AN INTRODUCTION TO UGRS: THE ULTIMATE GRADING AND REMANUFACTURING SYSTEM

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ABSTRACT

The Ultimate Grading and Remanufacturing System (UGRS) is an advanced computer program for grading and remanufacturing lumber. It is an interactive program that will both grade lumber according to NHLA rules and remanufacture it for maximum value. UGRS is written to run under Microsoft Windows 3.0 or later updates and provides a sophisticated graphical user interface. UGRS displays boards that have been digitally described in a computer file (x-y coordinates) showing the board outline and defects along with pertinent grading and remanufacturing information. Potential applications include: 1) training in the basics of lumber grading; 2) investigation into potential value increases obtainable from remanufacturing operations; 3) research into the effects of grading rules on lumber grades and value; and 4) yield optimization studies.

The complexities of the National Hardwood Lumber Association (NHLA) hardwood lumber grading rules (11) make designing a computer program that can provide accurate grading of hardwood lumber extremely difficult. Nonetheless, computer-based grading of hardwood lumber is attractive because grade determinations are consistent and computer grading can be more accurate than human grading.

Computer-based grading has evolved over the last three decades. The first hardwood lumber grading program was designed by Hallock and Galiger (3) in 1971. In 1988, Klinkhachorn et al. (7) presented a more sophisticated program. Consideration of both faces during the grading process was a major improvement. The grading program developed by Klinkhachorn et al. was later incorporated into a computer-based training program called HaLT (Hardwood Lumber Training Program) for hardwood lumber graders (6). HaLT was later refined into HaLT2 (5) which led to a program called ReGS (Realistic Grading System) (1,4). A major enhancement found in ReGS is the ability to grade boards that are tapered and/or contain 1/4 inch or so of side bend or crook.

The grading program by Klinkhachorn et al. (7) was later incorporated into HaRem (Hardwood Lumber Remanufacturing Program) (12), a program that attempted to remanufacture lumber for the highest dollar value based on the current market prices of the various lumber grades. HaRem was later enhanced and used to create another training program called TRSys (Training and Remanufacturing System) (8).

All of these programs were designed for use either as a learning/training tool or for possible incorporation into an Automated Lumber Processing System (ALPS) (9). While they were successful to some degree, none provided fast and accurate grading combined with remanufacturing of lumber. UGRS (Version 4) (10) provides this and more. It allows for human interaction through an easily operated graphical user interface that provides the ability to override key grading decisions and the ability to manually remanufacture boards after automatic remanufacturing has been attempted.

UGRS: AN OVERVIEW

The UGRS program consists of two modules: a grading module that provides flexible computer grading of lumber based on 1998 NHLA hardwood lumber grading rules (11) and a remanufacturing module that provides four different automatic methods for lumber remanufacture along with manual remanufacturing. The UGRS program and accompanying utilities are 32-bit executables and are designed to run under Microsoft Windows 3.0 or the newer Windows 95 and Windows NT (using the WIN32S extensions).

