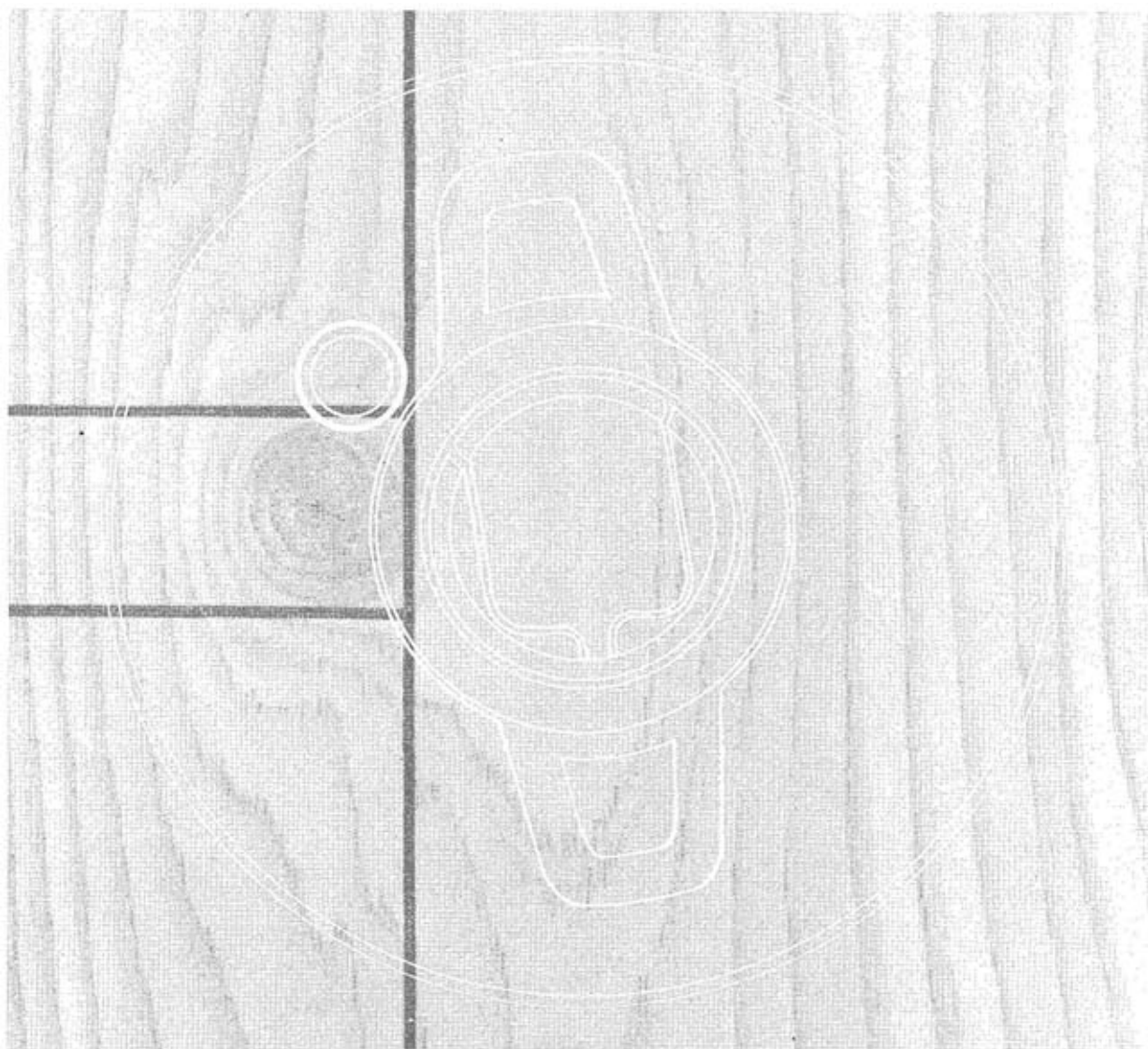


# **GRADING HARDWOOD LUMBER BY COMPUTER**

**U.S.D.A. FORESTSERVICE RESEARCHPAPER FPL 157 \* 1971**

**U. S. Department of Agriculture \* Forest Service \* Forest Products Laboratory \* Madison, Wis.**



## **ABSTRACT**

The computer program described in this report is part of a system being developed to automate the decision-making process in a sawmill. The function of this program is to simulate the grading of hardwood lumber according to the rules established by the National Hardwood Lumber Association. The grading program is being used as an evaluation tool in a decision-making computer program currently being developed. This program will optimize lumber values at the edger and trimmer in a hardwood sawmill.

The programming language used is 3600 Fortran. Processing was done on a Control Data Corporation 3600 computer.

Details of the program itself are described in "Computer Program for Grading Hardwood Lumber," by Lynn Galiger and Hiram Hallock. This FPL publication details the variables used in the program, lists program GRADE, and uses flow charts to illustrate the program and subroutines.

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# **GRADING HARDWOOD LUMBER BY COMPUTER**

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## **INTRODUCTION**

Most raw materials such as crude oil and metallic ores are more or less homogenous in nature and lend themselves to sophisticated systems of processing control. Developments in control systems have reduced the labor factor in these industries to a very low level. Paralleling this factor is a development of at least equal importance; that of improved product quality. Most of these systems include a form of control by computer in which the process is continually monitored, the feedback data are instantly processed, and corrective adjustments are automatically made.

The utilization of wood as a resource presents a quite different problem. It is definitely a non-homogenous raw material. As a product of biological growth processes it varies widely in physical and strength properties. It is also extremely variable in quality as evidenced by the size, quantity, and types of such defects as knots, splits, shakes that usually occur in lumber products of logs.

The nonhomogenous nature of wood as it occurs in logs has severely restricted the forest products industry in its effort to update processing tech-

niques. During the last two decades considerable new equipment has been designed and installed to reduce the labor force and increase production, thus presumably reducing the overall production cost.

Almost without exception the lumber produced and sold by a sawmill is segregated into grades based on the inherent quality and suitability of each for a given end use. The grades themselves are developed by technical committees in trade associations whose members are mainly the producing sawmills.

