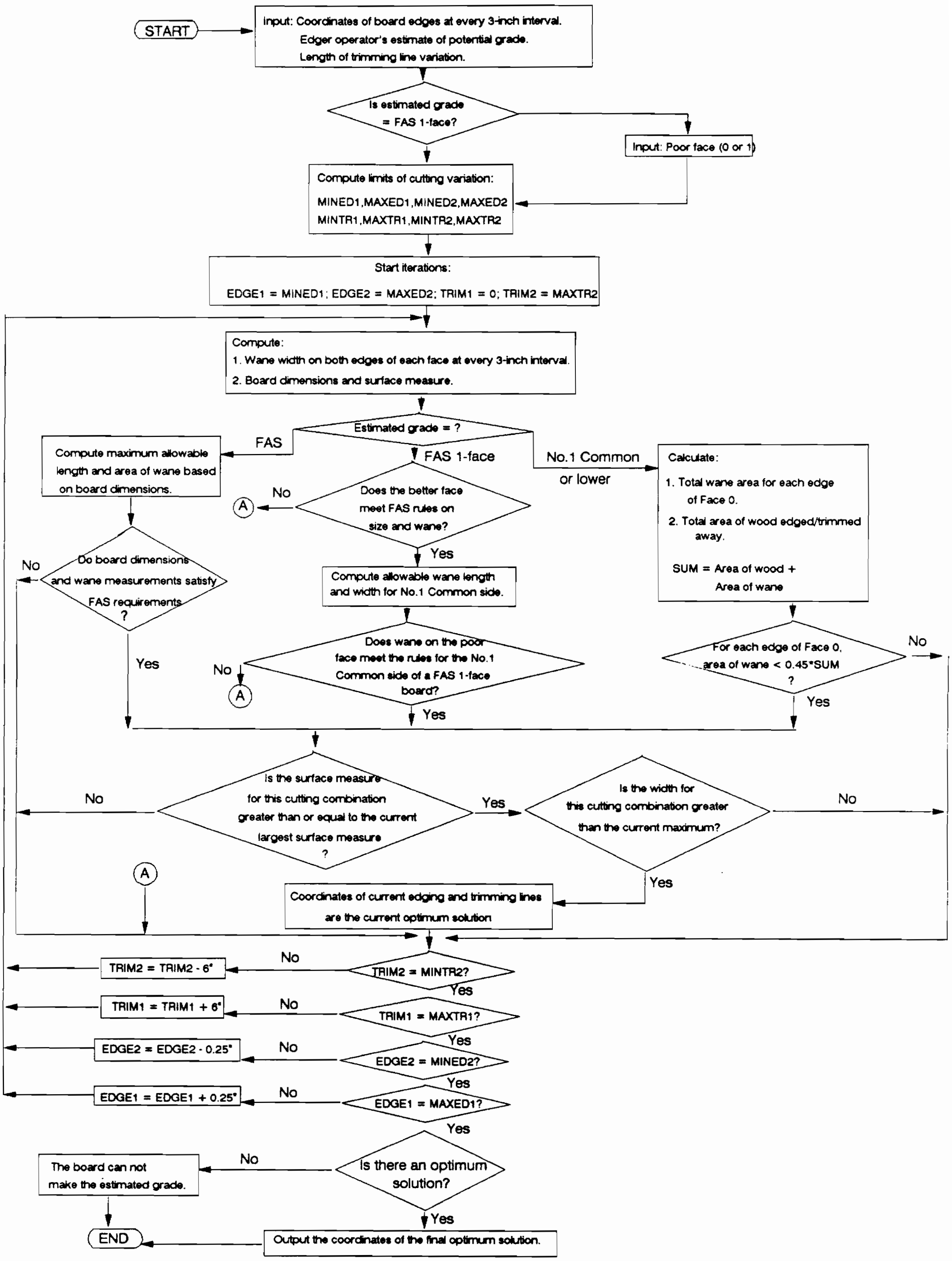
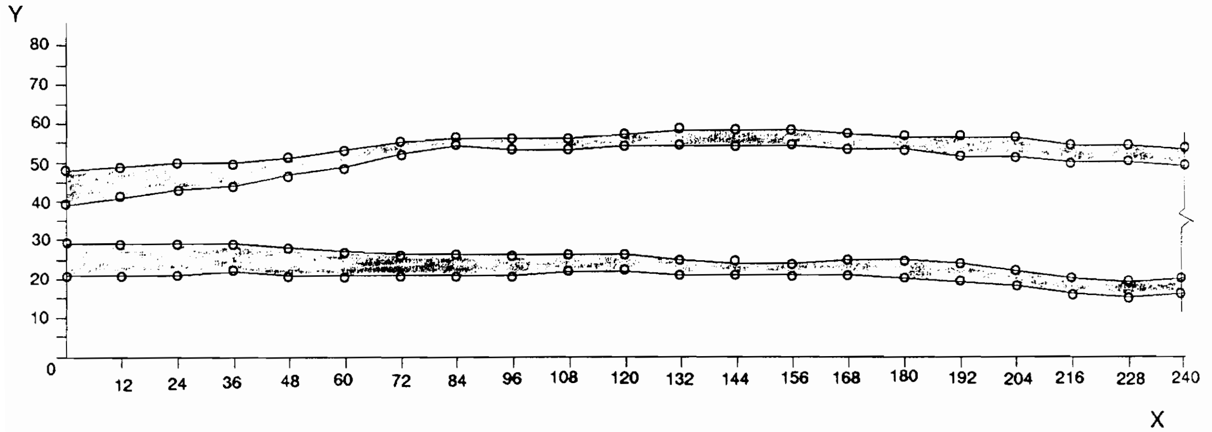


Fig. 11. Algorithm for wane-based edging and trimming optimization.



Distance along board length:	Y-coordinate of board edges:			
0	21	29	39	48
12	21	29	41	49
24	21	29	43	50
36	22	29	44	50
48	21	28	47	51
60	21	27	49	53
72	21	26	52	55
84	21	26	54	56
96	21	26	53	56
108	22	26	53	56
120	22	26	54	57
132	21	25	54	58
144	21	24	54	58
156	21	24	54	58
168	21	25	53	57
180	19	24	51	56
.				
.				
.				
.				
.				
.				
.				

1 unit = 0.25 inch

Fig. 12. Input data for wane-based optimization program.

from the outer limits proceeding inward on all four sides of the board. Increments used for varying cutting lines were one quarter inch and six inches for edging and trimming, respectively.

The limits for varying edging and trimming lines are illustrated in Fig. 13. Outer trimming limits were placed at end points of the board. The distance between inner and outer limits for trimming was variable and was left for the user to specify. In general, trimming line limits followed the same guidelines as those used in the regular (complete input) optimization. The range of edging lines covered all wane areas at the edges of the board. Outer edging limits were placed at the y-coordinates such that each edging line intersected at least 5 feet of the length of the board. The purpose of the above was to eliminate iterations resulting to excessively short boards.

For each combination of cutting lines, wane width values at both edges of each face were computed at every three-inch interval along the length of the board. This information was supplied to the appropriate subroutine based on the estimated grade. The following discussion gives a brief description of each grade subroutine.

Subroutine for the FAS grade:

If a board was estimated to be a potential FAS piece, board dimensions and area and length of wane were checked against FAS requirements. Unlike the optimization procedure described in Chapter 4 where wane areas were enclosed by rectangular regions, total wane area in this procedure was computed as a series of trapezoids with 3-inch bases and with the sides defined by the wane width at each interval endpoint. This method of wane representation is illustrated in Fig. 14.

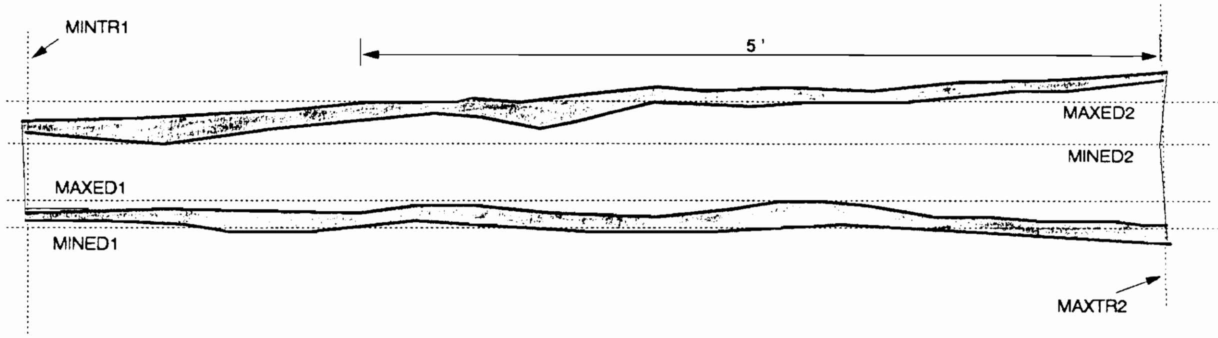


Fig. 13. Limits for varying cutting lines for wane-based optimization. (Refer to Table 3, Chapter 4 for variable definitions).

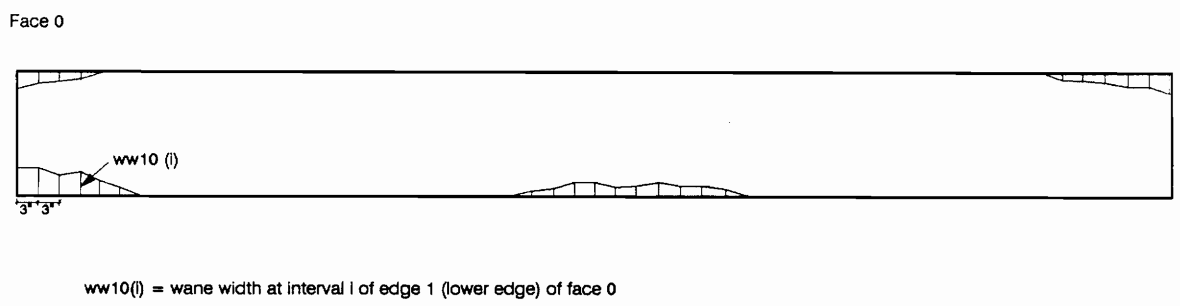


Fig. 14. Method of wane representation for wane-based optimization procedure.

Subroutine for the FAS 1-face grade:

An additional input information was required for boards expected to grade as FAS 1-face. Since wane rules for the better face of an FAS 1-face board differ from those for the poorer face, it must be specified whether the poorer face was Face 0 or Face 1. This information was determined by visual inspection of the board image on plastic sheet. Wane measurements on the better face were sent to the FAS subroutine, while those on the poorer face were checked against the wane rules for the No.1 Common side of an FAS 1-face lumber.

Subroutine for the Common grades:

A modification of the 50-50% edging rule was used for boards estimated to grade as No.1 Common and below. The above rule states that for Common grade boards, the area of wane remaining on the board should be approximately equal to the area of clear wood removed by edging and/or trimming. With wane as the only available data, it would not be possible to determine whether the area of wood removed was all clear wood. As such, a 5% allowance was made for other defects that may be present on the wood removed. Thus, instead of a 50:50 ratio of wane to removed wood, only those cutting line combinations resulting to a 45:55 wane to removed wood ratio were accepted as potential cutting solutions.

The combination of edging and trimming lines that yielded the highest surface measure while satisfying the size and wane requirements of the estimated grade was selected as the "optimum" cutting solution. In cases where several cutting combinations met the above criterion, the set of cutting lines producing the widest (and therefore shortest) board was preferred. This rule was aimed at minimizing the presence of end defects, specifically end splits.

COMPARISON OF OPTIMUM VS. WANE-BASED RESULTS

A. Lumber Value Comparison

Results comparing lumber values obtained from the wane-based model to values from the complete input optimization are tabulated in Tables 9a-c and summarized in Fig. 15. Computed values of lumber value recovery in Tables 4a-c and 9a-c show that values from the wane-based procedure were closer to the true optimum than the actual sawmill solutions. While value recovery from actual operations were 80.01%, 64.75%, and 62.47% for mills A, B, and C respectively, the following were yielded by the wane-based optimization procedure: 81.42%, 84.06%, and 74.93%. Thus, results of this study suggested that approximately 80%, on the average, of the theoretically possible lumber value can be obtained if wane were the sole basis of edging and trimming decisions.

