Enhancement of the computer lumber grading program to support polygonal defects

Technical Note

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Abstract

Computer grading of hardwood lumber promises to avoid regrading of the same lumber because of disagreements between the buyer and the seller. However, the first generation of computer programs for hardwood lumber grading simplify the process by modeling defects on the board as rectangles. This speeds up the grading process but can inadvertently put a board into a lower grade because rectangular approximation can cause clear board surface area to be lost. This paper presents a polygonal computer lumber grading program that models the defects on the boards as polygons, thereby making the grade determination process more accurate. The grading program presented herein allows species-independent rules and considers both faces of the board in the grading process. The approximation of defects as polygons does result in an increased amount of processing time, which can be readily offset with the fast and inexpensive computers that are now available.

It is not uncommon for the same lumber to be graded several times. Part of this regrading effort arises because of disputes between the buyer and seller in interpreting the National Hardwood Lumber Association (NHLA) grading rules.[1] Computer grading of hardwood lumber thus becomes an attractive proposition. Computers are consistent and fast, and computer-based grading is feasible more than ever due to the ever-decreasing cost and increasing power of successive generations of computers.

Computer grading of hardwood lumber has been accomplished by Hallock and Galiger.[2] However, deficiencies with this program impede widespread commercial applications. These deficiencies include the inability to adapt the program code into a working environment with other programs to evaluate and control lumber processing and the inability to extend the grading to specialized species. Probably its greatest limitation lies in the consideration of only one face in the grading process. These deficiencies have been addressed by Huang[3] and Klinkhachorn et al.[4] Both these efforts consider both faces in the grading process and can be extended to incorporate species-dependent rules.

These efforts,[3,4] however, still suffer from a disadvantage. The disadvantage arises from the rectangular modeling of the defects. Defects such as wane and knots are seldom rectangular in shape (Fig. 1). A rectangular modeling of the defects on a sample board, as shown in Figure 2, eliminates a substantial amount of clear wood from being considered in the grading process.

Rectangular modeling of defects is not without its merit. It reduces the amount of time required by the computer in determining the allowable clear cutting areas on the board, and hence, the grade of a board.

[1] National Hardwood Lumber Association. 1990. Rules for the measurement and inspection of hardwood and cypress lumber. NHLA, Memphis, Term.

[2] Hallock, H. and L. Galiger. 1971. Grading hardwood lumber by computer. Res. Pap. FPL-157. USDA Forest Serv., Forest Prod. Lab., Madison, Wis.

[3] Huang S. 1987. Expert systems for grading hardwood lumber. Ph.D diss. Purdue Univ., West Lafayette, Ind.

[4] Klinkhachorn P., J.P. Franklin, C.W. McMillin, R.W. Conners, and H.A. Huber. 1988. Automated computer grading of hardwood lumber. Forest Prod. J. 38(3):67-69.

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Forest Prod. J. 42(10):41-46.

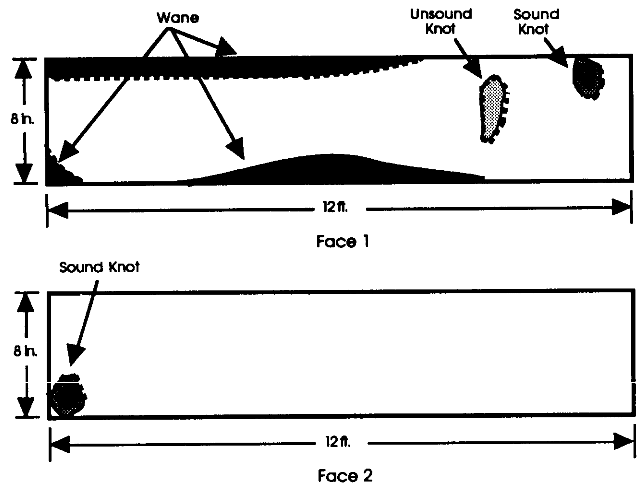

Figure 1. — A sample board.