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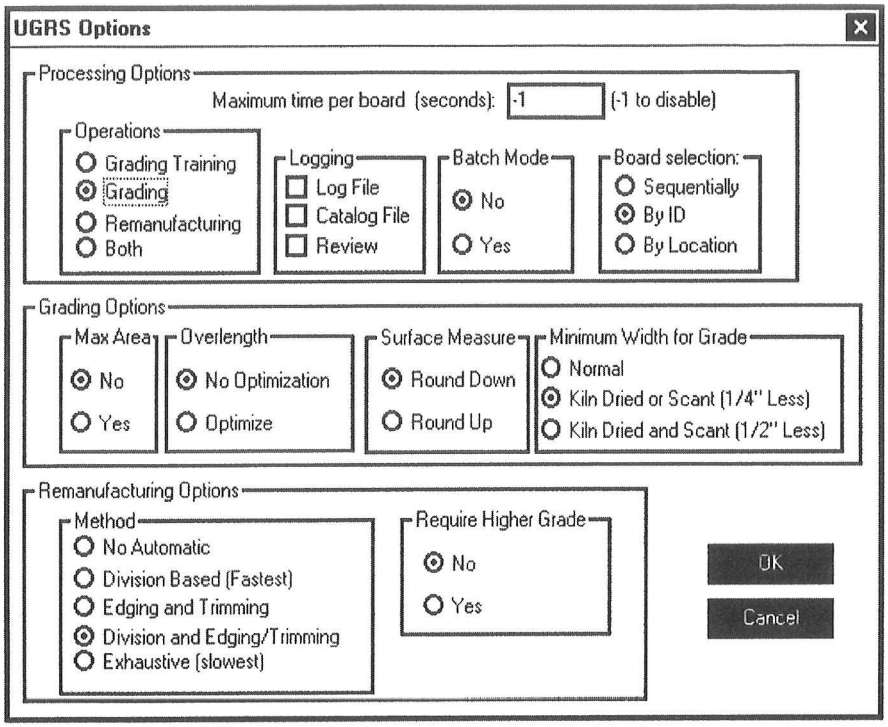

Figure 1. — UGRS options window.

The UGRS program was written to meet several needs. The program can be used to grade lumber data sets and to train people in the basics of grading lumber. It can provide grading solutions similar to those of humans (the first solution that meets the highest possible grade) or it can determine the maximum amount of surface measure in the maximum allowable number of grading cuttings. The latter is a more precise predictor of a board's utility. It can be used to study the effects of rounding up or down those boards whose surface measure is halfway between two whole feet. It can grade according to air-dried, kiln-dried, or scant widths. It can remanufacture boards to a higher value with or without requiring a higher grade in one of the remanufactured boards. UGRS can remanufacture by edging and trimming alone, by dividing a board into as many as four smaller unedged and untrimmed boards, and by edging and trimming the smaller boards if the results are higher in value.

UGRS comes with the 1998 Data Bank for Kiln-Dried Red Oak Lumber (2). This data bank contains 3,487 boards (20,021 board feet (BF)) that are straight or contain no more than 1/4 inch of crook. The lumber grades are FAS (654 boards), F1F (350 boards), Selects (281 boards), 1 Common (1,038 boards), 2A Common (925 boards), and 3A Common (239 boards). UGRS also contains a utility that allows the user to create boards.

UGRS provides a graphical display of each board in a window that the user may resize in one of three ways. First, there is a "Scale" view of the board. This is of limited value for long, narrow boards because small defects are hard to see. Second, there is the "Wide" view, which increases the width relative to the length. This makes identification of defects much easier but takes some mental adjustment as square defects become tall rectangles. Third is the "Expand" view, which enlarges a section of the board with the enlarged section displayed to scale. In addition, the user may click anywhere on the board or on any defect to open a new window for more information.

To provide maximum flexibility, UGRS stores many parameters in files so that modifications can be made without modifying the program itself. These parameters include lumber prices, remanufacturing costs, and grading rules. The remanufacturing costs consist of a fixed cost and a cost per lineal foot for rip and crosscuts. For manufacturers who do not know their overhead and processing costs, an arbitrary value can be assigned to the fixed cost that represents the minimum increase in value that will be accepted before remanufacturing will be done.

In addition to storing operating parameters in files, UGRS can create two types of output files for each board file processed. The first includes general information about each board, such as detailed grading information, remanufacturing information, and the final results obtained. The second lists only grading information. In addition, UGRS can store results for later viewing and printing by an external utility program called Review.

OPTIONS

When running UGRS, many options can be specified that affect the grading and remanufacturing processes. **Figure 1** shows the UGRS options window format. In the "Processing Options" box, options are set that affect the overall processing of the lumber. The first option is "Maximum time per board in seconds." This controls the maximum amount of time spent grading and remanufacturing a board. Under most circumstances, only a second or two will be needed to grade lumber. The timer can be set to allow from 1 to 30,000 seconds per board or disabled entirely to allow an unlimited amount of time. Using the most time-consuming options (exhaustive remanufacturing accuracy plus optimum overlength distribution), we have found an occasional board that requires several hours to process with a 233 MHZ Pentium processor. Such boards are large in size, contain many defects, and can be remanufactured into three or four smaller boards of many possible sizes and grades. Most of the excessive time is spent in developing the optimum remanufacturing solution.