B. Difference as a Function of Potential Grade

An analysis similar to that discussed in the previous chapter to assess the effect of board quality on percent difference values was performed on the data in Tables 9a-c. Explanation of the procedural steps and interpretation of computed values are discussed in Chapter 5 in the section having the same title as above. The results of this analysis shown in Table 10 indicate that wane information was not sufficient to optimally edge and trim potential FAS 1-face and No.1 Common pieces. For the low quality boards, i.e. those where the optimal grades are No.2 and No.3 Common, the wane-based model was able to arrive at the optimum solutions. Thus, results

Table 9a. Optimum lumber values vs. values from wane-based procedure, Sawmill A.

OPTIMIZATION BASED ON COMPLETE INPUT DATA					OPTIMIZATION BASED ON WANE INPUT ONLY				
BOARD LABEL	OPT. GRADE	$/BDFT.	VOLUME	VALUE	GRADE	$/BDFT.	VOLUME	VALUE	DIFFERENCE
A1	FAS 1-face	0.980	8	$7.84	FAS 1-face	0.980	8	$7.84	$0.00
A2	No.3 COMMON	0.195	4	$0.78	No.3 COMMON	0.195	4	$0.78	$0.00
A3	FAS 1-face	0.980	7	$6.86	No.1 COMMON	0.520	9	$4.68	$2.18
A4	No.1 COMMON	0.520	5	$2.60	No.2 COMMON	0.255	6	$1.53	$1.07
A5	No.1 COMMON	0.520	7	$3.64	No.2 COMMON	0.255	7	$1.79	$1.86
A6	No.1 COMMON	0.520	11	$5.72	NO.2 COMMON	0.255	12	$3.06	$2.66
A7	No.2 COMMON	0.255	10	$2.55	No.2 COMMON	0.255	10	$2.55	$0.00
A8	FAS 1-face	0.980	7	$6.86	No.1 COMMON	0.520	8	$4.16	$2.70
A9	FAS 1-face	0.980	6	$5.88	No.1 COMMON	0.520	7	$3.64	$2.24
A10	No.1 COMMON	0.520	4	$2.08	No.2 COMMON	0.255	6	$1.53	$0.55
A11	No.1 COMMON	0.520	7	$3.64	No.1 COMMON	0.520	7	$3.64	$0.00
A12	No.1 COMMON	0.520	6	$3.12	No.2 COMMON	0.255	9	$2.30	$0.83
A13	No.1 COMMON	0.520	6	$3.12	No.1 COMMON	0.520	6	$3.12	$0.00
A14	No.2 COMMON	0.255	9	$2.30	No.2 COMMON	0.255	9	$2.30	$0.00
A15	No.2 COMMON	0.255	7	$1.79	No.2 COMMON	0.255	7	$1.79	$0.00
A16	No.2 COMMON	0.255	11	$2.81	No.2 COMMON	0.255	11	$2.81	$0.00
A17	FAS 1-face	0.980	5	$4.90	No.1 COMMON	0.520	5	$2.60	$2.30
A18	FAS 1-face	0.980	10	$9.80	FAS 1-face	0.980	10	$9.80	$0.00
A19	FAS 1-face	0.980	7	$6.86	No.1 COMMON	0.520	8	$4.16	$2.70
A20	No.1 COMMON	0.520	9	$4.68	No.1 COMMON	0.520	9	$4.68	$0.00
A21	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
A22	No.3 COMMON	0.195	5	$0.98	No.3 COMMON	0.195	5	$0.98	$0.00
A23I*	No.1 COMMON	0.520	5	$2.60	No.2 COMMON	0.255	8	$2.04	$1.15
A23II*	No.3 COMMON	0.195	3	$0.59					
A24	No.1 COMMON	0.520	12	$6.24	No.1 COMMON	0.520	12	$6.24	$0.00
A25	FAS	0.990	9	$8.91	FAS	0.990	9	$8.91	$0.00
A26	NO.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	6	$1.17	$0.00
A27	No.1 COMMON	0.520	3	$1.56	No.2 COMMON	0.255	4	$1.02	$0.54
A29	FAS 1-face	0.980	7	$6.86	No.1 COMMON	0.520	8	$4.16	$2.70
A30	FAS 1-face	0.980	8	$7.84	No.1 COMMON	0.520	10	$5.20	$2.64
A31I*	NO.1 COMMON	0.520	8	$4.16	No.1 COMMON	0.520	8	$4.16	$0.00
A32	No.2 COMMON	0.255	5	$1.28	No.2 COMMON	0.255	5	$1.28	$0.00
A33	No.3 COMMON	0.195	5	$0.98	No.3 COMMON	0.195	5	$0.98	$0.00
A34	No.1 COMMON	0.520	4	$2.08	No.2 COMMON	0.255	5	$1.28	$0.81
A35	FAS 1-face	0.980	7	$6.86	FAS 1-face	0.980	7	$6.86	$0.00
A36I*	No.1 COMMON	0.520	4	$2.08	No.3 COMMON	0.195	6	$1.17	$0.91
A36II*	Below Grade			$0.00				$0.00	
A37	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	4	$1.02	$0.00
A38	FAS	0.990	12	$11.88	FAS	0.990	12	$11.88	$0.00
A39	FAS 1-face	0.980	7	$6.86	No.1 COMMON	0.520	7	$3.64	$3.22
A40	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
A41	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	6	$1.17	$0.00
			274	$167.08			293	$136.04	

$$\text{Value recovery} = \frac{\$\ 136.04}{\$\ 167.08} \times 100\% = 81.42\%$$

* Ripped or cross-cut

Table 9b. Optimum lumber values vs. values from wane-based procedure, Sawmill B.

OPTIMIZATION BASED ON COMPLETE INPUT DATA					OPTIMIZATION BASED ON WANE INPUT ONLY				
BOARD LABEL	OPT. GRADE	$/BDFT.	VOLUME	VALUE	GRADE	$/BDFT.	VOLUME	VALUE	DIFFERENCE
B2	No.3 COMMON	0.195	9	$1.76	No.3 COMMON	0.195	9	$1.76	$0.00
B3	No.2 COMMON	0.255	12	$3.06	No.2 COMMON	0.255	12	$3.06	$0.00
B4	No.1 COMMON	0.52	5	$2.60	No.1 COMMON	0.52	5	$2.60	$0.00
B5	FAS 1-face	0.98	6	$5.88	No.1 COMMON	0.52	7	$3.64	$2.24
B6	No.2 COMMON	0.255	14	$3.57	No.2 COMMON	0.255	14	$3.57	$0.00
B7	FAS 1-face	0.98	5	$4.90	No.1 COMMON	0.52	5	$2.60	$2.30
B8	FAS 1-face	0.98	14	$13.72	No.1 COMMON	0.52	14	$7.28	$6.44
B9	FAS 1-face	0.98	12	$11.76	FAS 1-face	0.98	12	$11.76	$0.00
B10	No.2 COMMON	0.255	7	$1.79	No.3 COMMON	0.195	8	$1.56	$0.23
B11	No.2 COMMON	0.255	11	$2.81	No.2 COMMON	0.255	11	$2.81	$0.00
B12	FAS 1-face	0.98	5	$4.90	No.1 COMMON	0.52	6	$3.12	$1.78
B13	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	6	$1.53	$0.00
B14	No.1 COMMON	0.52	9	$4.68	No.2 COMMON	0.255	11	$2.81	$1.87
B15	No.1 COMMON	0.52	16	$8.32	No.1 COMMON	0.52	16	$8.32	$0.00
B16	No.1 COMMON	0.52	14	$7.28	No.1 COMMON	0.52	14	$7.28	$0.00
B17	FAS 1-face	0.98	4	$3.92	FAS 1-face	0.98	4	$3.92	$0.00
B18	FAS	0.99	6	$5.94	No.1 COMMON	0.52	9	$4.68	$1.26
B19	FAS	0.99	12	$11.88	FAS	0.99	12	$11.88	$0.00
B20	FAS 1-face	0.98	6	$5.88	No.2 COMMON	0.255	9	$2.30	$3.59
B21	FAS 1-face	0.98	6	$5.88	No.1 COMMON	0.52	8	$4.16	$1.72
B22	FAS 1-face	0.98	11	$10.78	FAS 1-face	0.98	11	$10.78	$0.00
B23	No.1 COMMON	0.52	5	$2.60	No.2 COMMON	0.255	7	$1.79	$0.82
B24I*	No.1 COMMON	0.52	6	$3.12	No.2 COMMON	0.255	12	$3.06	$1.04
B24II*	No.3 COMMON	0.195	5	$0.98					
B25	No.1 COMMON	0.52	5	$2.60	No.2 COMMON	0.255	6	$1.53	$1.07
B26	No.2 COMMON	0.255	9	$2.30	No.2 COMMON	0.255	9	$2.30	$0.00
B27	FAS 1-face	0.98	7	$6.86	FAS 1-face	0.98	7	$6.86	$0.00
B28	No.1 COMMON	0.52	6	$3.12	No.2 COMMON	0.255	8	$2.04	$1.08
B29	No.1 COMMON	0.52	15	$7.80	No.1 COMMON	0.52	15	$7.80	$0.00
B30	FAS 1-face	0.98	6	$5.88	No.2 COMMON	0.255	8	$2.04	$3.84
B31	FAS 1-face	0.98	12	$11.76	FAS 1-face	0.98	12	$11.76	$0.00
B32	FAS 1-face	0.98	7	$6.86	No.1 COMMON	0.52	9	$4.68	$2.18
B33I*	No.2 COMMON	0.255	7	$1.79	No.1 COMMON	0.52	13	$6.76	$0.91
B33II*	FAS 1-face	0.98	6	$5.88					
B34	FAS 1-face	0.98	7	$6.86	No.2 COMMON	0.255	11	$2.81	$4.06
B35I*	No.2 COMMON	0.255	7	$1.79	No.1 COMMON	0.52	12	$6.24	$0.45
B35II*	FAS 1-face	0.98	5	$4.90				$0.00	
B36	No.1 COMMON	0.52	10	$5.20	No.1 COMMON	0.52	10	$5.20	$0.00
B37	No.1 COMMON	0.52	4	$2.08	No.2 COMMON	0.255	6	$1.53	$0.55
B38	No.1 COMMON	0.52	9	$4.68	No.1 COMMON	0.52	9	$4.68	$0.00
B39	No.1 COMMON	0.52	8	$4.16	No.1 COMMON	0.52	8	$4.16	$0.00
B40	FAS 1-face	0.98	10	$9.80	FAS 1-face	0.98	10	$9.80	$0.00
B41	FAS 1-face	0.98	11	$10.78	FAS 1-face	0.98	11	$10.78	$0.00
			357	$234.61			386	$197.21	

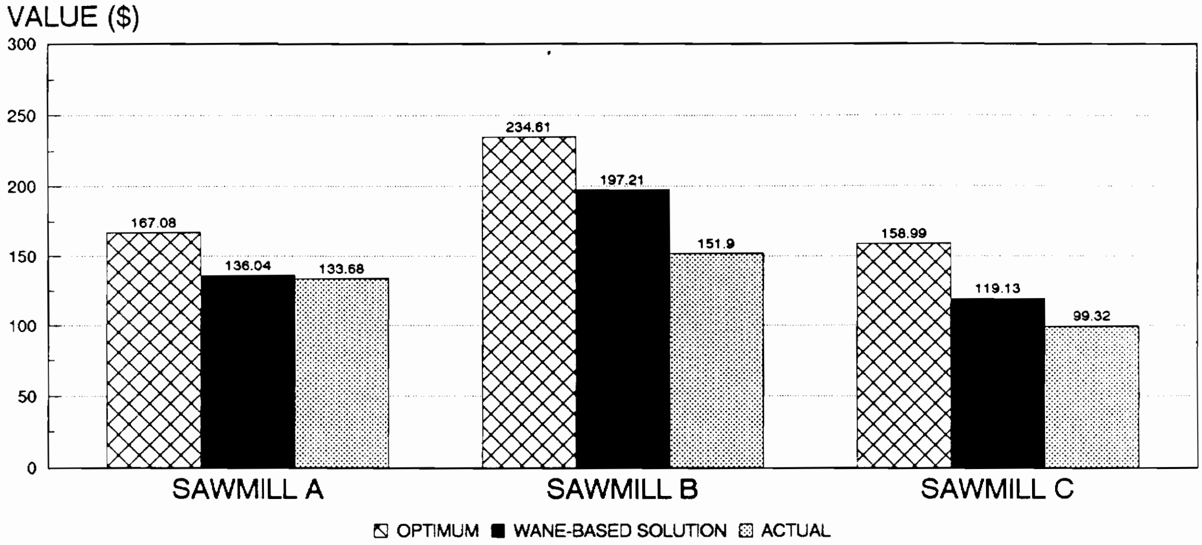
$$\text{Value recovery} = \frac{\$\ 197.21}{\$\ 234.61} \times 100\% = 84.06\%$$

* Ripped or cross-cut

Table 9c. Optimum lumber values vs. values from wane-based procedure, Sawmill C.