The relative value of the highest and lowest usable grades within a species varies greatly among the many species. In some of the small-diameter softwoods the highest grade may be worth three times as much as the lowest one; in black walnut the ratio may be as much as ten to one.

The profitability of many a forest products operation is grossly affected by the mix of grades that result from transforming the round log raw material into a sawn lumber product.

This mix of grades is, of course, at least partially limited by the average inherent quality of the logs. Within these limits, however, the final grade outcome can be influenced by the

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<sup>1</sup>Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

processing decisions made by the machine operator in the sawmill. This fact is universally recognized in the industry and supported by research.

Malcolm (3)<sup>2</sup> has shown that control of only two factors, defect placement and taper setout, can raise the value of lumber sawn from logs of northern red oak. His findings show an increase per MBF (thousand board feet) of \$9.67 for Grade 1 logs, \$26.41 for Grade 2 logs, and \$14.37 for Grade 3 logs.

Peter (6) in studying the influence of sawing methods on lumber values of yellow-poplar by diagram and theoretical techniques found the minimum difference between the best and poorest method to be \$16 per MBF. The maximum difference found was \$39 per MBF.

Flan and Lamb (1), working with hard maple lumber, have studied the effect of several edging practices in combination with ripping, trimming, and crosscutting in relation to the final value of lumber. Two grades only were considered; No. 1 Common and No. 2 Common. Based on value and scale when conventionally edged and trimmed compared to optimum value when properly edged, trimmed, crosscut, and ripped, they show gains of \$16.00 per MBF for lumber originally 1C and \$30.40 for the 2C.

### Fast and Correct Decisions

Mechanization in the sawmilling industry, for instance, has further complicated the making of proper decisions by the head sawyer, edgerman, and trimmerman. As the new and faster equipment increased production, it reduced the time the operator has to reach a decision for the processing of each board.

How rapidly can an operator evaluate information and make a correct processing decision? Research by Russian scientists (7) indicates that the maximum is five bits per second. If so, how many things are actually involved in such a seemingly simple decision as where to set the edger saws when edging a hardwood flitch?

First, the grading rules of the National Hardwood Lumber Association (NHLA) impose such considerations as minimum width for the grade, maximum wane allowances, maximum knot size, and the extent of splits. Further, will a rip cut produce two boards of differing grades and result

in increased value over a single board? What about actual position of the rip to maximize the quality of the boards recovered from the flitch? In addition, the price of each grade in each species must be integrated into the decision.

Exactly how many factor combinations exist is difficult to assess but it is well up in the thousands on most flitches. What it actually suggests is that the "correct" decision is seldom made.

Here at the U.S. Forest Products Laboratory, we believe that further real progress in processing must come through improvement in making processing decisions (2). A first step was to explore the use of the electronic computer in making these decisions. The initial work is being done with hardwoods. Hardwoods were chosen because their grading system is generally more mathematical in nature than the softwood grades, so there is a better possibility of handling manufacturing and grading by computer.

Logically, the decisions made in the sawmill can be divided into two categories. Those made at the edger and trimmer involve the basics of length and width, and may be considered two-dimensional. Those at the head saw involve not only length and width but also depth, and may be considered three-dimensional.

### Objectives

The solving of problems associated with making the two-dimensional decisions has been set as an initial objective, with the three-dimensional aspects to be considered in the future.

The initial objective can be more precisely described as the development of a computer program which will use the description of the flitch or board as input: as output it will develop the position of edging cuts, possible rip cut, trimming cuts, and possible crosscut to result in a board or boards of the highest quality and value. This objective requires the solving of two problems:

1. Developing technology for a system that can scan a board or flitch and mathematically describe that board and its defects.
2. Developing a computer program that; from the mathematical description of a board, can almost instantly give the grade of the board by NHLA grading rules.

Progress on describing the board and its defects

<sup>2</sup>Underlined numbers in parentheses refer to Literature Cited at the end of the report.

has been reported in Research Paper FPL 120 (4).

The present paper reports the completion of the computer program to grade hardwood lumber. First the capabilities of the program are considered, along with some inherent limitations, and then the program will be described.

## **CAPABILITIES AND LIMITATIONS**

This program is capable of grading lumber at the rate of about four boards per second when used with a Control Data Corporation 3600 computer. The authors do not expect it to operate completely free of grading errors. The NHLA allows their certified graders a grading error of  $\pm$  \$4.00 per thousand board feet. Tests of this program on 600 red oak and hard maple boards representing all standard grades and a range in lengths and widths showed complete accuracy. In fact, the computer uncovered 20 grading errors by the human grader. Its accuracy is believed to be well within NHLA tolerances.

The program classifies lumber according to the following classifications:

<u>Grades</u>	<u>Grading Output Code</u>
FAS	1
Selects	2
No. 1 Common	3
No. 2 Common	4
Below No. 2 Common	Below grade
Boards too small to meet NHLA minimum size limits	Not lumber

The NHLA grade of Select includes two types of lumber. The first is lumber whose minimum-size limits do not meet the requirements of FAS but whose quality characteristics do. The second is lumber which is basically FAS on its better face and either Sound or grading No. 1 Common on the poorer face. The input data (mathematical description) defines the board as if it were transparent and the location of defects on both faces is translated to a single plane. Thus the program correctly classifies the first type and drops the second to No. 1 Common in most cases.

In theory at least on low borderline boards, the single-plane defect data might result in lowering the board by one grade. Experience indicates this seldom happens.

The maximum number of cuttings allowed by the grading rules in grading lumber No. 2 Common and better is seven. Our test run of boards showed only one board out of 600 required as many as four cuttings to meet the grade, although several allowed four or more cuttings.

The program is believed to be 100 percent accurate in grading all boards (one to seven cuttings) having a nonoverlapping cutting solution, and those boards allowing a two-cutting solution where the overlap between these two cuttings must be resolved.

In boards allowed three cuttings, and where the three potential grading cuttings are found to overlap, there may be a possibility of missing a solution; however, this appears very slight, and did not occur in any real boards graded. With boards allowed four cuttings, the program will handle with a high degree of accuracy those boards whose solution involves a single cutting and a combination of three which overlap or a combination of two nonoverlapping cuttings and a pair that overlap. For those rare boards that allow five, six, or seven cuttings, the program will solve them if a nonoverlapping cutting solution exists.