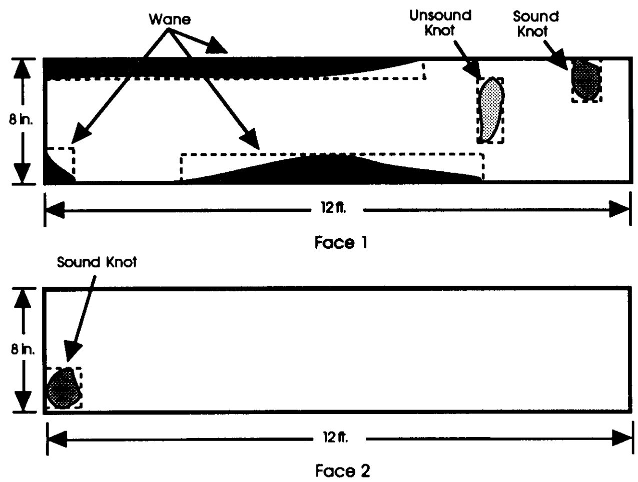

Figure 2. — Rectangular representation of the sample board.

The approximation of defects as polygons does result in an increased amount of processing time, which can be offset with the faster and less expensive computers that are now available. This paper presents an enhanced computer grading program (hereafter referred to as the polygonal grading program) based on the one developed by Klinkhachorn et al.[4] (hereafter referred to as the rectangular grading program). It is anticipated that such a polygonal modeling of defects will lead to a better estimate of the grade of hardwood boards.

The polygonal grading program

The polygonal grading program models the defects present on the board as convex polygons. A convex polygon is a polygon in which every point on a line segment joining two points within the boundary of the polygon also lie within the polygon. Figures 3a and 3b illustrate a convex and a non-convex polygon, respectively. Those defects that are not convex polygons are transformed into convex polygons automatically by

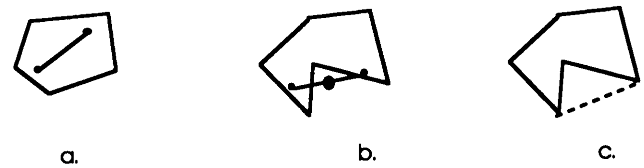

Figure 3. — Two types of polygons are possible: a) convex; and b) non-convex. Non-convex polygons are transformed to be convex (c). This is done to ensure proper program processing of each defect, while not removing clear wood area from consideration.

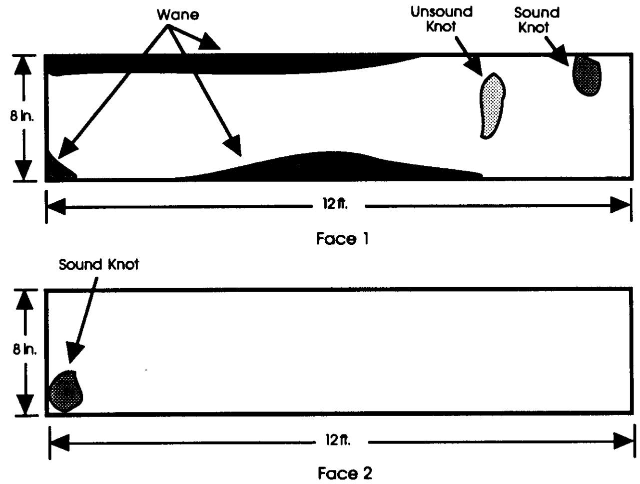

Figure 4 — Polygonal representation of defects more closely resembles defect boundaries and generally increases clear wood for processing.

the program (Fig. 3c). This modeling considerably reduces the number of computations that are required to determine the allowable cutting areas for a given grade.

Figure 4 shows the sample board shown in Figure 1 as modeled by this polygonal computer grading program. A comparison of Figure 2 (rectangular approximation) with Figure 4 (polygonal approximation) shows that the polygonal program allows more clear wood to be used in determining the grade of the board.

The grading process itself is carried out much the same way as a human grader would. The physical properties of the board, such as surface measure, standard length, width etc., are first evaluated. Once these measures are ascertained, the program considers each of the grades, one grade at a time beginning with the highest obtainable grade. If no grade-reducing defects are found for the grade under consideration, the evaluation continues to find the board area available in allowable cuts for the grade under consideration. To this end, the program is divided into three major components for grading FAS, Selects, and Common grade boards according to the NHLA grading rules.