The next processing option, "Operations," controls whether UGRS grades, remanufactures, or performs both operations. When grading only, the user can choose between "Grading Training" and "Grading." If "Grading Training" is selected, the user must click the mouse to continue through the grading process step-by-step answering questions about the board and drawing grading cutting solutions until UGRS displays the final grade along with a description of how it was obtained. If "Grading" is chosen, the

final grade is displayed initially and the steps in the grading process can be reviewed if desired. If "Remanufacturing" is chosen, the grading process will still be performed but processing will not pause until UGRS has attempted to remanufacture the board for higher total value. If "Both" is chosen, UGRS will grade the board and display the results, pause for user input if any overrides have been selected, and proceed to remanufacture the board.

"Logging" controls the method UGRS uses to store results. "Batch Mode" allows UGRS to process a group of boards at one time. "Board selection" allows the user to specify if the boards will be processed in sequence, by board number, or by location in a file.

The options within the "Grading Options" box control the speed and accuracy of the program while grading the lumber. "Max Area" tells UGRS to search for either the first solution that fulfills the minimum cutting unit requirements for each NHLA grade (click "no") or the solution containing the most cutting units in the largest allowable number of cuttings (click "yes"). Note that the latter has no effect on the grade the board receives. "Max Area" provides a better predictor of board utility but requires more time to grade. This option would typically be selected when using UGRS for research purposes.

In the "Overlength" box, UGRS can be instructed to position the overlength to achieve the highest grade. If "Optimum" is selected, the overlength may be divided between the ends or placed on either end. If "No Optimum" is selected, the overlength will be placed on the end with the greatest area of defects.

"Surface Measure" controls the rounding of surface measure when the value falls exactly between two whole numbers. Normally, rounding down would be used as this usually produces the highest grade.

"Minimum Width for Grade" allows the user to choose if boards less than the minimum nominal width for a grade will be accepted. All kiln-dried boards may be 1/4-inch scant. Up to 10 percent of all air-dried boards may be 1/4-inch scant. When the 10 percent scant rule is applied to kiln-dried boards, widths 1/2 inch narrower than nominal are allowed.

The options within the "Remanufacturing Options" box control how remanufacturing boards to a higher net value is done. Elsewhere, the costs of processing and the price per 1,000 BF of each grade of lumber are entered. These values are considered when determining whether there is a remanufactured solution for any board. When remanufacturing a board, an attempt is made to cut a board into one or more new boards that, together, have a higher overall value than the original board.

"Method" allows the user to select one of five methods to search for remanufacturing solutions. "No automatic" requires the user to do the remanufacturing manually. A comparison between the manually developed solution and the original board value is given. "Division Based" is the fastest and can divide each board into as many as four smaller boards. "Division Based" incrementally moves a vertical and a horizontal division line on the board and saves the combination of up to four boards that has the highest total value. "Edging and Trimming" will produce a shorter and/or narrower board. After it finds the highest valued solution, it "grows" the new board as large as possible without changing (reducing) the value. For example, "Edging and Trimming" could add an additional 11-3/4 inches to the length of a new board as NHLA rules require rounding this addition down to the nearest foot when determining surface measure. But, that extra length might contain useful yields or a part of a grading cutting.

"Division and Edging/Trimming" is a combination of the first two methods in which an edging and trimming solution is followed by a "Division Based" solution. But, there is an important addition here. During the "Division Based" process, each of the resulting boards is individually edged and trimmed. This can be very important when removing such defects as pith or wane from the new and smaller boards. The possibilities for finding Selects and better from the "Division Based" solutions are improved. The solution with the highest combined values and largest areas are retained. "Exhaustive" remanufacturing works like the "Division and Edging/Trimming" method but tests many more possibilities; however, considerably more processing time is required.