OPTIMIZATION BASED ON COMPLETE INPUT DATA					OPTIMIZATION BASED ON WANE INPUT ONLY				
BOARD LABEL	OPT. GRADE	$/BDFT.	VOLUME	VALUE	GRADE	$/BDFT	VOLUME	VALUE	DIFFERENCE
C1	No.2 COMMON	0.255	4	$1.02	No.3 COMMON	0.195	5	$0.98	$0.04
C2	No.1 COMMON	0.520	2	$1.04	No.2 COMMON	0.255	4	$1.02	$0.02
C3	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	4	$1.02	$0.00
C4	No.1 COMMON	0.520	6	$3.12	No.1 COMMON	0.520	6	$3.12	$0.00
C5	No.1 COMMON	0.520	5	$2.60	No.1 COMMON	0.520	5	$2.60	$0.00
C7	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	6	$1.17	$0.00
C8	FAS 1-face	0.980	6	$5.88	No.2 COMMON	0.255	6	$1.53	$4.35
C9	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	4	$1.02	$0.00
C11	FAS 1-face	0.980	5	$4.90	No.2 COMMON	0.255	7	$1.79	$3.12
C12	FAS 1-face	0.980	6	$5.88	No.2 COMMON	0.255	7	$1.79	$4.10
C13	FAS 1-face	0.980	6	$5.88	No.2 COMMON	0.255	7	$1.79	$4.10
C14	No.1 COMMON	0.520	2	$1.04	No.2 COMMON	0.255	4	$1.02	$0.02
C15	FAS 1-face	0.980	8	$7.84	FAS 1-face	0.980	8	$7.84	$0.00
C16	FAS 1-face	0.980	6	$5.88	FAS 1-face	0.980	6	$5.88	$0.00
C17	No.1 COMMON	0.520	2	$1.04	No.1 COMMON	0.255	2	$0.51	$0.53
C18	FAS 1-face	0.980	4	$3.92	No.2 COMMON	0.255	5	$1.28	$2.65
C19	FAS 1-face	0.980	5	$4.90	FAS 1-face	0.980	5	$4.90	$0.00
C20	FAS 1-face	0.980	4	$3.92	No.1 COMMON	0.520	6	$3.12	$0.80
C21	No.1 COMMON	0.520	5	$2.60	No.2 COMMON	0.255	6	$1.53	$1.07
C22	FAS 1-face	0.980	4	$3.92	No.1 COMMON	0.520	5	$2.60	$1.32
C23	No.1 COMMON	0.520	4	$2.08	No.2 COMMON	0.266	6	$1.60	$0.48
C24	FAS 1-face	0.980	5	$4.90	FAS 1-face	0.980	5	$4.90	$0.00
C25	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	6	$1.53	$0.00
C26	FAS 1-face	0.980	4	$3.92	FAS 1-face	0.980	4	$3.92	$0.00
C27	No.1 COMMON	0.520	3	$1.56	No.2 COMMON	0.255	4	$1.02	$0.54
C28	FAS 1-face	0.980	4	$3.92	No.1 COMMON	0.520	5	$2.60	$1.32
C29	No.3 COMMON	0.195	5	$0.98	No.3 COMMON	0.195	5	$0.98	$0.00
C30	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	6	$1.17	$0.00
C31	No.2 COMMON	0.255	10	$2.55	No.2 COMMON	0.255	10	$2.55	$0.00
C32	No.2 COMMON	0.255	9	$2.30	No.2 COMMON	0.255	9	$2.30	$0.00
C33	FAS	0.99	4	$3.96	No.1 COMMON	0.520	6	$3.12	$0.84
C34	FAS 1-face	0.980	9	$8.82	No.2 COMMON	0.255	10	$2.55	$6.27
C35	No.1 COMMON	0.520	7	$3.64	No.1 COMMON	0.520	7	$3.64	$0.00
C36	FAS 1-face	0.980	11	$10.78	FAS 1-face	0.980	11	$10.78	$0.00
C37	No.1 COMMON	0.520	3	$1.56	No.2 COMMON	0.255	5	$1.28	$0.29
C38	No.2 COMMON	0.255	8	$2.04	No.2 COMMON	0.255	8	$2.04	$0.00
C39	FAS 1-face	0.98	12	$11.76	No.1 COMMON	0.52	12	$6.24	$5.52
C40	No.1 COMMON	0.520	10	$5.20	No.2 COMMON	0.255	11	$2.81	$2.40
C41	FAS	0.990	10	$9.90	FAS 1-face	0.980	10	$9.80	$0.10
C42	FAS 1-face	0.980	8	$7.84	FAS 1-face	0.980	8	$7.84	$0.00
			232	158.99			256	$119.13	

$$\text{Value recovery} = \frac{\$\ 119.13}{\$\ 158.99} \times 100\% = 74.93\%$$



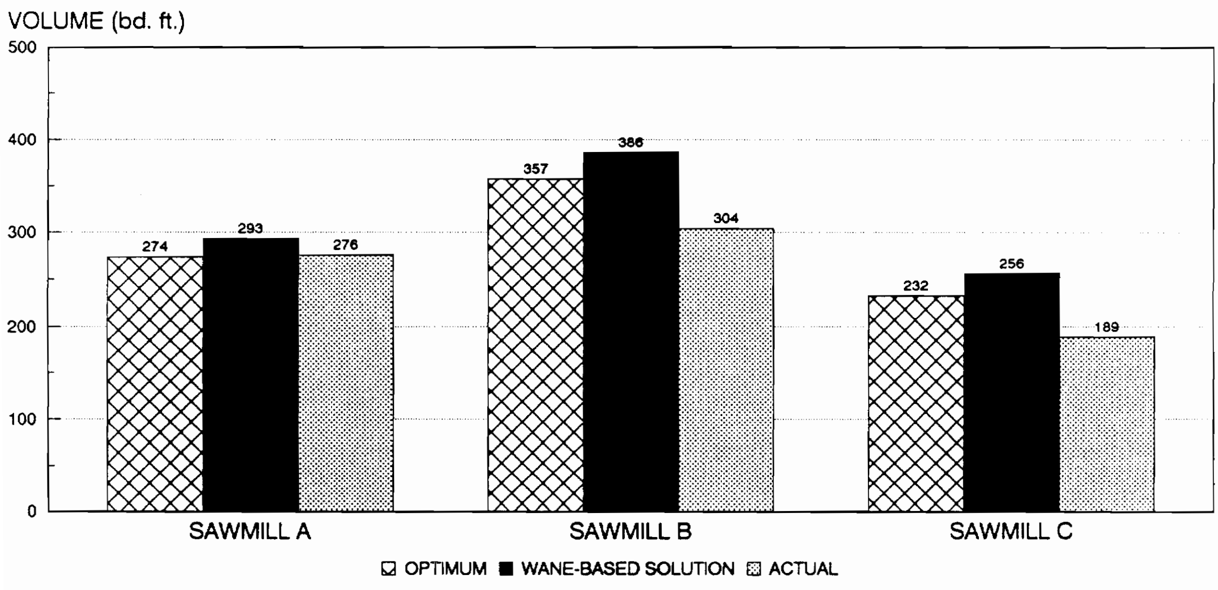


Fig. 15. Comparison of optimum, actual, and wane-based values.

Table 10. Contribution of each grade to overall difference between optimum and wane-based values.

SAWMILL A:

OPTIMUM GRADE (A)	AVERAGE % DIFFERENCE (B)	NUMBER OF BOARDS (C)	(B)X(C) ------- 40
FAS	0 %	2	0 %
FAS 1-face	26.71	11	7.35
No.1 Common	19.90	16	7.96
No.2 Common	0	6	0
No.3 Common	6.63	5	0.83

SAWMILL B:

OPTIMUM GRADE (A)	AVERAGE % DIFFERENCE (B)	NUMBER OF BOARDS (C)	(B)X(C) ------- 40
FAS	7.07%	2	.35 %
FAS 1-face	20.95	18	9.43
No.1 Common	10.83	13	3.53
No.2 Common	1.53	6	0.23
No.3 Common	0	1	0

SAWMILL C:

OPTIMUM GRADE (A)	AVERAGE % DIFFERENCE (B)	NUMBER OF BOARDS (C)	(B)X(C) ------- 40
FAS	6.78%	2	0.34 %
FAS 1-face	31.98	17	13.59
No.1 Common	20.96	11	5.76
No.2 Common	0.35	7	0.06
No.3 Common	0	3	0

of this study suggest that the way to maximize the value of low-quality boards is to maximize board foot yield, as was the objective of the wane-based model.

B. Effect of Operators' Estimate of Potential Grade

As mentioned earlier, part of the input of the wane-based optimization procedure was the edger operator's estimate of the grade potentially obtainable from each board. To determine how accuracy of estimate affected overall results, each grade estimate was compared to the true optimum grade. Due to the fact that wane rules for the FAS and FAS 1-face grades have many similarities, and the same wane criterion was used in this optimization model for **all** Common grades, there was essentially only two main categories of lumber grade as far as the wane-based model was concerned: FAS or FAS 1-face, and the Common grades. Thus, rather than examining the exact accuracy of each estimate, it is more relevant in the analysis of the wane-based model to investigate the effect of mis-estimating an FAS or FAS 1-face piece as a Common grade board, and vice versa. For each mill, the average value recovery of the wane-based optimization for all boards on which the grade estimation error described above was made was computed. The following are the results of this computation:

	No. of Boards	Average Value Recovery
SAWMILL A	5	91.05%
SAWMILL B	10	72.43%
SAWMILL C	12	64.58%

It is of interest to note that in Sawmills B and C, the error in grade estimation was in classifying potential FAS 1-face boards as No.1 Common. This occured in all but two of the 22 boards tabulated above for Sawmills B and C. On the other hand, the opposite occured in Sawmill A, i.e.,all five mis-estimates in the above table were a case of classifying boards which could only grade as No.1 Common as FAS 1-face boards. While the **group sized above may not be sufficient to formulate statistically conclusive statements**, the substantially higher average recovery for Sawmill A suggested that it is less costly to edge and trim a No.1 Common board according to FAS 1-face wane rules than to edge and trim a potential FAS 1-face board as one would process a No.1 Common piece. The first error entails volume loss while the second could mean a drop in lumber grade.