Once the physical properties are evaluated, the program determines if any overlength exists. If so, the end of the board that contains the most defective area is chosen as the overlength. For the sample board (Fig. 1), no overlength exists. The program then proceeds to evaluate the board as potential FAS. If it fails, other grades are sequentially evaluated until the board meets the requirements of a grade. During each grade evaluation, allowable defects are placed on an "invisible" face to prevent them from being considered in the grading process. This scheme is very useful in the grading of species that require clear cuttings in FAS or Selects grades but admit sound cuttings in the Common grades.

For the sample board shown in Figure 1, all of the defects must be considered. Additionally, the routines determine if the board meets the grading requirements

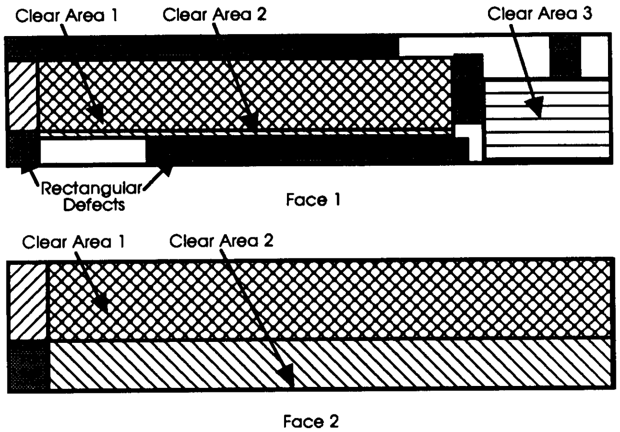

Figure 5. — Clear areas found on the sample board using rectangular defect representation.

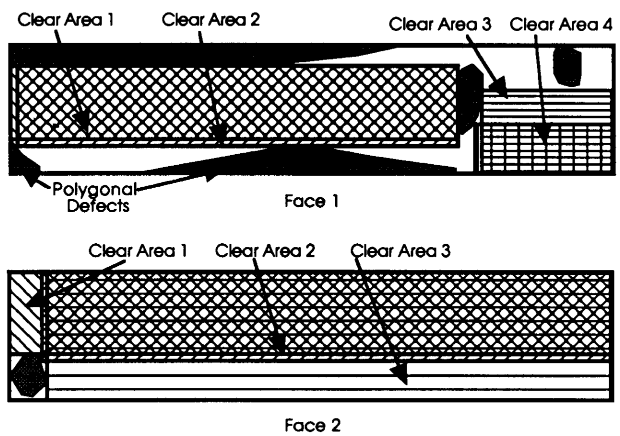

Figure 6. — Clear areas found on the sample board using polygonal defect representation.

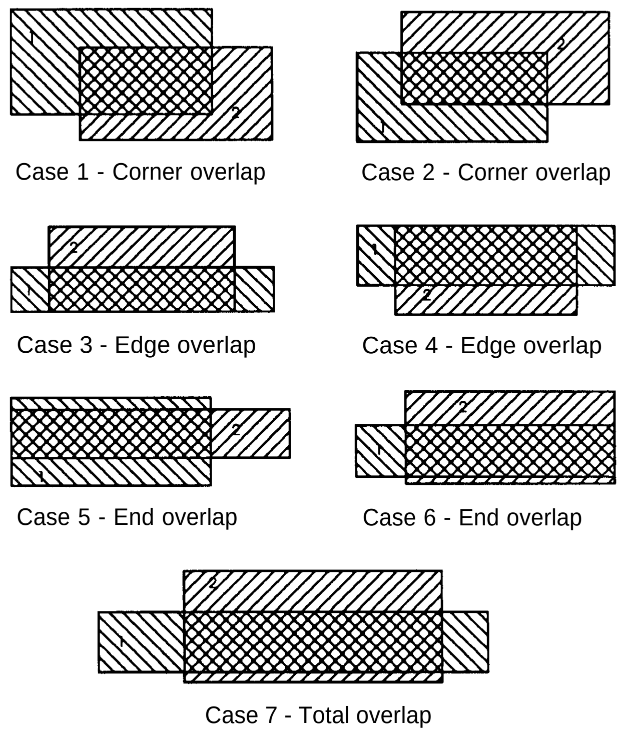

Figure 7. — Seven possible overlapping categories of cutting areas that could occur during grading.