In practice, those boards allowing five or more cuttings are usually No. 2 Common and have a large number of defects. The cuttings tend to occur singly between the defects and a nonoverlapping solution is frequently found.

In the present state of development the program is not expected to act as final 'authority in determining grade between buyer and seller. It is limited to the standard grades only. Many species are graded with limitations on color (maple, yellow-poplar, etc.) and other special characteristics such as 1/8-inch knots in cherry. Also special agreements between buyer and seller are often negotiated.

Grades established by the program should in all cases be correct or at most one grade low. It does not appear that overgrading can occur.

### Processing Alternatives

The number of possible combinations of processing sequences within the program is very large. It is entirely possible that some of them have not been tested by processing either the actual boards or the synthesized boards especially designed to test known possibilities not found in the actual boards.

## PROGRAM DESCRIPTION

The computer program analyzes the board with its defects, finds the number of cuttings of the sizes permitted, and assigns a grade according to NHLA rules (5). In effect, it simulates the visual and mental processes used in grading a board.

The data used in developing this program were taken from actual boards whose dimensions and defect dimension were recorded as coordinates of a Cartesian coordinate system. The boards were placed so that the lower left-hand corner was at the origin (0,0), the length of the board extended along the positive x-axis, and the width extended along the positive y-axis (fig. 1). The boards were described as rectangles by coordinate readings taken in quarter-inch units. The board and each of its defects were described completely by using just two pairs of points--the lower left corner and the upper right corner. All pairs were recorded in the form (y,x).

Each defect area was described so that as little clear area as possible would be included. For example, wane along the edge of the board would be described as a series of defects whose 2 coordinates describe the full width of the defect for that portion but whose  $\bar{x}$  coordinates describe only a section of the length of the defect (fig. 2). Some clear area was included as defect by making rectangular areas, but the loss was minimal. The program requires that defect readings be taken in this way. In fact, it closely duplicates human grading procedure.

The information for each defect is recorded on one card. Storage is provided for a maximum of 22 defects per board. A diagnostic statement is printed out if the number of defects exceeds this number.

The program will accept punched data for any number of boards. There are no header cards to precede the first board to be processed, but two trailer cards are needed to terminate processing. The first of these two cards has -1 punched in columns 71 and 72. The last card is blank.

A board is described by a series of cards. The first card identifies the number of the board in columns 32 through 36 and the total number of defects in columns 69 through 72. The second card gives the lower left  $\bar{y}$  and  $\bar{x}$  coordinates in columns 1 through 3 and 5 through 7. The upper right  $\bar{y}$  and  $\bar{x}$  are coordinates in columns 13 through 15 and 17 through 19.

The defects are described on the third and all subsequent cards using the same columns as designated for the board coordinates. Defect cards also contain a code number in columns 41 through 43 which identifies the type of defect. The code is as follows:

- 3 - knots
- 5 - wane
- 6 - splits - shakes
- 7 - pith

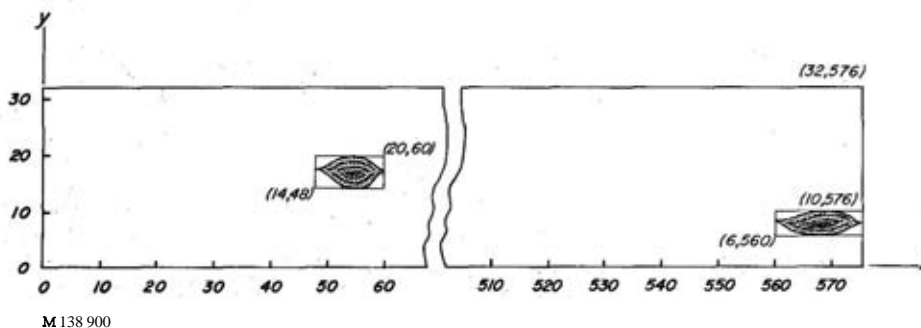
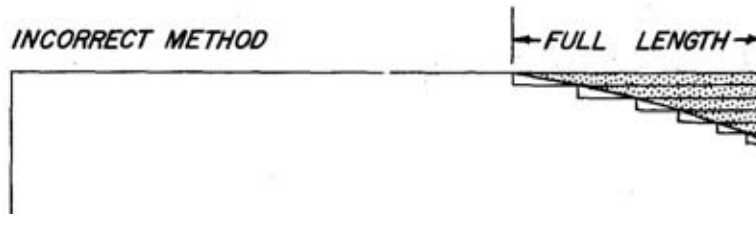


Figure 1.--A board 8 inches in width and 12 feet in length is indicated as it is oriented in the Cartesian coordinate system. Coordinates indicate in the form (y,x), the lower left and upper right limits of the board and its defects in quarter-inch units.

**CORRECT METHOD**



**INCORRECT METHOD**



M 138 901

Figure 2.--Defects which are long and tapered are described by a series of rectangles to minimize the clear area contained within the defect limits. Both the correct and incorrect methods are shown here for wane: Correct method, each rectangle within the series describes the entire width of the defect for a portion of the length; incorrect method, each rectangle describes the entire length of the defects for a portion of the width.

Below is an example of the input data of one board with 13 defects

Board Number	262 RO	Total Number of Defects	13
000000	024670		
000000	008008	3	
019104	024121	3	
000136	006140	3	
007136	008137	3	
000140	002141	5	
000202	002204	3	
000225	006230	5	
000231	004234	3	
022374	024480	3	
022499	024503	3	
014496	017499	3	
020584	024594	3	
014594	016597	3	

The main program regulates the order of execution of the two subroutines, MCA (Maximum Clear Area) and BCC (Best Combination of Cuttings); it also handles all input and output operations, and sets up some information needed by the subroutine to which it is going to release control.

Main Program

Processing begins with the reading in of data. The board is assigned a potential grade based on its size. Potential FAS and potential Sel boards are then checked to see if their defects lie within the allowable limits as defined by the NHLA grading rules.