Table 10 indicated that the largest value differences between the true optimum and the wane-based procedure were with boards that optimally graded as FAS 1-face. As discussed in the previous paragraph, part of the difference could be attributed to erroneous judgement by the edger operator about the potential grade of these boards. The lumber value difference for FAS and FAS 1-face boards whose grades were correctly estimated prior to processing was also investigated. The following gives a summary of this analysis:

	No. of Boards	Average Value Recovery
SAWMILL A	13	78.03%
SAWMILL B	10	87.63%
SAWMILL C	8	83.89%

Comparing the average value recovery above to those of the mis-estimated FAS and FAS 1-face boards in Sawmills B and C (72.43% and 64.58%) discussed previously, it can be seen that correct grade estimation improved the output of the wane-based optimization procedure for the two highest lumber grades. However, it can also be seen that even with the correct grade estimates, using wane as the only input can not, as a whole, equal the values yielded by the complete-input optimization, particularly for higher quality boards. For a given board, there are several combinations of edging and trimming lines that can satisfy the wane requirements of the FAS or FAS 1-face grades. Which particular combination (or combinations) would actually produce these grades can not be ascertained without taking into consideration other board information such as the location, size, and type of other defects.

COMPARISON OF RESULTS FROM THE WANE-BASED MODEL TO ACTUAL VALUES

The results of comparing the values obtained from the wane-based optimization model to actual lumber values are shown in Tables 11a-c. Negative values in the "DIFFERENCE" column indicate that in some cases, actual solutions yielded higher lumber values. The presence of such negative values and the large variablity of value differences among individual boards made a statistical test necessary to establish whether there was a significant difference between the results of the model and the actual values. Paired t tests (using a 0.10 level of significance) indicated that 1) the lumber values resulting from the wane-based optimization model are significantly higher than actual mill output for Sawmills B and C; and 2) for Sawmill A, there was not enough evidence to conclude that the optimization model improved on the actual values. It should be recalled that edging decisions for the boards in Sawmill A were made by an operator who was familiar with NHLA grading rules, and who was observed to be conscientious of his performance during the time of the study. Thus it may be concluded that the wane-based optimization procedure can produce results comparable to well-decided manual edging and trimming solutions.

Table 11a. Comparison of values from wane-based model to actual sawmill values, Sawmill A.

OPTIMIZATION BASED ON WANE INPUT ONLY					ACTUAL DATA FROM SAWMILL				
BOARD LABEL	GRADE	$/BDFT.	VOLUME	VALUE	ACTUAL GRADE	$/BD.FT.	VOLUME	VALUE	DIFFERENCE**
A1	FAS 1-face	0.980	8	$7.84	No.1 COMMON	0.520	8	$4.16	$3.68
A2	No.3 COMMON	0.195	4	$0.78	No.3 COMMON	0.195	4	$0.78	$0.00
A3	No.1 COMMON	0.520	9	$4.68	No.1 COMMON	0.520	9	$4.68	$0.00
A4	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	5	$1.28	$0.26
A5	No.2 COMMON	0.255	7	$1.79	No.2 COMMON	0.255	7	$1.79	$0.00
A6	No.2 COMMON	0.255	12	$3.06	No.1 COMMON	0.520	11	$5.72	($2.66)
A7	No.2 COMMON	0.255	10	$2.55	No.2 COMMON	0.255	9	$2.30	$0.25
A8	No.1 COMMON	0.520	8	$4.16	No.1 COMMON	0.520	8	$4.16	$0.00
A9	No.1 COMMON	0.520	7	$3.64	No.1 COMMON	0.520	8	$4.16	($0.52)
A10	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	5	$1.28	$0.26
A11	No.1 COMMON	0.520	7	$3.64	No.1 COMMON	0.520	7	$3.64	$0.00
A12	No.2 COMMON	0.255	9	$2.30	No.2 COMMON	0.255	9	$2.30	$0.00
A13	No.1 COMMON	0.520	6	$3.12	No.1 COMMON	0.520	6	$3.12	$0.00
A14	No.2 COMMON	0.255	9	$2.30	No.2 COMMON	0.255	9	$2.30	$0.00
A15	No.2 COMMON	0.255	7	$1.79	No.2 COMMON	0.255	7	$1.79	$0.00
A16	No.2 COMMON	0.255	11	$2.81	No.2 COMMON	0.255	10	$2.55	$0.26
A17	No.1 COMMON	0.520	5	$2.60	No.2 COMMON	0.255	6	$1.53	$1.07
A18	FAS 1-face	0.980	10	$9.80	FAS 1-face	0.980	10	$9.80	$0.00
A19	No.1 COMMON	0.520	8	$4.16	No.1 COMMON	0.520	7	$3.64	$0.52
A20	No.1 COMMON	0.520	9	$4.68	No.1 COMMON	0.520	8	$4.16	$0.52
A21	No.1 COMMON	0.520	4	$2.08	No.2 COMMON	0.255	4	$1.02	$1.06
A22	No.3 COMMON	0.195	5	$0.98	Below Grade	0.000	5	$0.00	$0.98
A23	No.2 COMMON	0.255	8	$2.04	No.2 COMMON	0.255	7	$1.79	$0.25
A24	No.1 COMMON	0.520	12	$6.24	No.1 COMMON	0.520	10	$5.20	$1.04
A25	FAS	0.990	9	$8.91	FAS	0.990	9	$8.91	$0.00
A26	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	6	$1.17	$0.00
A27	No.2 COMMON	0.255	4	$1.02	No.1 COMMON	0.520	3	$1.56	($0.54)
A29	No.1 COMMON	0.520	8	$4.16	No.1 COMMON	0.520	8	$4.16	$0.00
A30	No.1 COMMON	0.520	10	$5.20	FAS 1-face	0.980	7	$6.86	($1.66)
A31I*	No.1 COMMON	0.520	8	$4.16	No.2 COMMON	0.255	4	$1.02	$1.06
A31II*					No.1 COMMON	0.520	4	$2.08	
A32	No.2 COMMON	0.255	5	$1.28	No.3 COMMON	0.195	5	$0.98	$0.30
A33	No.3 COMMON	0.195	5	$0.98	No.3 COMMON	0.195	5	$0.98	$0.00
A34	No.2 COMMON	0.255	5	$1.28	No.1 COMMON	0.520	4	$2.08	($0.81)
A35	FAS 1-face	0.980	7	$6.86	FAS 1-face	0.980	6	$5.88	$0.98
A36I*	No.3 COMMON	0.195	6	$1.17	No.1 COMMON	0.520	4	$2.08	($0.91)
A36II*				$0.00	Below Grade				
A37	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	4	$1.02	$0.00
A38	FAS	0.990	12	$11.88	FAS	0.990	12	$11.88	$0.00
A39	No.1 COMMON	0.520	7	$3.64	FAS 1-face	0.980	7	$6.86	($3.22)
A40	No.1 COMMON	0.520	4	$2.08	No.1 COMMON	0.520	4	$2.08	$0.00
A41	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	5	$0.98	$0.19
			293	$136.04			276	$133.68	

* Ripped or cross-cut

** Values in parentheses represent negative values.

Table 11b. Comparison of values from wane-based model vs. actual values, Sawmill B.

OPTIMIZATION BASED ON WANE INPUT ONLY					ACTUAL VALUES OBTAINED FROM SAWMILL				
BOARD LABEL	GRADE	$/BDFT.	VOLUME	VALUE	ACT. GRADE	$/BDFT	VOLUME	VALUE	DIFFERENCE **
B2	No.3 COMMON	0.195	9	$1.76	No.3 COMMON	0.195	7	$1.37	$0.39
B3	No.2 COMMON	0.255	12	$3.06	No.2 COMMON	0.255	10	$2.55	$0.51
B4	No.1 COMMON	0.52	5	$2.60	No.2 COMMON	0.255	5	$1.28	$1.33
B5	No.1 COMMON	0.52	7	$3.64	No.2 COMMON	0.255	4	$1.02	$2.62
B6	No.2 COMMON	0.255	14	$3.57	No.2 COMMON	0.255	10	$2.55	$1.02
B7	No.1 COMMON	0.52	5	$2.60	No.1 COMMON	0.52	4	$2.08	$0.52
B8	No.1 COMMON	0.52	14	$7.28	No.1 COMMON	0.52	13	$6.76	$0.52
B9	FAS 1-face	0.98	12	$11.76	No.1 COMMON	0.52	11	$5.72	$6.04
B10	No.3 COMMON	0.195	8	$1.56	No.3 COMMON	0.195	5	$0.98	$0.59
B11	No.2 COMMON	0.255	11	$2.81	No.2 COMMON	0.255	7	$1.79	$1.02
B12	No.1 COMMON	0.52	6	$3.12	No.1 COMMON	0.52	5	$2.60	$0.52
B13	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	5	$1.28	$0.26
B14	No.2 COMMON	0.255	11	$2.81	No.2 COMMON	0.255	8	$2.04	$0.77
B15	No.1 COMMON	0.52	16	$8.32	No.2 COMMON	0.255	12	$3.06	$5.26
B16	No.1 COMMON	0.52	14	$7.28	No.1 COMMON	0.52	13	$6.76	$0.52
B17	FAS 1-face	0.98	4	$3.92	No.1 COMMON	0.52	4	$2.08	$1.84
B18	No.1 COMMON	0.52	9	$4.68	FAS	0.99	5	$4.95	($0.27)
B19	FAS	0.99	12	$11.88	FAS	0.99	10	$9.90	$1.98
B20	No.2 COMMON	0.255	9	$2.30	No.2 COMMON	0.255	7	$1.79	$0.51
B21	No.1 COMMON	0.52	8	$4.16	No.1 COMMON	0.52	5	$2.60	$1.56
B22	FAS 1-face	0.98	11	$10.78	FAS 1-face	0.98	8	$7.84	$2.94
B23	No.2 COMMON	0.255	7	$1.79	No.1 COMMON	0.52	5	$2.60	($0.82)
B24	No.2 COMMON	0.255	12	$3.06	No.2 COMMON	0.255	10	$2.55	$0.51
B25	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	3	$0.77	$0.77
B26	No.2 COMMON	0.255	9	$2.30	No.3 COMMON	0.195	7	$1.37	$0.93
B27	FAS 1-face	0.98	7	$6.86	FAS 1-face	0.98	5	$4.90	$1.96
B28	No.2 COMMON	0.255	8	$2.04	No.2 COMMON	0.255	7	$1.79	$0.25
B29	No.1 COMMON	0.52	15	$7.80	No.1 COMMON	0.52	13	$6.76	$1.04
B30	No.2 COMMON	0.255	8	$2.04	No.1 COMMON	0.52	5	$2.60	($0.56)
B31	FAS 1-face	0.98	12	$11.76	FAS 1-face	0.98	10	$9.80	$1.96
B32	No.1 COMMON	0.52	9	$4.68	FAS 1-face	0.98	6	$5.88	($1.20)
B33	No.1 COMMON	0.52	13	$6.76	No.1 COMMON	0.52	12	$6.24	$0.52
B34	No.2 COMMON	0.255	11	$2.81	FAS 1-face	0.98	6	$5.88	($3.08)
B35	No.1 COMMON	0.52	12	$6.24	No.2 COMMON	0.255	11	$2.81	$3.44
B36	No.1 COMMON	0.52	10	$5.20	No.1 COMMON	0.52	9	$4.68	$0.52
B37	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	4	$1.02	$0.51
B38	No.1 COMMON	0.52	9	$4.68	No.1 COMMON	0.52	8	$4.16	$0.52
B39	No.1 COMMON	0.52	8	$4.16	No.1 COMMON	0.52	7	$3.64	$0.52
B40	FAS 1-face	0.98	10	$9.80	FAS 1-face	0.98	9	$8.82	$0.98
B41	FAS 1-face	0.98	11	$10.78	No.1 COMMON	0.52	9	$4.68	$6.10
			386	$197.21			304	$151.90	

** Values in parentheses represent negative values.

Table 11c. Comparison of results from wane-based model to actual sawmill values, Sawmill C.