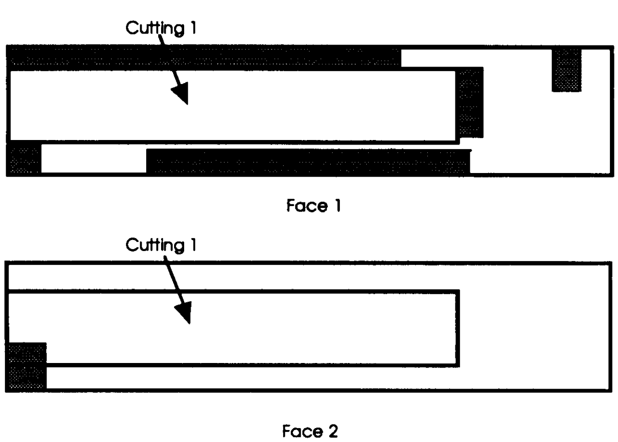

Figure 8. — Resolved cuttings using rectangular defect representation for the sample board.

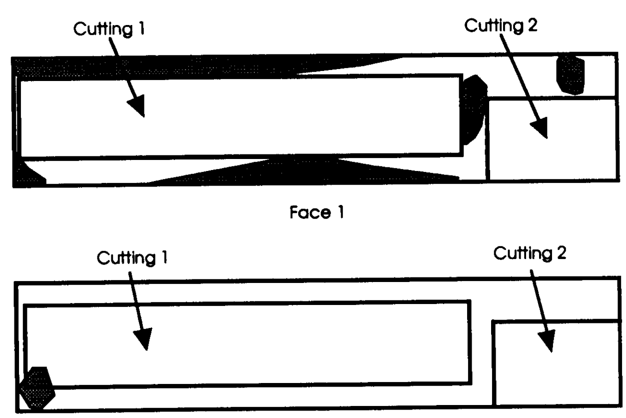

Figure 9. — Resolved cuttings using polygonal defect representation for the sample board.