All potential FAS and potential Sel boards processed by the defect check, and all potential No. 1C following the potential grade assignment, go to the same area for future analysis (computation or calculation). Here surface measure, the number of cuttings allowed, and the required number of cutting units for grading are calculated. Minimum cutting sizes are also assigned.

The first of three checks made involves split and shake defects. If any split or shake defect extends beyond either the left or right end foot, the total length of all splits and shakes is calculated. If total length exceeds two times the surface measure, the board is assigned the potential grade of No. 1C. If the total length of splits and shakes does not exceed the limit, the second check is made. This check calculates the total area of the defects which lie in either the

left end foot or the right end foot. If either of these two areas is greater than 50 percent of the area in the end foot, the board will have its potential grade dropped to No. 1C. The boards which satisfy this check will then be processed for wane. The method of recording (fig. 2) is critical to the wane check. In the check on wane, the defect's upper  $y$  coordinate is checked to see if it is the same as the upper edge of the board. All defects with the upper  $y$  coordinate the same as the upper edge of the board are added together. Likewise all those that are not, are added together in a second group that represents wane in the bottom of the board. If either sum exceeds half the length of the board, the potential grade will be reassigned to No. 1C.

Control is then passed to the first subroutine, MCA.

### Maximum Clear Area Subroutine

Subroutine MCA provides for a systematic scanning of the board description to locate all cuttings which are at least as large as the minimum sizes permitted in the potential grade under consideration. A cutting in the MCA subroutine by definition is a rectangular portion of a board in which no defect lies, and which is bounded on each of its four sides by either a defect or one of the four sides of the board. In effect, a cutting extends from the upper boundary of one defect to the lower boundary of another, moving in a positive direction on each axis.

The computer stores the coordinates of the board and the defects in such a way that their storage position determines whether they are the lower or upper coordinates. For the sake of convenience, the computer stores the lower coordinates of the board as upper coordinates of a defect, and the upper coordinates of the board as lower coordinates of a defect. As the first step in this subroutine, the coordinates of the board and of the defects are ordered according to magnitude. All the  $x$ 's are ordered in a group and all the  $y$ 's are ordered in another group.

The scanning process for finding cuttings (fig. 3) has two steps. Step 1 considers the cutting width by  $y$ -coordinates. It begins in the lower left-hand corner of the board. The distance between the first upper  $y$ -coordinate (lower edge of the board) and each succeeding lower  $y$ -coordinate is checked until the first such distance is found, which is at

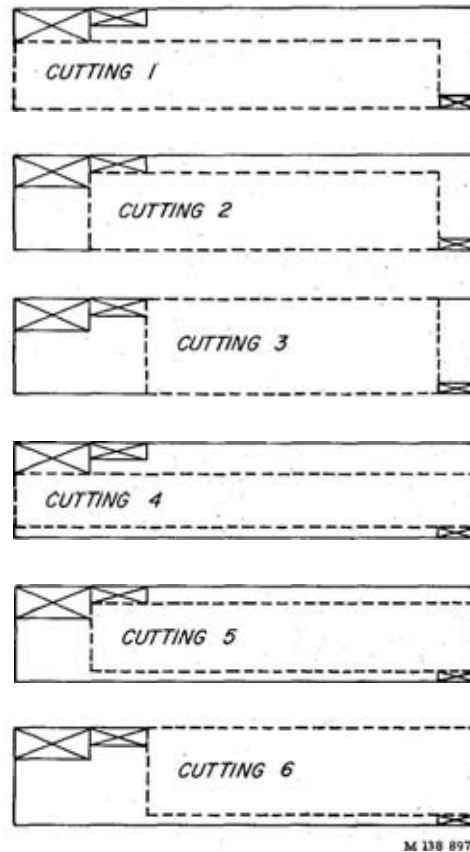


Figure 3.--All possible cuttings located by MCA for this board are shown in the order in which they are found. X-bearing rectangles enclose defects.

least as large as the smallest allowable cutting width. This determines the  $y$ -bounds of the cutting.

Step 2 considers the cutting length by  $x$ -coordinates. The distance between the first upper  $x$ -coordinate (left-hand end of the board) and each succeeding lower  $x$ -coordinate is checked. The procedure is to skip over those  $x$ -distances which do not lie within the established  $y$ -bounds, until the first such distance is found which is at least as large as the minimum length required for the width already selected. This determines the  $x$ -bounds of the cutting.

The cutting description, including its length, width, and area, is then stored. Since there may be other clear areas within the  $y$ -bounds chosen in Step 1, these  $y$ -bounds are not changed and the scanning process begins at the point where it stopped in Step 2. Those  $x$ -distances which had not yet been considered in Step 2 are now checked. When all the  $x$ -distances have been checked, the

scanning process returns to Step 1 to find a new set of y-bounds and then goes to Step 2 to consider the x-distances over again. In brief, what happens is that a set of y-bounds is chosen in Step 1 and then a set of x-bounds is chosen in Step 2. For each set of y-bounds chosen, all x-distances are considered. In this way, all clear areas up to a maximum of 25 are considered.

As each cutting is found, a check is made to see if it has by itself enough cutting units to meet the requirements for grading. If a cutting does satisfy the requirement, control will pass to the main program where the final grade will be printed out and processing of that board will be terminated. The next board would then be read in for processing. If all the cuttings in the board have been found and none of the cuttings found were large enough to meet the cutting unit requirement, control returns to the main program for further processing.

In the main program, if it is determined that MCA has not found any cuttings, the board will be reassigned the next lower potential grade. MCA will be called again and cuttings of new size specifications will be found if they exist. If no cuttings are found, the potential grade will again be reassigned. This reassignment and processing by MCA can continue until a board drops below No. 2C. At that point a message "Board Number X Below Grade SM=" is printed out and processing of that board is terminated.