The "Require Higher Grade" option allows the user to eliminate a class of potential remanufacturing solutions from consideration by UGRS. When remanufacturing a board, UGRS may occasionally find a solution that has an overall higher value than the original board even though the solution contains no subboard with a higher grade than the original board. This is generally due to the rounding associated with calculating the board surface measure. For example, a No. 1 Common board with 40 cutting units contains 3 feet of surface measure (closer to 36 cutting units than 48 cutting units). It could be crosscut to two No. 1 Common boards each of which contains 20 cutting units. The 20 cutting units would be rounded up to 2 feet of surface measure (24 cutting units) and the total of 4 feet of surface measure for both new boards means an extra board foot has been generated. If "No" is selected, UGRS will consider this type of solution as valid. If "Yes" is selected, UGRS will not consider this solution valid even though it has a higher value than the original board. However, UGRS will provide a warning that a solution of this type was found and discarded.

How UGRS works

When grading a board, UGRS determines one of seven grades: FAS, F1F, Selects, No. 1 Common, No. 2A Common, No. 3A Common, or Below Grade. UGRS considers both board faces and evaluates 10 defect types according to NHLA rules and 1 artificial defect, void. The 10 defects are: stain, checks, sound knots, unsound knots, wane, splits, pith, holes, decay, and bark pockets.

The void defect was introduced in ReGS (1,4) to allow grading of boards with slight crook or taper. For computer-aided grading, a board must be placed in a rectangle that touches the sides and ends of the board. When the board is a perfect rectangle, the sides and ends of the board and the enclosing rectangle are the same. For air- or kiln-dried boards affected by differential shrinkage or tapered boards, gaps or spaces will often appear between the board perimeter and the enclosing rectangle. In UGRS, this gap or space is labeled as a void. Void is not a true defect because it occurs outside the board. Therefore, size and length of void are not evaluated as, for example, the size of a knot or length of wane would be when calculating FAS or Selects grades.

UGRS considers all defects as rectangles with sides parallel to the sides of

the board. For small or round defects, this does not introduce important errors. There are two places, however, where this presents a problem and special handling is required: consideration of "stepped defects" and the ends of FAS boards.

If a defect is encoded using a single rectangle enclosing the entire defective area, the area of the encoded defect can greatly exceed the physical area of the defect. **Figure 2** shows an example of encoding a split using a single rectangle. This can severely limit the placement of grading cuttings. A solution to this problem is to encode the defect as a series of smaller rectangles known as "stepping the defect." With most types of large defects this works well. However, when considering some defects, the length and/or width of the entire defect is required for grading (i.e., split length or knot diameter). With all earlier computer grading programs, "stepping the defect" precluded consideration of defect size limitations because each rectangle was considered to be a different defect. UGRS calculates the true length and width of a "stepped defect" by calculating the total length and width of all touching defects of the same type, thereby providing the benefits of "stepping defects" to more accurately model the dimensions of the physical defect along with the true length and width. It also calculates the slope of end splits that could affect grading of FAS lumber.

According to paragraph 59 of the 1998 National Hardwood Lumber Associations grading rules (11), the first foot of either end of boards being considered for FAS (or the FAS face of Selects or F1F boards) will be treated as follows:

"59. Within one lineal foot from the ends of the boards of standard lengths there must be 50 percent clear wood, and not less than 25 percent of sound wood in the aggregate."

UGRS adds up all non-clear areas and checks that the total does not exceed 50 percent. Then, UGRS also adds up all non-sound areas and checks that the total does not exceed 25 percent. Extra clear areas may be used to reach the needed amount of sound area.