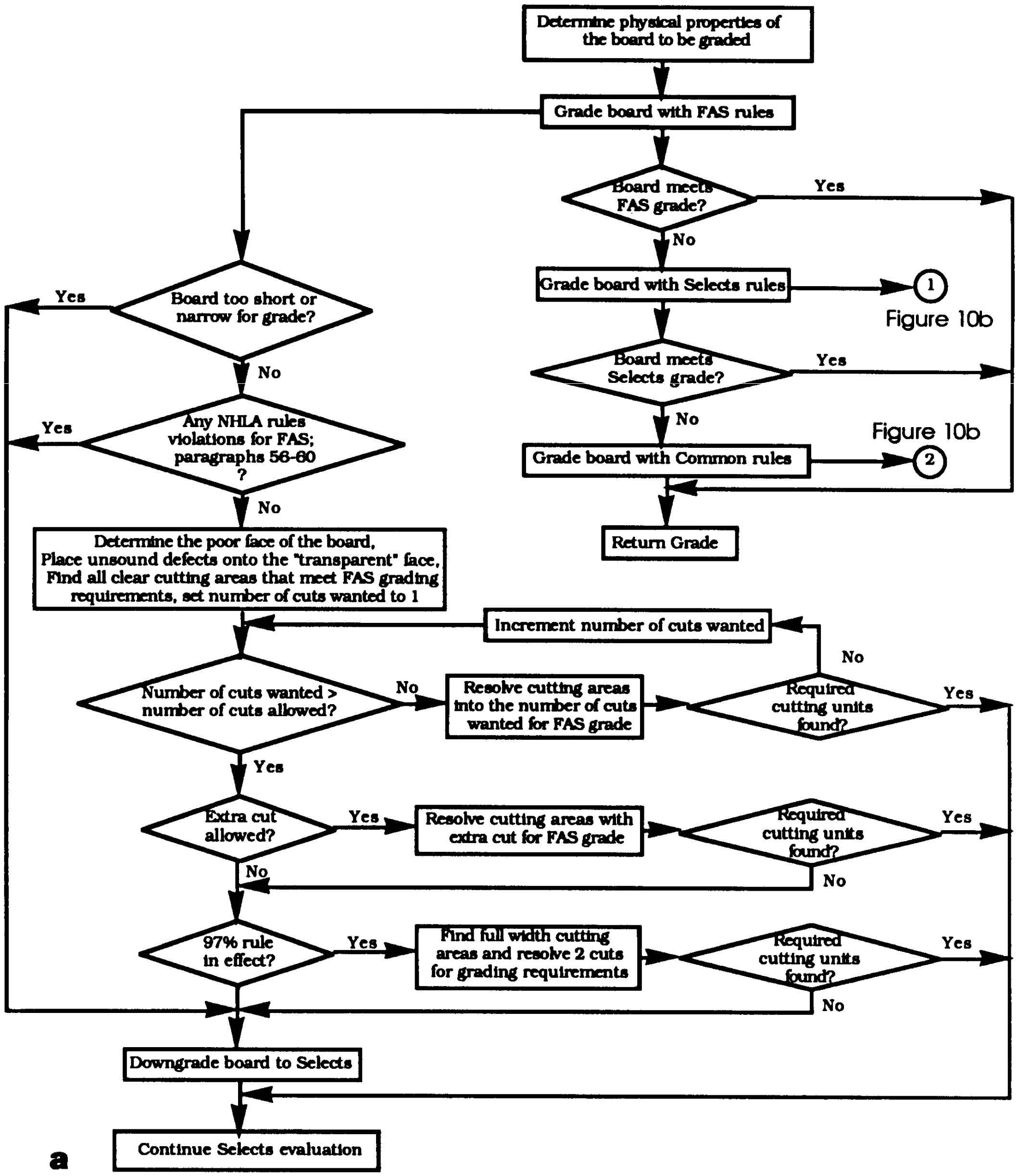

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Figure 10a. — Flowchart of the polygonal grading program.

based on length and width. The defects on each face are evaluated with respect to the corresponding grading paragraphs in the NHLA rules. If any violations exist, a corresponding code is recorded to identify the violation. Proceeding, the FAS and Common routines determine the poor and good face of the board and the Selects routine determines if either face can be graded as Selects with sound back cuttings, or failing that, as Selects with a No. 1 Common back. The poor face in the sample board is Face 1. Also, due to oversized defects on both faces, the board will fail FAS and Selects rules. Therefore, the board is downgraded to No. 1 Common consideration.

The board is then analyzed to locate rectangular regions free from unacceptable defects and larger than the minimum cutting size requirements for the grade being evaluated. The grading programs developed by previous researchers[2,3,4] found the vertices of the rectangular defects and located the clear areas between the defective rectangles. With polygonal modeling of defects however, the program must determine all possible rectangular clear regions between line segments that describe the defective regions. Using this procedure, a greater number of clear areas are found, thus increasing the possible clear cutting area for determining the grade of the board. Figures 5 and 6 show the clear areas found when the defects are modeled as rectangles and polygons, respectively.

It should be noted that those clear areas found using rectangular defects are among those found using polygonal defects. Those clear areas that overlap are resolved in an optimum method according to the