If MCA finds more than one cutting, and none alone have enough cutting units to make the board grade, a check is made to see if combinations of cuttings can be considered for solution. If the number of cuttings permitted is at least two and MCA has found at least two cuttings, control will pass to BCC. If MCA finds only one cutting and the number of cuttings permitted is at least two, the board will be reassigned the next lower potential grade. If MCA finds more than one cutting but the number of cuttings permitted is one, a check will be made to see if the grading rules will allow an extra cutting to be used if the cutting unit requirement is also increased. If this is allowed, the necessary recalculations are made and control will pass to subroutine BCC,

#### Best Combination of Cuttings Subroutine

Subroutine BCC has two main functions. The first is to form combinations of cuttings. The

other is to resolve overlap when it exists in combinations of two, three, and four cuttings.

The number of cuttings in a combination depends upon the number of cuttings permitted by the grading rules. If for example, the number permitted is four, all possible combinations of two, three, and four cuttings that can be made from those found by MCA will be formed. Each cutting is put into combination with every other cutting. A maximum of 25 combinations that have at least the number of cutting units required to grade will be stored from each group. If more than 25 combinations can be formed, the 25 combinations with the most cutting units are stored.

When combinations of cuttings are formed, the total area of the combination is calculated by adding the areas of the cuttings together. When an area of overlap exists, a correction is made by calculating the area of the overlap and subtracting it from the total cutting unit area. The cuttings still overlap but the net cutting unit area for the combination now indicates the size of the area of the board which the combination covers. The net area determines the limiting bounds of the solution cuttings. By proper analysis and coordinate adjustment, two cuttings of at least minimum size will be placed within this area. The overlapping cutting boundaries serve as a basis for defining the nonoverlapping cuttings whose coordinates are determined by maximization routines and not by defect location as in MCA.

Since the cuttings are placed within the net area, this area must be at least as large as the cutting unit area required to grade, to allow for some area loss due to the placing of artificial boundaries.

At the time combinations are being formed, any combination of nonoverlapping cuttings that has enough cutting units to meet the grading requirements will register as a solution; control will then immediately return to the main program for printing the final grade and terminate the processing of that board.

The combinations stored for later use are ordered so that the combination with the most net cutting units is stored at the top of the list. It has the best potential for solution in any of the overlap resolution routines.

All three of the overlap-resolving routines which will be explained later will process up to three combinations in an attempt to find a solution. The routines are executed in order. If any combinations of two cuttings are stored, they will be

processed first. If a resolved combination of cuttings has sufficient cutting units to meet the grade, control will be transferred to the main program so that the final grade can be printed out. If none of the combinations of two cuttings processed have sufficient cutting units to meet the grade, combinations of three cuttings stored will be processed. If none of the combinations of three cutting resolutions have enough units to meet the grade, the combinations of four cuttings stored will be processed next.

In addition to solution cases, control will be returned to the main program if either the number of cuttings permitted limits the routines to be executed or all routines have been executed without finding a solution. At this point, the direction of further processing is determined. If the grading rules allow an additional cutting with an increase in required cutting units, BCC will be re-entered with this new information and processing will continue as described above. The only change will be in the combination-forming part of BCC. Since all combinations of cuttings less than the number allowed now have already been formed, only the combinations with the newly assigned number of cuttings will be formed. Then processing of the new combinations formed will follow. Again a maximum of three combinations will be processed in a search for a grading solution.

If an additional cutting is not allowed, the main program will "quick check" to see if any of the cuttings found by MCA or any of the combinations of cuttings resolved by BCC would have enough cutting units to meet the cutting unit requirement of the next lower potential grade. If a cutting or resolved combination does, the "quick check" will immediately classify the board in the next lower grade. If this cannot be done, the board is temporarily assigned the next lower potential grade with new minimum cutting sizes. The number of cuttings allowed and the cutting units required in the new grade are recalculated. The process is then repeated. MCA is entered to find new cuttings followed by the execution of BCC to form new combinations and resolve overlap between the cuttings in the combinations.

If an additional cutting is allowed and the combinations of this number of cuttings do not yield a solution, the "quick check" is made before the board is processed in the next lower potential grade.

BCC thus performs two major functions--

forming combinations of cuttings and resolving overlap. When MCA finds a cutting, it assigns a number to it so that it can be identified later in the program. The number assigned to a cutting indicates when the cutting was found and gives no indication of the size of the cutting.

One of the first places the numbers are used to reference cuttings is in the combination-forming section of BCC. Assume, for example, the number of cuttings permitted for grading is three and MCA found four cuttings. Six combinations of two cuttings and four combinations of three cuttings would be formed in the following order.

<u>Combination No.</u>		<u>Combination No.</u>	
First	1, 2	Sixth	1, 4
Second	1, 2, 3	Seventh	2, 3
Third	1, 2, 4	Eighth	2, 3, 4
Fourth	1, 3	Ninth	2, 4
Fifth	1, 3, 4	Tenth	3, 4

Notice that cutting No. 1 is used in the first six combinations formed. The only reason this cutting is given priority is that it happened to be the first cutting found by MCA and therefore assigned as No. 1. Even though the total number of cutting combinations of n cuttings exceeds 25, all cuttings are considered in the selection of the top priority combinations. Only the 25 combinations with the most cutting units will be retained in storage.

After all combinations have been formed there may be up to six groups of combinations stored. Group 1 would include combinations of two cuttings. Group 2 would include combinations of three cuttings and so on. One or more of these groups will be formed depending upon the number of cuttings permitted for the potential grade under consideration.

By this time all single cuttings and combinations of nonoverlapping cuttings with enough cutting units to meet the grading requirements will have been found. If no solution has been found, the only combinations not processed yet are combinations of cuttings which share some area (overlap). It is possible to "make" new cuttings by adjusting one or more boundary lines or cutting coordinates. This can only be done effectively by analyzing the case and making an adjustment which retains the maximum area in the resolved combination. Three routines have been developed to resolve overlap between cuttings. All three will take a combination

of cuttings and adjust one or more coordinates so that the cuttings are adjacent but do not share any common area.

Overlap-two-cutting routine.--The first of these is the two-cutting routine. The combination of two cuttings with the greatest cutting unit area is taken from storage. Calculations are made to determine the relative position of the two cuttings. There are two general classifications of two overlapping cuttings (fig. 4).