UGRS starts with grading and, if selected, continues with remanufacturing. The grading module begins by reading the information associated with the board. It then considers any overlength. If "No Optimization" is selected, the overlength is placed on the end having the most defective area. If "Optimize" is selected, the overlength will be placed to maximize the board grade. UGRS will grade the board several times to determine the optimal placement and will display the solution that best splits the overlength between the two ends.

UGRS next analyzes the board to determine whether violations of the grading rules exist. It starts with board dimension specifications and then checks for defect size and placement rule violations. If no violations are found, UGRS attempts to find the required number of cutting units for the grade under consideration. It considers basic cases, extra grading cuttings, and the 97 percent rule.

As with ReGS (1), UGRS allows all 1/4-inch and smaller unsound defects and rejects all 1/2-inch unsound defects on the sound face side of the grading cuttings. The research leading to this compromise is described in detail elsewhere (5). Simply summarized, all defects are counted when determining the grading face and when grading F1F and Selects lumber. When grading FAS and No. 1, No. 2A, and No. 3A Common lumber, grading is done from the poorer face and all defects on that face are counted. It is rare to find defects on the better face that are not traceable to the poorer face. When found, it is rarer still to find one whose presence alone prevents a grading cutting from being determined. In a study of 1,006 No. 1 and 2A Common boards, no boards were misgraded because 1/4-inch or smaller unsound defects on the better face were ignored. Eleven boards were downgraded owing to counting all 1/2-inch unsound defects on the better face.

The general operation of the UGRS algorithm is depicted in the flowchart in **Figure 3**. UGRS can provide either the first solution found that satisfies the requirements for a grade or it can search all potential solutions for the one that provides the maximum number of cutting units. Once the required number of cutting units is found, the user is informed of the grade that the board receives and the value of the board.

Initially, all potential cuttings on a board are found and ordered based on the area of the cuttings. A potential cutting consists of a rectangular area on the board (clear face and sound back as required) that meets or exceeds the minimum cutting size requirements for the grade in question. UGRS begins with the largest cutting and tests against the requirements of the grade under consideration. If only one cutting is allowed and the requirements are not met, special rules (if any) are examined. Failing that, the next lower grade is considered. If two or more cuttings are allowed, the program starts as before and tests against the grade requirements. If that cutting fails to meet requirements, it is combined

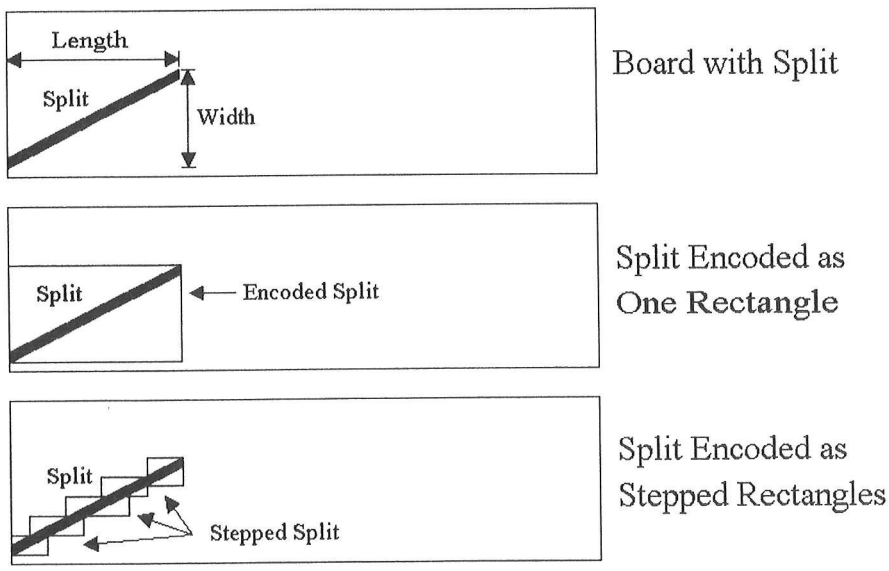

Figure 2. — Example of how stepped rectangles can be used to reduce the defect area of steeply sloped splits.

with successive cuttings in order of size, and any overlap is resolved. If, after combining and resolving any overlaps, the largest cutting does not result in success, the next largest cutting is used as the initial cutting.