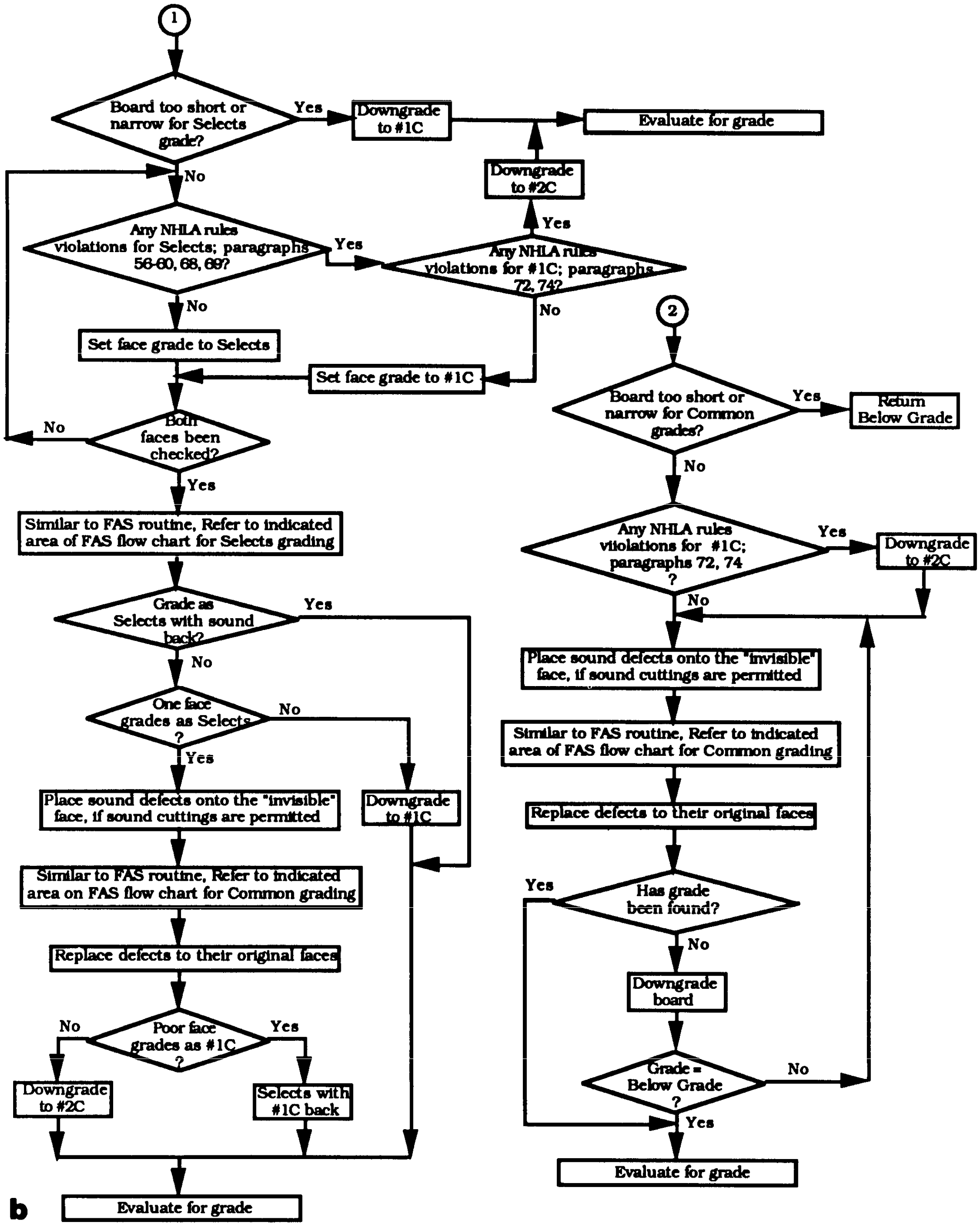

Figure 10b. — Flowchart of the polygonal grading program (continued).

number of overlapping areas and according to the type of overlap that occurs. Three overlapping areas can be divided into one of three categories, which involves isolating one clear area and resolving the other two clear areas. Two overlapping areas fall into one of seven categories and are resolved accordingly. During the grading process, the program only uses those clear cutting areas that allow the board to meet a grade, whether they are the maximum clear cutting areas or not. Figure 7 illustrates the seven possible overlapping categories.