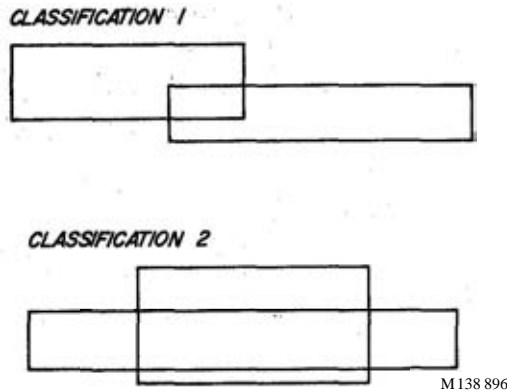
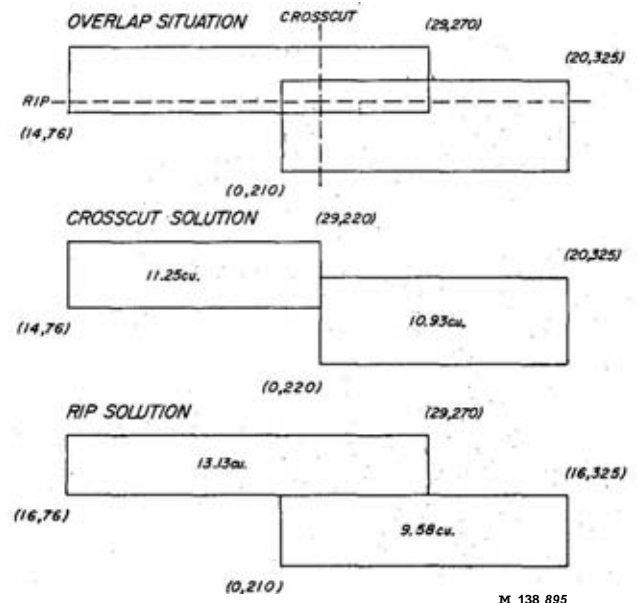


Figure 4.--The two general ways a combination of two cuttings may overlap are by partial overlap (classification 1) or complete overlap (classification 2) of one cutting on the length or width of the other.

With this information stored, further interrogation is made to determine overall physical lengths and widths as well as relative sizes such as which cutting is longer, shorter, wider, or narrower. This information is used to fit the combination into one of ten solution types. Six of these are designed to maximize the area retained in non-overlapping cuttings by placement of a new appropriate crosscut or rip boundary? Three solution types will consider both a crosscut and a rip (fig. 5) before deciding which boundary adjustment will be used to separate the two overlapping cuttings into cuttings that do not overlap. No area can be gained by the resolution; most likely some area will be lost, but this loss is minimized by careful screening of the combinations before the cut is placed. The tenth type indicates a case in which no solution is possible,

The area of the resolved cuttings is calculated and checked to see if the cutting unit requirement is satisfied. If it is, control is returned to the main program where the solution condition is printed out. If too few cutting units are in the resolution, the next combination in storage is processed. This processing of combinations of two cuttings continues until at most three combinations are processed.

Figure 5.--Of the 10 types of double overlap, three require a comparison of both the maximized crosscut and rip solutions in the determination of the optimum solution. Shown here is an example of one of these three. Numbers within the cuttings indicate their area in cutting units (cu). The rip solution with 22.71 (13.13 + 9.58) cu. is better than the crosscut solution.



<sup>3</sup>The terms crosscut and rip are used figuratively in the program descriptions to imply the formation of a boundary similar to one formed by crosscutting or ripping.

If combinations of three cuttings are permitted and no single cutting or resolution of two cuttings yields a solution, the combination of three cuttings with the most cutting units is taken from storage for processing.

Overlap -- three-cutting routine--There are three classifications of three-cutting overlap (fig. 6). A combination is placed in one of these groups initially and processing continues for that particular classification. The least complex, classification 3 (fig. 6), has one independent cutting

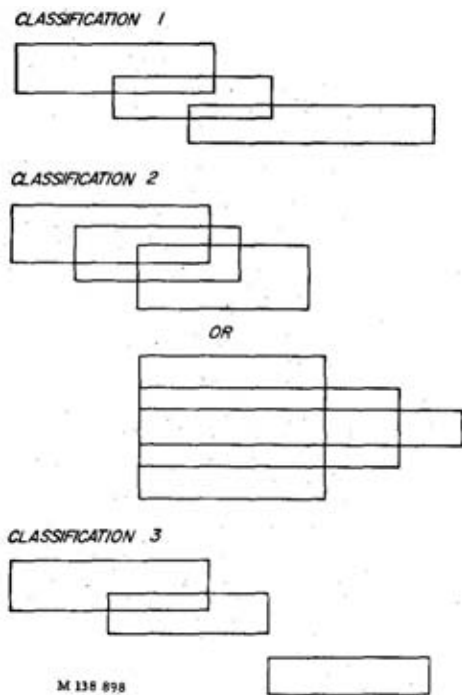


Figure 6.--The three general ways a three cutting Combination may overlap are: Classification 1, only one cutting overlaps both of the other two cuttings; classification 2, each cutting overlaps the other two cuttings; classification 3, one cutting is independent of the other two cuttings which do overlap.

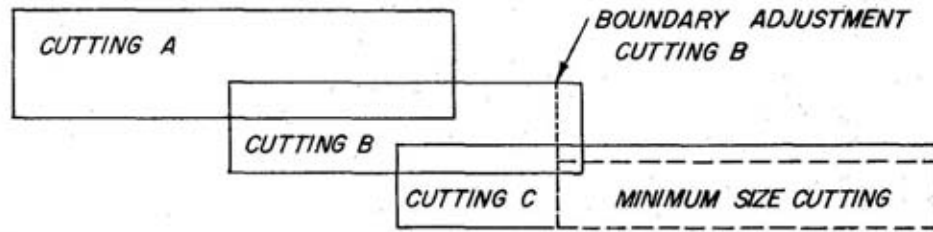
and one pair of cuttings which overlap. The necessary indicators are set and then control is passed to the two-cutting routine to resolve the overlap between the two overlapping cuttings. After the two overlapping cuttings have been resolved into two adjacent nonoverlapping cuttings, this information is returned to the three-cutting routine where the total number of cutting units for the resolved combination is calculated. If the combination has sufficient cutting units to

grade, control passes to the mainprogram. If not, the next combination in storage is processed.