OPTIMIZATION BASED ON WANE INPUT ONLY					ACTUAL DATA FROM SAWMILL				
BOARD LABEL	GRADE	$/BDFT	VOLUME	VALUE	ACT. GRADE	$/BDFT.	VOLUME	VALUE	DIFFERENCE**
C1	No.3 COMMON	0.195	5	$0.98	No.2 COMMON	0.255	4	$1.02	($0.04)
C2	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	3	$0.77	$0.26
C3	No.2 COMMON	0.255	4	$1.02	No.3 COMMON	0.195	2	$0.39	$0.63
C4	No.1 COMMON	0.520	6	$3.12	No.1 COMMON	0.520	2	$1.04	$2.08
C5	No.1 COMMON	0.520	5	$2.60	No.1 COMMON	0.520	4	$2.08	$0.52
C7	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	4	$0.78	$0.39
C8	No.2 COMMON	0.255	6	$1.53	No.1 COMMON	0.520	4	$2.08	($0.55)
C9	No.2 COMMON	0.255	4	$1.02	No.2 COMMON	0.255	2	$0.51	$0.51
C11	No.2 COMMON	0.255	7	$1.79	No.1 COMMON	0.520	6	$3.12	($1.34)
C12	No.2 COMMON	0.255	7	$1.79	No.2 COMMON	0.255	5	$1.28	$0.51
C13	No.2 COMMON	0.255	7	$1.79	FAS 1-face	0.980	6	$5.88	($4.10)
C14	No.2 COMMON	0.255	4	$1.02	No.1 COMMON	0.520	2	$1.04	($0.02)
C15	FAS 1-face	0.980	8	$7.84	FAS 1-face	0.980	6	$5.88	$1.96
C16	FAS 1-face	0.980	6	$5.88	FAS	0.990	4	$3.96	$1.92
C17	No.1 COMMON	0.255	2	$0.51	No.1 COMMON	0.520	2	$1.04	($0.53)
C18	No.2 COMMON	0.255	5	$1.28	No.1 COMMON	0.520	3	$1.56	($0.29)
C19	FAS 1-face	0.980	5	$4.90	No.1 COMMON	0.520	4	$2.08	$2.82
C20	No.1 COMMON	0.520	6	$3.12	FAS 1-face	0.980	4	$3.92	($0.80)
C21	No.2 COMMON	0.255	6	$1.53	No.1 COMMON	0.520	5	$2.60	($1.07)
C22	No.1 COMMON	0.520	5	$2.60	No.2 COMMON	0.255	5	$1.28	$1.33
C23	No.2 COMMON	0.266	6	$1.60	No.2 COMMON	0.255	4	$1.02	$0.58
C24	FAS 1-face	0.980	5	$4.90	No.2 COMMON	0.255	4	$1.02	$3.88
C25	No.2 COMMON	0.255	6	$1.53	No.2 COMMON	0.255	4	$1.02	$0.51
C26	FAS 1-face	0.980	4	$3.92	No.1 COMMON	0.520	3	$1.56	$2.36
C27	No.2 COMMON	0.255	4	$1.02	No.1 COMMON	0.520	3	$1.56	($0.54)
C28	No.1 COMMON	0.520	5	$2.60	No.1 COMMON	0.520	3	$1.56	$1.04
C29	No.3 COMMON	0.195	5	$0.98	No.3 COMMON	0.195	3	$0.59	$0.39
C30	No.3 COMMON	0.195	6	$1.17	No.3 COMMON	0.195	6	$1.17	$0.00
C31	No.2 COMMON	0.255	10	$2.55	No.2 COMMON	0.255	9	$2.30	$0.25
C32	No.2 COMMON	0.255	9	$2.30	No.3 COMMON	0.195	7	$1.37	$0.93
C33	No.1 COMMON	0.520	6	$3.12	No.1 COMMON	0.520	4	$2.08	$1.04
C34	No.2 COMMON	0.255	10	$2.55	FAS 1-face	0.980	8	$7.84	($5.29)
C35	No.1 COMMON	0.520	7	$3.64	No.1 COMMON	0.520	7	$3.64	$0.00
C36	FAS 1-face	0.980	11	$10.78	FAS	0.990	9	$8.91	$1.87
C37	No.2 COMMON	0.255	5	$1.28	No.2 COMMON	0.255	2	$0.51	$0.77
C38	No.2 COMMON	0.255	8	$2.04	No.2 COMMON	0.255	6	$1.53	$0.51
C39	No.1 COMMON	0.52	12	$6.24	No.1 COMMON	0.52	9	$4.68	$1.56
C40	No.2 COMMON	0.255	11	$2.81	No.1 COMMON	0.520	8	$4.16	($1.36)
C41	FAS 1-face	0.980	10	$9.80	FAS	0.990	8	$7.92	$1.88
C42	FAS 1-face	0.980	8	$7.84	No.1 COMMON	0.520	5	$2.60	$5.24
			256	$119.13			189	$99.32	

** Values in parentheses represent negative values.

Chapter 7

SUMMARY AND CONCLUSIONS

SUMMARY

Improvement in sawmill profit through better raw material utilization is a topic often discussed in literature. In the lumber manufacturing process, the edging and trimming operations have been identified as opportunity areas for increasing lumber dollar values. Results of actual studies conducted in softwood mills showed the benefits from upgrading these two operations through the successful application of computerized optimizing systems. Although not as extensively investigated, it is felt that the same improvements may be expected if optimization technology were applied to hardwood lumber manufacturing.

This research project studied the maximization of red oak lumber value through computer-aided optimization of edging and trimming. The main objective was to evaluate how the lumber value recovered by actual hardwood operations compare with the maximum value obtainable by optimizing the edging and trimming operations. Such evaluation would serve to assess the potential benefit of edging and trimming optimization.

An iterative computer procedure was developed for finding the optimum cutting solution for boards coming off the headrig. An optimum cutting solution, in this context, was defined as the combination of edging and trimming lines that maximizes the dollar value of red oak lumber. For this procedure, data describing the board shape and the size, location, and type of defects present were required. Decision parameters included the National Hardwood Lumber Association (NHLA) grading rules and the green lumber prices for 4/4 red oak [Weekly Hardwood Review, September 15, 1989].

The optimization procedure was applied to 120 sample boards obtained from 3 sawmills. Results were compared to the lumber values actually obtained by sawmill operators from the same boards. In two of the mills studied, actual value recovery was 64.75% and 62.47% of the optimized value. A value recovery of 80.01% of the optimum was obtained in the third sawmill.

Analysis of the optimum vs. actual value comparisons showed that the greatest opportunities for value improvement were on boards which could optimally grade as FAS 1-face or No.1 Common. Furthermore, it was found that for the two mills showing 64.75% and 62.47% recovery, the loss in value in the actual boards could be significantly attributed to severe cutting, which not only reduced volume but also lowered the grade of a significant number of boards.

The optimization procedure referred to in the previous paragraphs may be considered as one under ideal conditions, characterized by the availability of complete input information (specifically board description data) and the coordinated optimization of edging and trimming lines. Other less-than-ideal optimization procedures were investigated, namely:

1. Independent optimization of edging and trimming, i.e.,
    a. optimization of edging only, given a predetermined trimming solution as actually decided by the trimmer operator.

    b. optimization of trimming only, given the edger operator's placement of edging lines.

2. Optimization of edging and trimming using only wane data to describe the unprocessed board. Such input represents the scanning capability of edger and trimmer optimizing systems currently used in softwood sawmills.

The results of the procedure in which only edging was optimized were compared to actual sawmill values. The computed value recovery varied from one sawmill to another but in all 3 mills, the semi-optimized values showed a general improvement over the actual. Values of 90.31%, 95.34%, and 93.41% were computed. Similarly, a higher overall value than actual output resulted from trimming optimization. However, Fig. 15 shows that the improvements of trimming optimization over the actual output where small when compared to the results of edging optimization. Comparison of volume yields from edging vs. trimming optimization further revealed that in the two sawmills where low value recovery was largely attributed to severe cutting, most of the volume loss occured at the edger.

The optimization procedure based on wane data employed an iterative algorithm to search for the optimum cutting solution. Cross-section data at every 3-inch interval along the length of the board and the edger operator's estimate of potential grade were used as input data. For this model, the optimum cutting solution was the combination of edging and trimming lines that maximizes surface measure without exceeding the NHLA wane restrictions for the estimated grade. When results from this model were compared to the true optimum lumber values (i.e. the results from the ideal optimization procedure), it was found that on the average , approximately 80% of the optimum was obtained by the wane-based model (values actually computed were 81.42%, 84.06%, and 74.93%). It was observed that lumber value differences occured mostly with boards that graded as FAS 1-face in the complete-input optimization model. To a lesser extent, the above was also true for potential No.1 Common boards. No significant differences between the results of the two procedures were noted on lower quality boards. Such findings were consistent among the 3 sawmills.

As evidenced by the computed values of lumber value recovery, the wane-based model showed substantial value improvements over the actual output in two of the three sawmills: 84.06% vs. 64.75%, and 74.93% vs. 62.47%. However, based on the outcome of a statistivcal test, it was found that no significant difference existed between the results of the model and the values actually obtained in the third sawmill. The latter was the same sawmill that recovered 80.01% of the optimum value.

Table 12 summarizes the significant results of this study. In interpreting these results, several things have to be kept in mind. These include, among others, the sample size (120 boards), the locale used for the study (all 3 sawmills are in the Appalachian area), the choice of species (red oak), and the use of NHLA grading rules as the sole basis for evaluating board quality. It should also be noted that for Common grade boards, no cutting solutions were considered beyond that allowed by the 50/50% wane rule for "well-manufactured" boards [Malcolm, 196 ; Petro, 1982].

CONCLUSIONS

The following conclusions are drawn from the results of this study.

1. Manually determined edging and trimming solutions do not achieve the maximum obtainable lumber value from red oak boards. Based on the results of this research, between 63% to 80% of the theoretical optimum value is achievable by manually operated edging and trimming.

Thus, given this level of lumber value recovery actually attained by sawmills, it can be concluded that substantial increase in value can be expected from edging and trimming optimization.

2. The practice of overedging significantly accounts for the low lumber value recovery in some hardwood sawmills.

3. The greatest losses in value occur when boards which could potentially grade as FAS or FAS 1-face are dropped to a Common grade through non-optimal edging or trimming. To a lesser extent, the above was also true for potential No.1 Common boards degraded to a No.2 Common lumber.

4. Errors in edging decisions have a greater impact on lumber value than trimming errors.

5. A procedure for edging and trimming red oak boards that uses wane as the only board defect input information generates cutting solutions that yield lumber values approximately equal to 80% (on the average) of the optimum.

6. For boards which can not optimally grade higher than No.2 Common, wane data is sufficient input information to arrive at the correct edging and trimming solution. More information is required for higher grade boards.

Table 12. Lumber value recovery under different edging/trimming situations.*
(Summary of results).

	Actual	Optimization of Edging Only	Optimization of Trimming Only	Wane-based Model
SAWMILL A	80.01%	90.31%	89.31%	81.42%
SAWMILL B	64.75%	95.34%	70.87%	84.06%
SAWMILL C	62.47%	93.41%	64.87%	74.93%

* Entries in the above table are percentages of the true optimum lumber values.

Literature Cited

Ailport, J., 1983. A new type of trimmer Optimizer. *In* Proceedings of the Annual Northwest Wood Products Clinic, May 1983. (38th).

Anon., 1978. Test optimizer gets 94% recovery at the edger. World Wood, 1978. 19(8).

Araman, P. A., 1990. Possible computer systems for future hardwood mills. Forest Industries, May 1990.

Bennett, W. 1978. Increasing lumber recovery at the edger. *In* Complete tree utilization of southern pine. Proceedings of a Symposium, New Orleans, LA, April 1978. McMillin, C. W. (Editor).

Bousquet, D. M., 1989. Saving volume and making oney at the edger. Northern Logger and Timber Processor, June 1989.

Browne, A and L. Norton-Wayne, 1986. Vision and Information Processing for Automation. Plenum Press, New York.

Conners, R. W.; T. H. Cho and P. A. Araman, 1989. Lumber grading with a computer vision system. *In* Proceedings of the seventeenth annual hardwood symposium of the hardwood research council; May 1989, Merrimac, Wisconsin.

Dessy, Raymond (Contributing Editor), 1983. Robots in the laboratory, Part I. A/C Interface. American Chemical Society.