Finally, the total sum of the resolved cutting areas determines the number of cutting units available in each face. If the cutting units found meet the requirements for the grade, the routine stores the grade and the various cutting parameters into data structures and assigns the grade to the board. However, if sufficient cutting units are not available to meet the requirements of the grade, the next grading routine is applied until all of the possible grades have been expired, in which case, a below grade is assigned to the board. Figure 8 illustrates the resolved cuttings when the defects are modeled as rectangles, and Figure 9 illustrates the resolved cuttings when the defects are modeled as polygons. For the sample board, a grade of No. 2 Common Is assigned for the case of rectangular defects because 96 cutting units in 4 cuts are required for No. 1 Common and these cannot be obtained. Since only one clear cutting area is needed to meet the No. 2 Common grade, the program returns that cut only as shown in Figure 8. However, a grade of No. 1 Common is assigned for the case of polygonal defects because the required cutting units are obtainable. This example serves as a good illustration of the possible advantages of modeling the defects as polygons. Figure 10 shows the complete flowchart of the polygonal grading program just presented.

Additional notes on defect modeling

The modeling of defects as polygons leads to an increased amount of clear surface area that can be considered during the grading process. In the best case, this may result in an increased grade as compared to the grade obtained by enclosing each defect with a rectangular boundary. The sample board used in this paper is one such example. However, an increase in grade may not be obtained for all boards. The randomness of defect occurrence, their shape and size manifestations, precludes a quantitative analysis. Even so, the use of polygonal defect modeling implies a more subtle advantage. The rectangular grading program seeks to find a minimal solution to meet a grade in accordance with the NHLA rules. A polygonal approximation of the defects, however, is essential if maximal solutions are desired, as in the case of remanufacturing lumber for a higher grade and value. Thus, we believe that the additional amount of time required to process polygonal defects should not be a limiting factor and especially with more powerful computers becoming readily available.

We wish to point out, however, that a defect can also be represented by a series of stepped rectangles to approximate the original defect shape. The approximation of a defect by a series of stepped rectangles may be necessary if defect digitizing equipment that can handle only four vertices is used to create a data file describing the board. In such a situation, the large wane appearing at the bottom edge of Figure 2, Face 1, may be represented by small rectangles progressively increasing in height from the left end of the defect to the middle and rectangles progressively decreasing in height from the middle of the defect to the right edge.

In both the polygonal and stepped rectangle defect representation schemes, very little clear surface area is actually lost. However, with stepped rectangles representing a large defect, the number of defects increases. Each of the defects then has to be analyzed to check if it is a grade-reducing defect, thereby increasing the time to process a board. More important, if a split is represented by a series of small rectangles, rules such as the split divergence rule cannot be applied to the split but rather to each of its constituent rectangles. The rule can be well interpreted if it is a continuous defect. Thus, we believe that polygonal representation of defects provides substantial benefits to merit its use.

Additional features of the polygonal grading program

A prominent feature of the grading program is the ease of re-configuring the rules. The *'C'" programming language permits the use of data structures to logically separate program data and program code. The rules are formulated mathematically in terms of program variables that are initialized in the data structures, making it possible at run-time to grade a given species. Therefore, the program code remains unaltered for various species of hardwood lumber.

The use of data structures in the program enhances the capabilities, adaptability, and portability. Data structures representing the rules for various species, the dimension and the physical properties of a board, the violations of the various rules, and the grade of a board contribute greatly to the flexibility of the polygonal grading program. The rules and violations data structures represent a one-to-one correspondence between the rules of the hardwood species and the deficiencies of the board. These data structures can be accessed by other programs for automated processing, training graders, and other utilities.

Conclusion

This paper presented a polygonal computer lumber grading program that models the defects on hardwood lumber boards as convex polygons. The polygonal modeling of defects leads to an increased amount of clear wood being considered in the grading process as compared to the case where defects are modeled as single rectangles. The polygonol program obtains more cutting units, and in some cases, a higher grade can be assigned compared to using rectangular defective regions.

The polygonal grading program presented was specifically designed to be easily integrated with the automated lumber grading portion of the Automated Lumber Processing System (ALPS) and to be flexible and maintainable. The strategies utilized overcome deficiencies of previous grading programs[2,3,4] and seine to enhance the program's utility in an automated lumber processing scheme. However, modeling of the defects as polygons requires more processing time when compared to the rectangular approximation of defects. This increased processing time, however, can be readily offset with increasingly powerful computers that are becoming readily available. Although the polygonal grading program has been designed to interface with ALPS, a computer-vision system coupled to the program could also make it a stand-alone grading system.