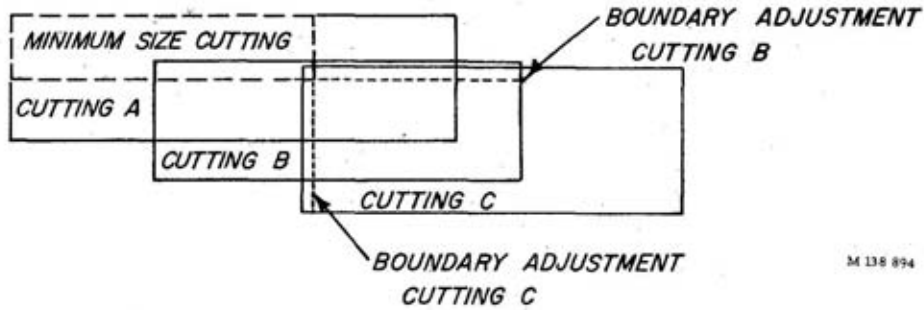
The other two classifications of three-cutting overlap (fig. 6) do not have an independent cutting. In effect, the routine has to make one of the overlapping cuttings independent of the other two. This is done by placing a cutting of minimum size within one of the cuttings. In classification 1 this minimum-size cutting is placed in the cutting which overlaps only one cutting and has the smaller amount of overlap. The minimum-size cutting is placed as far from the overlap area as possible (fig. 7). The actual size of the minimum-size cutting is determined by the length of the cutting in which it is to be placed. The narrower allowable width and its corresponding length are chosen. After the minimum-size cutting is placed, a check is made to see if it overlaps with the cutting closer to it. If it does, that cutting is adjusted so that the minimum-size cutting is independent. The two cuttings in the combination that is left are then processed by the two-cutting routine to resolve the overlap between them. Next the two resolved cuttings are brought back to the three-cutting routine where they are stored as defects. MCA is then called and allowed to find the largest cutting left in the board. This pass of MCA usually just expands the minimum-size cutting if the area adjacent to it is clear. On returning to the three-cutting routine, the total number of cutting units in the resolved combination is calculated. Processing continues as mentioned above,

Classification 2 (fig. 6), which does not have an independent cutting, has all three cuttings overlapping each other. The outermost widest, usually nonoverlapping, area of the combination configuration near either the top or bottom of the board is selected as the location for the minimum-size cutting (fig. 7). Again the size of the minimum-size cutting is determined by the length of the cutting in which it is to be placed. In this type of combination, it may be necessary to adjust the boundaries of both of the other cuttings so they do not overlap the minimum-size cutting just placed. Once the boundaries of the other two cuttings are adjusted properly, the two cuttings are processed by the two-cutting routine to have the overlap resolved. On coming back to the three-cutting routine, the resolved cuttings are stored as defects, the minimum-size cutting is expanded and the total number of cutting units in the nonoverlapping combination is calculated. If the two-cutting routine placed a crosscut to resolve the

*CLASSIFICATION 1*



*CLASSIFICATION 2*



M 138 894

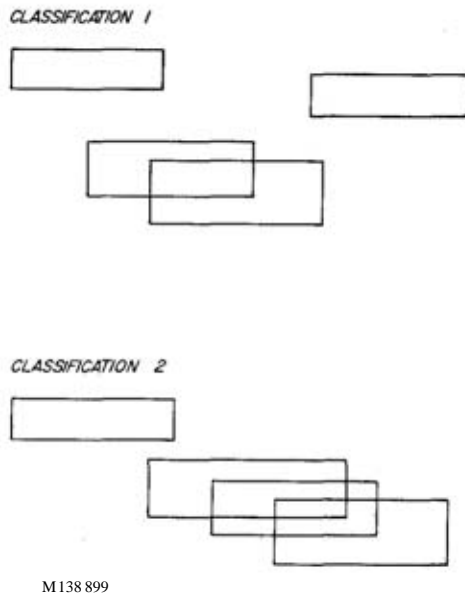
Figure 7.--Examples of placement of the minimum-size cutting and boundary adjustment for three-cutting combination, classifications 1 and 2, are shown: Classification 1 requires the adjustment of one boundary in cutting B; classification 2 requires the adjustment of one boundary in cutting B and one boundary in cutting C.

overlap, the combination is checked to see if it has enough cutting units to meet the grade (Old Routine). If a rip had been used the following conditions will be checked First, the solution type used in the two-cutting routine was one which tried both a rip and crosscut adjustment; second, the residual of the cutting in which the minimum-size cutting had been placed was not used as one of the cuttings in the combination processed by the two-cutting routine; third, the cutting in which the minimum-size cutting had been placed is longer than the resolved cutting adjacent to it. If all these conditions pertain, a short routine (New Routine) will be executed to improve, with respect to the three-cutting combination, the rip placed by the two-cutting routine. The cutting units in the resolved combination with the newly placed rip are then calculated. A comparison of the cutting units in the two resolutions of the same combination is made. The greater of the two is then checked to see if it meets the requirements for grading. If any of the three conditions above is not met, the New Routine is not executed and the original rip solution is checked for grade (Old Routine). Control will

either return to the main program to indicate a solution or remain in BCC to process up to three combinations of three cuttings,

Overlap--four-cutting routine. --if the number of cuttings allowed is at least four and no solution has been found, the combinations of four cuttings will be processed to resolve overlap. The four-cutting routine will take the combinations of four cuttings stored and sort out two classifications of overlapping combinations (fig. 8). When it finds a total of three combinations or exhausts the combinations stored, sorting will stop. Classification 1 (fig. 8) has two independent cuttings and one pair of cuttings which overlap. Once these cuttings are identified, the overlapping pair is put into the two-cutting routine where the cuttings are resolved into two nonoverlapping cuttings. The total number of cutting units in the combination is calculated when the two resolved cuttings are returned to the four-cutting routine. The cutting units in the combination are checked for grading purposes before either control is returned to the main program or the next combination of four cuttings is processed.