Once a cutting is selected, it is marked as a computer-generated defect and a new set of potential cuttings is found from the remainder of the board. Another cutting is then selected from the new set, marked as a defect, and its area is added to that of the first cutting. If "No" is selected under the maximum area grading options, the program will start with the largest cutting and will test smaller initial cuttings only if the grade under consideration is not achieved. If the maximum area in the greatest number of allowable cuttings is selected, then many more sizes of initial cuttings will be examined. This process continues until either the required number of cutting units is located, the allowable number of grading cuttings is exceeded, or no more potential grading cuttings can be found.

UGRS places each board in the highest grade possible. When a defect is found that causes a board to be placed in a lower grade, UGRS calls this a rule violation. The user may disagree with the UGRS decision or may be curious about what the grade would be if the violation did not exist. The user is allowed to override these violations to study the effects of such changes. For all grades, the choice of the grading face or the way overlength is placed can be overridden. For No. 1 Common, overrides exist for the amount of pith and defects present in boards of 1-foot surface measure. Numerous overrides exist for the higher grades (Selects, First One Face, and FAS) associated with pith, wane, size of defects, splits, first-foot rules, and board length and width.

When remanufacturing, UGRS begins by determining the highest possible grade of a board and its associated value. If the board grades as FAS, no additional remanufacturing is performed because the value of the board cannot be increased. If the board does not grade FAS solely because of its width or length, any further division of the board would yield only boards of smaller dimensions and remanufacturing efforts are likewise suspended. In all other cases, an attempt is made to obtain a remanufacturing solution that produces lumber with a higher total value and, when specified, a higher grade. In cases where the dollar value of two remanufactured solutions is the same, the solution that contains the largest percentage of the original boards surface measure is retained.

If the "Division Based" algorithm is selected, UGRS attempts to remanufacture the board by dividing it into as many as four smaller boards ending with the highest total value that exceeds the value of the original board. The "Division Based" algorithm tends to be effective when grade-reducing defects are present toward the center of the board.

If the "Edging and Trimming" algorithm is selected, an attempt is made to rip and/or crosscut from the edges and/or ends of the piece in order to increase the value of the board. In general, "Edging and Trimming" is effective in cases where grade-reducing defects such as wane are present along the edges of the board. The solution with the highest value containing the most board area is retained and displayed.

If the "Division and Edging/Trimming" algorithm is selected, UGRS first attempts an "Edging and Trimming" solution and then attempts an expanded "Division Based" solution in which each of the resulting boards is individually edged and trimmed. This expanded "Division Based" algorithm can remove pith and wane, thus allowing Selects and better boards to be more easily found. It is more time consuming, however. The re-