Flann, I. B and F. M. Lamb, 1966. Effect of sawmill edging practice on the value of hard maple lumber. Forest Products Journal 16(5).

Franklin, J.B. and L. Koenigsberg, 1982. Computerized linear setworks. *In* Proceedings of the "Computer Automation for Sawmill Profit" Forest Products Research Society Conference, Norfolk, Virginia, Oct. 1982.

Giese, P. J.and K. A. McDonald, 1982. OPTYLD: A multiple rip-first computer program to maximize cutting yield. Forest Products Laboratory Research Paper 387, USDA Forest Service.

Griffin, G.,1989. Edger optimization vital to hardwood mill upgrade. Forest Industries, March 1989.

Grove, L., 1983. State-of-the-art edger and trimmer optimizers. *In* Improving productivity through microelectronics. Special Publication, Forintek Canada Corp. (No. SP 12). Proceedings...regional seminars on microelectronics in the wood products industry, Ontario, Canada.

Hallock, H.and D. W. Lewis, 1971. Increasing softwood dimension yield from small logs. Res. Paper FPL 166. USDA Forest Service, Forest Products Lab., Madison, Wisconsin.

Klinkhachorn, P.; J. P. Franklin; C. W. McMillin; R. W. Conners and H. A. Huber, 1988. Automated computer grading of hardwood lumber. Forest Products Journal 38(3).

Malcolm, F. B., 196 . A simplfied procedure for developing grade lumber from hardwood logs. US Department of Agriculture Forest Products Lab. Research Note FPL-098, Madison, Wisconsin.

Maxey, C., 1979. Optimizing production at the edger. *In* Electronics at the sawmill. Proceedings of the Electronics Workshop, Sawmill and Plywood Clinic, Portland, Oregon, March 1979.

Pease, C. E., 1980. Considerations in the application of optimized edging. *In* Proceedings...Annual Northwest Wood Products Clinic, Pullman, Washington. (35th).

Petro, F. J., 1982. How to Edge and Trim Hardwood Lumber. Forintek Canada Corporation. Eastern Laboratory, Ottawa, Ontario.

Price, D. R., 1979. Edging optimizers---circa 1979. *In* Proceedings...Annual Northwest Wood Products Clinic, Kalispell, Montana. (34th).

Szymani, R. and K. A. McDonald,1981. Defect detection in lumber: state of the art. Forest Products Journal 31(11).

Schwehm, C. J.; P. Klinkhachorn; C. W. McMillin and H.A. Huber, 1990. HaRem: hardwood lumber remanufacturing program for maximizing value based on size, grade, and current market prices. Forest Products Journal, 40(7/8).

Weekly Hardwood Review, Sept. 15, 1989. Hardwood Publishing Company, Inc. Charlotte, North Carolina.

Williston, E. 1979. Electronics in the sawmill: Opportunity areas and leverage points. *In* Proceedings of the Electronics Workshop, Sawmill and Plywood Clinic, Portland, Oregon.

APPENDICES

Appendix A.

```
**********************************************************************
*  Program name:  CUTCOMB.FOR                                        *
*                                                                    *
*      This program generates combinations of edging and            *
*  trimming lines to search for the optimum cutting solution         *
*  for hardwood boards following the National Hardwood Lumber        *
*  Association (NHLA) standard grading rules.  The output data       *
*  file serves as input to the Hardwood Lumber Grading Program       *
*  developed by Klinkhachorn et. al. (1988).                         *
*                                                                    *
**********************************************************************
*
* List of Variables:
*
*
*    EDGE1 =  Y-coordinate of lower edging line currently
*             under investigation.
*
*    EDGE2 =  Y-coordinate of current upper edging line.
*
*    TRIM1 =  X-coordinate of current left trimming line.
*
*    TRIM2 =  X-coordinate of current right trimming line.
*
*    LENGTH = Length of board as determined by current
*             trimming lines.
*
*    WIDTH  = Width of board as determined by current
*             edging lines.
*
*    XLT(I), XRT(I):
*             X-coordinates of the left and right sides,
*             respectively, of the rectangle enclosing defect I
*             as read from the raw data file.  Points of
*             reference are the coordinate axes of the
*             unedged/untrimmed board.
*
*    YDN(I), YUP(I):
*             Y-coordinates of the bottom and top sides,
*             respectively, of the rectangle enclosing defect I
```

```
*           as read from the raw data file.  Points of
*           reference are the coordinate axes of the
*           unedged/untrimmed board.
*
* DEFLAB(I) = Identification label for defect I used in the
*           raw data file.
*
* DEFTYP(I) = Code for the type of defect I, e.g. 1 for stain,
*           5 for wane, etc...
*
*   FACE(I) = Face of the board on which defect I appears
*           (0 for the narrow face, 1 for the wide face).
*
*     RESOL = Resolution used for all measurements, equal
*           to 1 quarter inch.
*
*    DEFOUT = Variable denoting the status of a defect, equal to
*           1 if the defect has been eliminated by current edging
*           and trimming lines, 0 otherwise.
*
*     KOUNT = Total number of defects removed from the board
*           as a result of current edging and trimming lines.
*
*      NDEF = Number of defects remaining on the board.
*
*     TEMP1, TEMP2:
*           X-coordinates of the left and right sides,
*           respectively, of the rectangle enclosing the
*           defect currently being investigated.  Points of
*           reference are the coordinate axes defined by
*           the current EDGE1 and TRIM1.
*
*     TEMP3, TEMP4:
*           Y-coordinates of the bottom and top sides,
*           respectively, of the rectangle enclosing the
*           defect currently being investigated.  Points of
*           reference are the coordinate axes defined by
*           current EDGE1 and TRIM1.
*
*     XLEFT, XRIGHT:
*           X-coordinates of the left and right sides,
*           respectively, of the rectangle enclosing the
*           uncut  portion  of a  defect (i.e. the portion
*           contained within the area defined by the current
*           edging and trimming lines.  Points of reference
*           are the coordinate axes defined by EDGE1 and
*           TRIM1.
*
*
*     YBOTT, YTOP:
*           Y-coordinates of the bottom and top sides,
*           respectively, of the rectangle enclosing the
```

```
*            uncut portion of a defect.
*            (Refer to definition of XLEFT and XRIGHT).
*
************************************************************************
*
      INTEGER DEFLAB(100), DEFTYP(100), FACE(100)
      INTEGER DEFOUT, LENGTH, WIDTH, TEMP1, TEMP2, TEMP3, EDGE1
      INTEGER TEMP4, XLEFT, XRIGHT, YTOP, YBOTT, EDGE2, TRIM1, TRIM2
      CHARACTER BDNAME*3
      CHARACTER FOUT1*14
      CHARACTER FINP*14
      INTEGER XLT(100),XRT(100), YUP(100), YDN(100)
      REAL RESOL
*******************************************************************
* Read from data file describing the unedged/untrimmed board:
*******************************************************************
      WRITE (*,*) 'Enter name of raw data file:'
      READ (*,1) FINP
      WRITE(*,*)'Enter name of output file for use in lumber grading:'
      READ(*,1) FOUT1
1     FORMAT (A14)
      OPEN (2, FILE = FOUT1, STATUS = 'NEW')
      OPEN (3, FILE = FINP, STATUS = 'OLD')
      WRITE(*,*) ' Enter boardname (A1, A2, B1,...):'
      READ (*,2) BDNAME
2     FORMAT(A3)
      READ(3,*) N
      DO 5 I = 1,N
        READ(3,*)DEFLAB(I),XLT(I),YDN(I),XRT(I),YUP(I),DEFTYP(I),
     &  FACE(I)
5     CONTINUE
********************************************************************
*  Enter the coordinates of the limits for varying edging and
*  trimming lines:
********************************************************************
      WRITE(*,*) 'Enter max. coordinate of EDGE1 (low edge):'
      READ(*,*) MAXED1
      WRITE(*,*) 'Enter min. coordinate of EDGE1:'
      READ(*,*) MINED1
      WRITE(*,*) 'Enter max. coordinate of EDGE2 (top edge):'
      READ(*,*) MAXED2
      WRITE(*,*) 'Enter min. coordinate of EDGE2:'
      READ(*,*) MINED2
      WRITE(*,*) 'Enter max. coordinate of TRIM1 (left trim):'
      READ(*,*) MAXTR1
      WRITE(*,*) 'Enter min. coordinate  of TRIM1:'
      READ (*,*)MINTR1
      WRITE(*,*) 'Enter max. coordinate of TRIM2 (right trim):'
      READ(*,*) MAXTR2
      WRITE(*,*) 'Enter min. coordinate of TRIM2 :'
      READ(*,*) MINTR2
      WRITE(*,*) 'Enter trimming increment:'
```

```
      READ(*,*) INCR
      RESOL = 0.250
*
************************************************************************
*  Start iteration for edging and trimmming line combinations:
************************************************************************
      DO 90 EDGE1 = MINED1, MAXED1
      DO 80 EDGE2 = MINED2, MAXED2
      DO 70 TRIM1 = MINTR1, MAXTR1, INCR
      DO 60 TRIM2 = MINTR2, MAXTR2, INCR
        LENGTH = TRIM2- TRIM1
        WIDTH = EDGE2 - EDGE1
        WRITE(2,7) BDNAME
7       FORMAT (A3)
        WRITE(2,8) RESOL
 8      FORMAT (F4.3)
        WRITE(2,9) LENGTH, WIDTH
 9      FORMAT(I3,1X,I2)
*
*  Count number of defects removed by current edging and trimming
*  lines:
*
        KOUNT = 0
        DO 50 I = 1,N
          DEFOUT = 0
          TEMP1 = XLT(I) - TRIM1
          TEMP2 = XRT(I) - TRIM2
          TEMP3 = YDN(I) - EDGE1
          TEMP4 = YUP(I) - EDGE2
          IF (TEMP1.GE.LENGTH.AND.DEFOUT.EQ.0) THEN
            KOUNT = KOUNT + 1
            DEFOUT = 1
          ENDIF
          IF (XRT(I).LE.TRIM1.AND.DEFOUT.EQ.0) THEN
            KOUNT = KOUNT + 1
            DEFOUT = 1
          ENDIF
          IF (TEMP3.GE.WIDTH.AND.DEFOUT.EQ.0) THEN
            KOUNT = KOUNT + 1
            DEFOUT = 1
          ENDIF
          IF (YUP(I).LE.EDGE1.AND.DEFOUT.EQ.0) THEN
            KOUNT = KOUNT + 1
            DEFOUT = 1
          ENDIF
50      CONTINUE
        NDEF = N - KOUNT
        WRITE(*,*)'  '
        WRITE(*,*) 'No. of defects removed =',KOUNT
        WRITE(*,*) 'No. of remaining defects =',NDEF
        WRITE(2,*) NDEF
*
```

```
*  Calculate coordinates of all remaining defects with respect
*  to the coordinate axes defined by EDGE1 and TRIM1 (i.e., with
*  (0,0) located at the lower left corner of the edged and trimmed
*  board).
*
      DO 51 I = 1, N
       DEFOUT = 0
       TEMP1 = XLT(I) - TRIM1
       TEMP2 = XRT(I) - TRIM1
       TEMP3 = YDN(I) - EDGE1
       TEMP4 = YUP(I) - EDGE1
       IF (TEMP1.GE.LENGTH) DEFOUT = 1
       IF (XRT(I).LE.TRIM1) DEFOUT = 1
       IF (TEMP3.GE.WIDTH) DEFOUT = 1
       IF (YUP(I).LE.EDGE1) DEFOUT = 1
*
       IF (DEFOUT.EQ.0) THEN
*
         IF (TEMP1.GE.0) THEN
          IF (TEMP1.LT.LENGTH) THEN
           XLEFT = TEMP1
          ENDIF
          IF (TEMP1.LT.LENGTH.AND.TEMP2.LE.LENGTH) THEN
           XRIGHT = TEMP2
          ENDIF
          IF (TEMP1.LT.LENGTH.AND.TEMP2.GE.LENGTH) THEN
           XRIGHT = LENGTH
          ENDIF
         ENDIF
*
         IF (XLT(I).LT.TRIM1.AND.XRT(I).GT.TRIM1) THEN
          XLEFT = 0
          XRIGHT = TEMP2
         ENDIF
*
         IF (TEMP3.GE.0) THEN
          IF(TEMP3.LT.WIDTH) THEN
            YBOTT = TEMP3
          ENDIF
          IF (TEMP3.LT.WIDTH.AND.TEMP4.LE.WIDTH) THEN
            YTOP = TEMP4
          ENDIF
          IF (TEMP3.LT.WIDTH.AND.TEMP4.GE.WIDTH) THEN
            YTOP = WIDTH
          ENDIF
         ENDIF
*
         IF (YDN(I).LE.EDGE1.AND.YUP(I).GT.EDGE1) THEN
           YBOTT = 0
           YTOP = TEMP4
         ENDIF
*
```

```
* Write all defect data to a file to be used as input to
* the hardwood lumber grading program:
*
         WRITE(2,49) XLEFT,YBOTT,XRIGHT,YTOP,DEFTYP(I),FACE(I)
49        FORMAT(I3,1X,I3,1X,I3,1X,I3,1X,I3,1X,I3)
       ENDIF
51     CONTINUE
60    CONTINUE
70    CONTINUE
80    CONTINUE
90    CONTINUE
      STOP
      END
```