Classification 2 of the four-cutting overlap



M138 899

Figure 8.--The two classifications of four-cutting overlap that are processed by the program are: Classification 1, two independent cuttings and a pair of overlapping cuttings; and classification 2, one independent cutting and three cuttings that overlap.

(fig. 8) has one independent cutting and three cuttings which overlap, After cutting identification, the three cuttings are put into the three-cutting routine. The three-cutting routine processes the combination just as it would any combination of three cuttings coming directly from storage. It will use the two-cutting routine to resolve overlap between a pair of cuttings, expand the minimum-size cutting, and put the three resolved cuttings together before it returns them to the four-cutting routine. In the four-cutting

routine, the independent cutting is put with the three resolved cuttings and the total cutting units of the combination is calculated. The procedure for Classification 1 (fig. 8) is followed from this point.

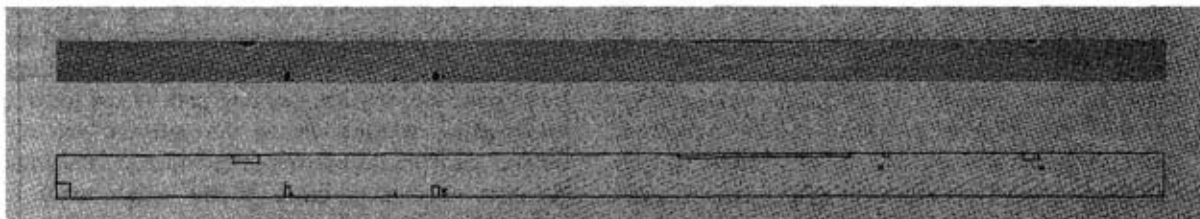
#### A Grading Example

Some of the aspects of the grading program as applied to one test board are illustrated in figures 9, 10, and 11. Figure 9 shows this board as it appears, with defects emphasized, and also as the computer sees it. It also illustrates the mathematical description and the defect-enclosing rectangles.

In figure 10 the upper view shows all 12 clear cuttings, as found by the MCA subroutine, that are large enough to meet the minimum-size standards for the grade of No. 1 Common. The program has already determined that the board is neither FAS nor Sel. It is evident there is repeated overlap--a situation not allowed in the grading solution.

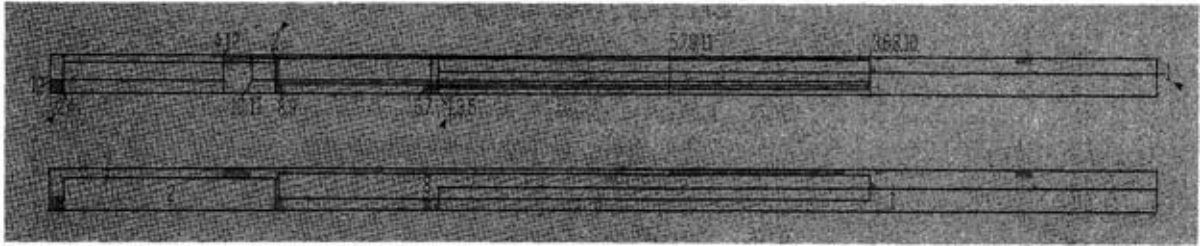
The lower view (fig. 10) shows the three cuttings which the BCC subroutine selected (from the 12) as having the potential to yield a No. 1 Common solution with the largest number of cutting units. Note that overlap still exists between cuttings 1 and 8. The BCC subroutine then analyzes this overlap and reforms the boundaries of overlapped cuttings 1 and 8. The resultant cuttings contain all cutting units possible while still meeting the minimum-size restrictions for the grade.

The grading solution applied to both the real and computer boards is shown in figure 11. The program has established the grade as No. 1 Common under the extra-cutting rule with a yield of 55 cutting units--54 were required.



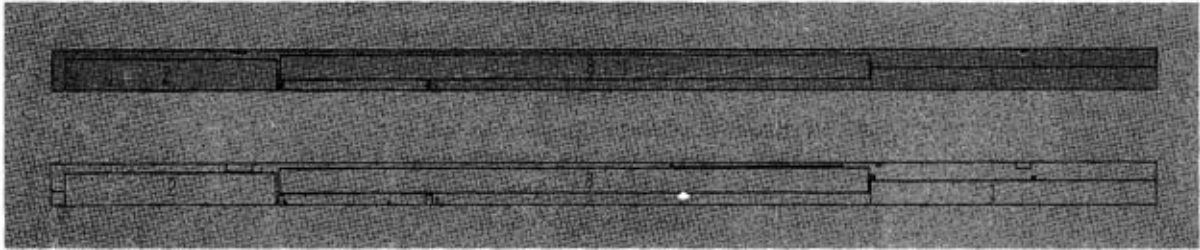
(M 137 726)

Figure 9.--A 6-inch by 12-foot red oak board with defects accented. Below the actual board is the same board as the computer sees it--a graphic display of its mathematical description.



(M 137 729)

Figure 10.--Upper view, all clear cuttings, found by subroutine MCA, which meet the minimum requirements of the No. 1 Common grade. Numbers such as 1,1 and 2,2 indicate the lower left and upper right corners of the same cuttings. Lower view, the three cuttings selected by the BCC subroutine as having the best potential for being reallocated into a three-cutting nonoverlapping solution.



(M 137 727)

Figure 11.--The computer-developed grading solution as applied to the real board (upper) and computer board (lower). Grade is No. 1 Common under extra-cutting rule.

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## ***ADDITIONAL NOTE***

Since the development of this program for the Control Data Corporation 3600 computer, the FPL has made the necessary alterations and developed a version of the program which will run on a UNIVAC 1108. This is a faster computer than the CDC 3600 and grades boards at a rate of about 10 or more per second. A listing of this version can be made available on request to the Laboratory.

The University of Kentucky, Department of Forestry, Lexington, Ky., has also altered the program to run on an IBM 360 computer.

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