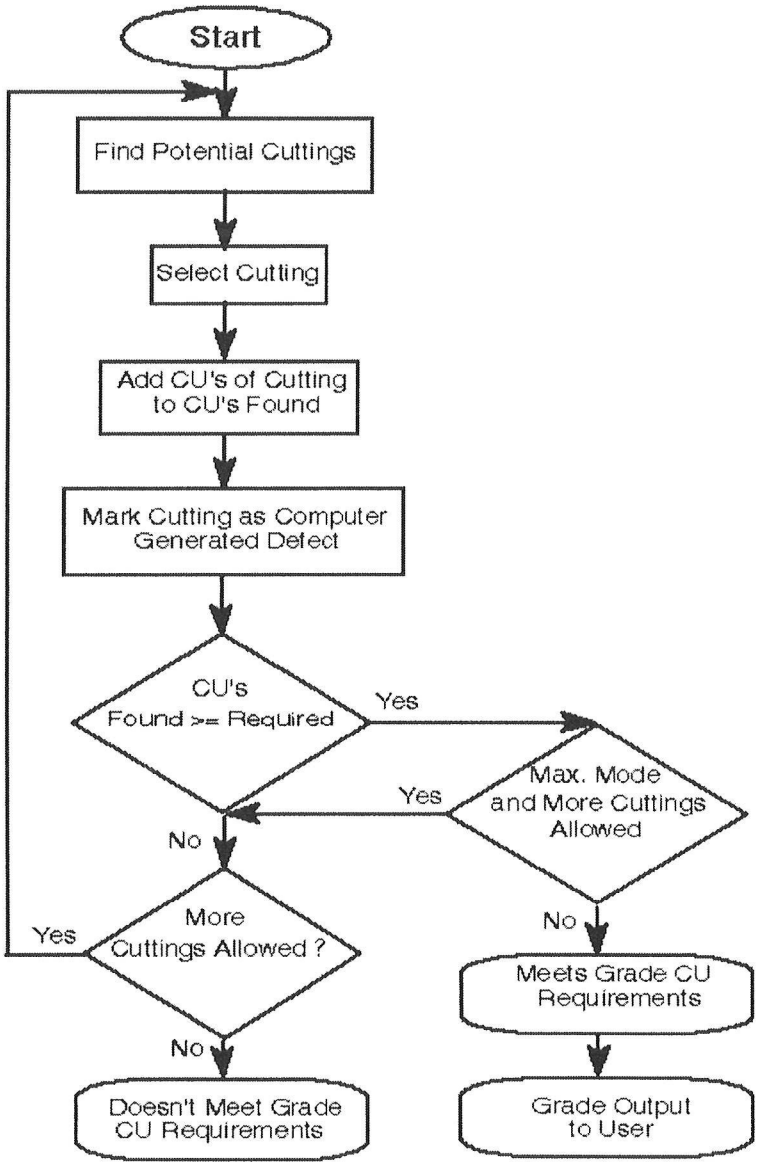

Figure 3. — Cutting unit search algorithm.

sults from the two algorithms are then compared and the one resulting in the highest value and largest board area is retained as the final solution.

If the "Exhaustive" algorithm is selected, UGRS performs the same operations as with the "Division and Edging/Trimming" algorithm, but inspects many more potential solutions by evaluating divisions of the board on a much finer scale. The "Division Based" analysis examines all combinations of length and width that change the surface measure. The "Exhaustive" algorithm examines all combinations of length and width with a length resolution to the nearest inch. In general, the solution obtained using the "Edging/Trimming" and "Division Based" algorithm is very nearly optimal. The "Exhaustive" algorithm can produce better results but with a severe penalty in processing time.

After remanufacturing, the user is presented with the option of manually remanufacturing the board. This is performed by selecting areas of the original board that will be considered and graded individually. UGRS calculates the new value of the board(s) and shows it, along with the old value for comparison purposes.

Overall, UGRS provides a flexible research tool for both computer-based grading and remanufacturing of boards with a high level of human interaction through overridable grading decisions and manual remanufacturing. In addition, results obtained with UGRS are the same or better than those obtained with earlier grading programs. In general, UGRS processes boards at least 50 times faster than earlier programs due to an enhanced cutting unit algorithm.

Due to its flexibility, accuracy, and speed of operation, the UGRS program will provide an invaluable tool for learning about the hardwood lumber grading rules. In addition, the effects of the remanufacturing process on lumber value within the lumber processing industry can now be examined. A study is currently in progress to evaluate the effects of lumber prices and remanufacturing costs on the potential increase in value of No. 1 and No. 2A Common lumber from the 1998 red oak data bank. When used for grading training alone, UGRS provides in-depth information on how grading decisions are made.

A copy of the UGRS program and a Users Manual can be obtained by writing to: UGRS, USDA Forest Serv., Forestry Sciences Lab., 241 Mercer Springs Rd., Princeton, WV 24740.

For use with Windows 95 or Windows NT, one 3-1/2-inch diskette is required. For use with Windows 3.X, three 3-1/2-inch diskettes may be required.

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