Appendix B.

```
*****************************************************************
*                                                               *
*  Program name:  MAINWANE.FOR                                  *
*  MAIN PROGRAM FOR OPTIMIZING EDGING AND TRIMMING BASED*
*  ON WANE  INPUT ONLY.                                         *
*                                                               *
*****************************************************************
*
*  Variables used:
*
*       X(I) : X-coordinate of the Ith 3-inch interval,
*              in quarter inch units.
*
*    LOW1(I) : Y-coordinate of the board's wide face's lower
*              edge, X(I) units from the left end.
*
*    LOW2(I) : Y-coordinate of the board's narrow face's lower
*              edge, X(I) units from the left end.
*
*     UP1(I) : Y-coordinate of the board's narrow face's upper
*              edge, X(I) units from the left end.
*
*     UP2(I) : Y-coordinate of the board's wider face's upper
*              edge, X(I) units from the left end.
*
*    WW10(I) : Wane width at the lower edge of the board's
*              narrow face X(I) units from the left.
*
*    WW11(I) : Wane width at the lower edge of the board's
*              wider face X(I) units from the left.
*
*    WW20(I) : Wane width at the upper edge of the board's
*              narrow face X(I) units from the left.
*
*    WW21(I) : Wane width at the upper edge of the board's
*              wider face X(I) units from the left.
*
*    EDGE1,EDGE2:  Y-coordinate of the current edging line
*                  for the board's lower and upper edges,
*                  respectively.
*
*    TRIM1,TRIM2:  X-coordinate of the current trimming line
```

```
*                 for the board's left and right ends,
*                 respectively.
*
*     LOWEDG : Current best lower edge line.
*
*      UPEDG : Current best upper edge line.
*
*      LEFTR : Current best left trim line.
*
*     RIGHTR : Current best right trim line.
*
*         SM : Board's surface measure.
*
*      MAXSM : Current largest SM
*
*     MAXWID : Current largest width.
*
*        TIP : The right-most coordinate of the board's end.
*
*        TOP : The uppermost Y- coordinate of the board.
*
*     ISTART : The Ith 3-inch interval from which to start
*              the computation of wane, a function of TRIM1.
*
*       IEND : The Ith 3-inch interval where wane computation
*              ends, a function of TRIM2.
*
*****************************************************************
*
*
      REAL LOW1(60), LOW2(60), UP1(60),UP2(60), X(60)
      REAL WW10(60),WW11(60),WW20(60),WW21(60),PRFACE
      INTEGER LOWEDG, UPEDG, LEFTR, RIGHTR,EDGE1,EDGE2
      INTEGER  SM,maxsm,maxwid
      CHARACTER FN*14,BDNAME*3
      WRITE(*,'(A\)')' Name of cross-section data file?'
      READ(*,10) FN
10    FORMAT(A14)
      OPEN(UNIT=1,FILE=FN,STATUS = 'OLD')
*
*     Read data:
      READ(1,'(A3)') BDNAME
      READ (1,*) N
      DO 20 I = 1,N
        READ(1,*) X(I), LOW1(I), LOW2(I), UP1(I),UP2(I)
20    CONTINUE
      TIP = X(N)
*
      WRITE(*,'(A\)')' Enter estimated grade:'
      WRITE(*,*)
```

```
      WRITE(*,'(A)')' Enter 1 for FAS'
      WRITE(*,'(A)')'       2 for FAS 1-Face'
      WRITE(*,'(A)')'       3 for No.1 Common'
      WRITE(*,'(A)')'       4 for No.2 Common'
      WRITE(*,'(A)')'       5 for No.3 Common'
      WRITE(*,*)
      READ(*,'(f2.0)') GRADE
      WRITE(*,*)
      WRITE(*,*)
      IF (GRADE.EQ.2) THEN
        WRITE(*,'(A\)')' Enter poor (grading) face (0 or 1):'
        READ(*,*)PRFACE
      ENDIF
*
*     Find outermost cross-section  Y-coordinates:
      MIN1 = 999
      MAX2 = 0
      DO 30 I = 1,N
        IF (LOW1(I).LT.MIN1) MIN1 = LOW1(I)
        IF (UP2(I).GT.MAX2) MAX2 = UP2(I)
30    CONTINUE
      WRITE(*,'(A\)')' Length of trimming variation in quarter
&           inches?'
      READ(*,*) LENTRM
*
 * *****************************************************************
*      The following routine shortens the execution time of the
*  program by setting limits for varying edging lines.  If EDGE1  were
*  to start from the lowermost point of the board, the no. of quarter
*  inch increments inward to the coordinate of the widest wane could make
*  execution intolerably long. It is arbitrarily decided that EDGE1
*  should start from the coordinate of the line that covers at least
*  5 ft. (240 quarter inch units)  of the length of the board.  This
*  coordinate is given the name MINED1.  Likewise, EDGE2 should proceed
*  from MAXED2 ( the coordinate of the line covering at least 5 ft. of
*  the length of the upper edge) inward to the coordinate of the widest
*  wane at the top edge.
*
*      USABL1 : Usable length , i.e . length of the board
*               included within the edging line at the bottom.
*
*      USABL2 : Usable length of the board at the top edge.
*
*     LIMIT1, LIMIT2 : Temporary variables used for finding
*                    MINED1 and MAXED2.
*
*
*     Limits for varying cutting lines:
      LIMIT2 = MAX2 + 1
32    USABL2 = -12
```

```
      LIMIT2 = LIMIT2 - 1
      DO 35 K = 1,N
        IF (UP2(K).GE.LIMIT2) USABL2 = USABL2 + 12
35    CONTINUE
      IF (USABL2-240)32,34,34
34    MAXED2 = LIMIT2
      LIMIT1 = MIN1 - 1
36    USABL1 = -12
      LIMIT1 = LIMIT1 + 1
      DO 37 K = 1,N
        IF (LOW1(K).LE.LIMIT1) USABL1 = USABL1 + 12
37    CONTINUE
      IF (USABL1-240) 36,38,38
38    MINED1 = LIMIT1
      INCR1 = 0
      INCR2 = 0
      DO 40 K = 1,N
        IF (MAXED2-UP1(K).GT.INCR2) INCR2 = MAXED2 - UP1(K)
        IF (LOW2(K)-MINED1.GT.INCR1) INCR1 = LOW2(K) - MINED1
40    CONTINUE
      MINED2 = MAXED2 - INCR2
      MAXED1 = MINED1 + INCR1
      MINTR2 = TIP - LENTRM
      WRITE(*,'(A\,I5)')' MAXED2 =',MAXED2
      WRITE(*,'(A\,I5)')' MINED2 =',MINED2
      WRITE(*,'(A\,I5)')' MAXED1 =',MAXED1
      WRITE(*,'(A\,I5)')' MINED1 =',MINED1
      write(*,'(a)')' Press RETURN key to continue.'
      read(*,*)
*
************************************************************************
*
*     Cutting combinations:
      DO 45 EDGE1 = MINED1, MAXED1
      DO 50 EDGE2 = MAXED2, MINED2, -1
      DO 60 TRIM1 = 0,LENTRM,24
      DO 70 TRIM2 = TIP, MINTR2, -24
        IF ((EDGE2-EDGE1.LT.12).OR.(TRIM2-TRIM1.LT.192)) GOTO 70
        WANEOK = 1
*           (WANEOK = 0 means that wane and size rules are not met.)
        ISTART = TRIM1/12 + 1
        REMLEN = TRIM2/12 - INT(TRIM2/12)
        IF (REMLEN.GT.0) THEN
          IEND = INT(TRIM2/12) + 2
        ELSE
          IEND = INT(TRIM2/12) + 1
        ENDIF
*
*       Calculate wane width at each 3-inch interval:
        DO 80 I = ISTART, IEND
```

```
        WW10(I) = LOW2(I) - EDGE1
        WW11(I) = LOW1(I) - EDGE1
        WW20(I) = EDGE2 - UP1(I)
        WW21(I) = EDGE2 - UP2(I)
        IF (WW10(I).LT.0) WW10(I) = 0
        IF (WW11(I).LT.0) WW11(I) = 0
        IF (WW20(I).LT.0) WW20(I) = 0
        IF (WW21(I).LT.0) WW21(I) = 0
80     CONTINUE
*
*      Board dimensions and surface measure:
      WIDTH = 0.25*(EDGE2-EDGE1)
      LENGTH = INT((TRIM2-TRIM1)/48)
      VOLUME = LENGTH*WIDTH/12
      TEMP = VOLUME - INT(VOLUME)
      IF (TEMP.GT.(0.5)) THEN
        SM = INT(VOLUME) + 1
      ELSE
        SM = INT(VOLUME)
      ENDIF
*
*      Check if wane and size rules are satisfied:
      IF (GRADE.EQ.1) CALL FASRULE(ISTART, IEND,
     &      TRIM2,LENGTH,WIDTH,WW10,WW20,SM,WANEOK)
      IF (GRADE.EQ.2) THEN
         CALL F1FRULE(ISTART, IEND, PRFACE,
     &     LENGTH, WIDTH,WW10,WW20,WW11,WW21,SM,WANEOK,TRIM2)
      ENDIF
      IF ((GRADE.EQ.3.OR.GRADE.EQ.4)
     &     .OR.(GRADE.EQ.5)) CALL COMRULE(ISTART,IEND,
     &      LOW2,UP1,WW10,WW20,TRIM2,EDGE1,EDGE2,WANEOK)
*
*     Note current best cutting combination:
      IF (WANEOK.EQ.1) THEN
       IF (SM.GE.MAXSM) THEN
        if (width.ge.maxwid) then
          LOWEDG = EDGE1
          UPEDG = EDGE2
          LEFTR = TRIM1
          RIGHTR = TRIM2
          MAXSM = SM
          maxwid = width
        endif
       ENDIF
      ENDIF
70    CONTINUE
60    CONTINUE
50    CONTINUE
45    CONTINUE
*
```

```
*     Write output:
      IF (MAXSM.GT.0) THEN
         WRITE(*,'(A\,A11)') ' Board label:', BDNAME
         WRITE(*,*)
         WRITE(*,'(A\,I5)') ' BOTTOM EDGE =',LOWEDG
         WRITE(*,'(A\,I5)') ' TOP EDGE    =',UPEDG
         WRITE(*,'(A\,I5)') ' LEFT TRIM   =',LEFTR
         WRITE(*,'(A\,I5)') ' RIGHT TRIM  =',RIGHTR
         WRITE(*,*)
         WRITE(*,'(A\,I5)') ' SURFACE MEASURE =',MAXSM
      ELSE
         WRITE(*,'(A)')' The size of this board does not allow it'
         WRITE(*,'(A)')' to meet the requirements of the estimated'
         WRITE(*,'(A)')' potential grade.'
      ENDIF
*
      STOP
      END
```

```
*****************************************************************
*                                                               *
*  Subroutine name:  FAS.FOR                                    *
*  SUBROUTINE CONTAINING SIZE AND WANE RULES OF THE FAS         *
*  HARDWOOD LUMBER GRADE.                                       *
*                                                               *
*****************************************************************
*
*  Variable definition:
*
*      LEN1 : Length of wane at the lower edge of the
*             face of the board being graded.
*
*      LEN2 : Length of wane at the upper edge of the
*             face of the board being graded.
*
*      LAST : Length of the board beyond the last 3-inch interval.
*
*     WNAR1 : Wane area at the bottom edge.
*
*     WNAR2 : Wane area at the top edge.
*
*    MAXLEN : Maximum allowable length of wane for FAS grade,
*             equal to 1/2 the length of the board.
*
*    MAXARE : Maximum allowable total area of wane in square
*             inches, equal to 1/12 of the surface measure.
*
*    WANEOK : Equal to 1 if all wane requirements for this grade
*             are satisfied, otherwise equal to 0.
*
* ADD1, ADD2 : Increments of wane length in inches at the bottom and
*             top, respectively.
*
******************************************************************
*
      SUBROUTINE FASRULE(ISTART,IEND,TRIM2,LENGTH,WIDTH,
     &       WW1,WW2,SM,WANEOK)
      INTEGER SM
      REAL MAXARE, MAXLEN, LEN1, LEN2,last
      DIMENSION WW1(60),WW2(60)
      LEN1 = 0
      LEN2 = 0
      WNAR1 = 0
      WNAR2 = 0
      MAXLEN = 0.5*LENGTH
      MAXARE = SM*12
*
```

```
*     Check dimensions: (Minimum width = 6 in., minimum length = 8 ft.)
      IF (WIDTH.LT.6) GOTO 50
      IF (LENGTH.LT.8) GOTO 50
*
*     Check wane area and length:
      DO 10 I = ISTART, IEND-2
        WNAR1 = WNAR1 + 0.375*(WW1(I) + WW1(I+1))
        WNAR2 = WNAR2 + 0.375*(WW2(I) + WW2(I+1))
        IF ((WW1(I).EQ.0).AND.(WW1(I+1).EQ.0)) THEN
          ADD1 = 0
        ELSE
          ADD1 = 3
        ENDIF
        IF ((WW2(I).EQ.0).AND.(WW2(I+1).EQ.0)) THEN
          ADD2 = 0
        ELSE
          ADD2 = 3
        ENDIF
        LEN1 = LEN1 + ADD1
        LEN2 = LEN2 + ADD2
10    CONTINUE
      LAST = (TRIM2 - (IEND -2)*12)/4
      WNAR1 = WNAR1 + 0.125*LAST*(WW1(IEND-1)+WW1(IEND))
      WNAR2 = WNAR2 + 0.125*LAST*(WW2(IEND-1)+WW2(IEND))
      IF ((WW1(IEND-1).NE.0).OR.(WW1(IEND).NE.0)) LEN1 = LEN1 + LAST
      IF ((WW2(IEND-1).NE.0).OR.(WW2(IEND).NE.0)) LEN2 = LEN2 + LAST
      IF ((LEN1/12.GT.MAXLEN).OR.(LEN2/12.GT.MAXLEN)) GOTO 50
      IF ((WNAR1+WNAR2).GT.MAXARE) GOTO 50
      GOTO 60
50    WANEOK = 0
60    RETURN
      END
```

```
*********************************************************************
*                                                                   *
*  Subroutine name:  F1F.FOR                                        *
*  THIS SUBROUTINE CONTAINS THE SIZE AND WANE RULES OF THE*
*  FAS 1-face GRADE OF HARDWOOD LUMBER.                             *
*                                                                   *
*********************************************************************
*
*   Variable definition:
*
*       PRFACE: Equal to 0 if the poorer face of the board
*               is the narrow face, otherwise equal to 1.
*
*         LEN1: Length of wane at the lower edge of the poor face.
*
*         LEN2: Length of wane at the top edge of the poor face.
*
*       MAXLEN: Maximum allowable length of wane at each edge.
*
*       MAXWID: Maximum allowable wane width  equal to 1/3 of
*               the width of the board.  The sum of the largest
*               wane width at the bottom (MAXW1) and the largest wane
*               width at the top edge (MAXW2) should not exceed
*               this value.
*
*************************************************************************
*
      SUBROUTINE F1FRULE(ISTART,IEND,PRFACE,LENGTH,WIDTH,WW10,WW20,
     &    WW11,WW21,SM,WANEOK,TRIM2)
      REAL LEN1,LEN2,MAXLEN,MAXWID,PRFACE,ADD1,ADD2,LAST
      REAL MAXW1,MAXW2
      INTEGER SM
      REAL WW1(60),WW2(60),WW10(60),WW20(60),WW11(60),WW21(60)

*
*     Check board dimensions:
      IF (WIDTH.LT.6) GOTO 50
      IF (LENGTH.LT.8) GOTO 50
*
*
*     Check better face if FAS rules are met:
      IF (PRFACE.EQ.0) THEN
       CALL FASRULE(ISTART,IEND,TRIM2,LENGTH,WIDTH,WW11,WW21,SM,WANEOK)
      ELSE
       CALL FASRULE(ISTART,IEND,TRIM2,LENGTH,WIDTH,WW10,WW20,SM,WANEOK)
      ENDIF
      IF (WANEOK.EQ.0) GOTO 60
*
```

```
*
*     Check poorer face if No.1 COMMON rules of F1F grade are met:
      IF (PRFACE.EQ.0) THEN
        DO 10 I = ISTART, IEND
          WW1(I) = WW10(I)
          WW2(I) = WW20(I)
10      CONTINUE
      ELSE
        DO 20 I = ISTART, IEND
          WW1(I) = WW11(I)
          WW2(I) = WW21(I)
20      CONTINUE
      ENDIF
*  1. Check wane length:
      MAXLEN = 0.5*LENGTH
      LEN1 = 0
      LEN2 = 0
      DO 30 I = ISTART,IEND-2
        IF ((WW1(I).EQ.0).AND.(WW1(I+1).EQ.0)) THEN
          ADD1 = 0
        ELSE
          ADD1 = 3
        ENDIF
        IF ((WW2(I).EQ.0).AND.(WW2(I+1).EQ.0)) THEN
          ADD2 = 0
        ELSE
          ADD2 = 3
        ENDIF
        LEN1 = LEN1 + ADD1
        LEN2 = LEN2 + ADD2
30    CONTINUE
      LAST =(TRIM2 - (IEND-2)*12)/4
      IF ((WW1(IEND-1).NE.0).OR.(WW1(IEND).NE.0)) LEN1=LEN1+LAST
      IF ((WW2(IEND-1).NE.0).OR.(WW2(IEND).NE.0)) LEN2=LEN2+LAST
      IF ((LEN1/12.GT.MAXLEN).OR.(LEN2/12.GT.MAXLEN)) GOTO 50
*  2. Check wane width:
      MAXWID = WIDTH/3
      MAXW1 = 0
      MAXW2 = 0
      DO 40 I = ISTART,IEND
        IF (WW1(I).GT.MAXW1) MAXW1 = WW1(I)
        IF (WW2(I).GT.MAXW2) MAXW2 = WW2(I)
40    CONTINUE
      IF ((MAXW1+MAXW2)/4.GT.MAXWID) GOTO 50
*
*
      GOTO 60
50    WANEOK = 0
60    RETURN
      END
```

```
***********************************************************************
*                                                                     *
*   Subroutine name:  COMM.FOR                                        *
*   THIS SUBROUTINE CALCULATES THE ALLOWABLE AREA OF WANE FOR *
*   No.1 Common and Below HARDWOOD LUMBER BASED ON THE AREA OF*
*   CLEAR WOOD EDGED OR TRIMMED AWAY.                                 *
*                                                                     *
***********************************************************************
*
*   Variable definition:
*
*       WNAR1:  Total wane area at the bottom of the narrow face.
*
*       WNAR2:  Total wane area at the top edge of the narrow face.
*
*       WDAR1:  Total area of wood edged away at the bottom of the
*             narrow face.
*
*       WDAR2:  Total area of wood edged away at the top edge of the
*             narrow face.
*
*     WOOD1(I):  Width of the wood being edged away at the bottom
*             X(I) units from the left end.
*
*     WOOD2(I): Width of the wood being edged away at the top edge
*            X(I) units from the left end.
*
***********************************************************************
*
*
      SUBROUTINE COMRULE(ISTART,IEND,LOW2,UP1,WW1,
     &      WW2,TRIM2,EDGE1,EDGE2,WANEOK)
      REAL LOW2(60),LAST,UP1(60)
      INTEGER EDGE1,EDGE2
      REAL WOOD1(60),WOOD2(60),WW1(60),WW2(60)
***********************************************************************
*
*    Calculate area of wane:
      WNAR1 = 0
      WNAR2 = 0
      WDAR1 = 0
      WDAR2 = 0
      DO 10 I = ISTART, IEND-2
        WNAR1 = WNAR1 + 0.375*(WW1(I)+WW1(I+1))
        WNAR2 = WNAR2 + 0.375*(WW2(I)+WW2(I+1))
10    CONTINUE
      LAST = (TRIM2 - (IEND-2)*12)/4
      WNAR1 = WNAR1 + 0.125*LAST*(WW1(IEND-1) + WW1(IEND))
```

```
      WNAR2 = WNAR2 + 0.125*LAST*(WW2(IEND-1) + WW2(IEND))
*
*     Calculate area of wood edged/trimmed away:
      DO 20 I = ISTART,IEND
        WOOD1(I) = EDGE1 - LOW2(I)
        IF (WOOD1(I).LT.0) WOOD1(I) = 0
        WOOD2(I) = UP1(I) - EDGE2
        IF (WOOD2(I).LT.0) WOOD2(I) = 0
20     CONTINUE
      DO 30 I = ISTART, IEND-2
         WDAR1 = WDAR1 + 0.375*(WOOD1(I) + WOOD1(I+1))
         WDAR2 = WDAR2 + 0.375*(WOOD2(I) + WOOD2(I+1))
30     CONTINUE
      WDAR1 = WDAR1 + 0.125*LAST*(WOOD1(IEND-1) + WOOD1(IEND))
      WDAR2 = WDAR2 + 0.125*LAST*(WOOD2(IEND-1) + WOOD2(IEND))
*
*     Compare wane and wood areas:
      SUM1 = WDAR1 + WNAR1
      SUM2 = WDAR2 + WNAR2
*     NOTE:  Following the 50-50% rule, WDAR1 should be 1/2 of SUM1
*            and WDAR2 should be 1/2 of SUM2. However, to give
*            allowance for other defects that may be present in the
*            edged-off wood, a 5% safety margin is added to WDAR1
*            and WDAR2. Hence the following statements:
*
      IF (WDAR1.LT.(0.55*SUM1)) WANEOK = 0
      IF (WDAR2.LT.(0.55*SUM2)) WANEOK = 0
      RETURN
      END
```

Vita

Name: Carmen de Castro Regalado

Place and Date of Birth: Metro-Manila, Philippines; March 13, 1962.

Education:

* Completed Master of Science in Forest Products, Virginia Polytechnic Institute and State University, January 1991.
  Thesis: Optimization of Edging and Trimming Operations for Red Oak Lumber.

* Attended Diploma Course in Industrial Engineering, University of the Philippines, 1985-1987.

* Completed Bachelor of Science in Civil Engineering, University of the Philippines, March 1983.

Scholarship received: University of the Philippines Government Scholar, 1978-1983.

Work experience:

* Graduate Research Assistant, Virginia Polytechnic Institute and State University, 1988-1990.

* Instructor, Virginia Polytechnic Institute and State University, Spring Semester, 1990.
  Course: Introduction to Microcomputing in Natural Resources.

* Trainor and Researcher, University of the Philippines Transport Training Center, 1983-1987.