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The Best Opening Face (BOF) log breakdown model was modified to keep track of growth ring angle and growth ring density in boards. The model was used to determine the effects of producing rectangular rather than square pencil stock. While an increase in volume did result, there was also a decrease in pencil stock quality regarding ring angle due to the lack of choice left in orienting these pencil stock when producing slats. The results were expressed as the percentage of change that occurred in both volume and value recovery between rectangular and square sawing. Overall, when considering both pencil stock prices and ring angle factors, there was an increase in value of 0.64% when sawing rectangles instead of squares. However, a high standard deviation of 1.97% was linked to that average. No trends were found as a function of log diameter, but the total value increased slightly with an increase in log length and taper rate.

From a pencil stock seller's viewpoint, only pencil stock prices needed to be considered. Due primarily to an

increase in volume recovery, there was an average value increase of 6.85% when sawing rectangles instead of squares. Once again, an increasing trend was observed as a function of log length and taper rate.

From a pencil slats producer's viewpoint, a per board foot approach was taken. An average decrease in value of 6.51% per board foot resulted when rectangles were sawn instead of squares. In addition, the distribution of pencil stock in the three ring angle classes varied dramatically between rectangular and square sawing. Results were sensitive to relative prices given to pencil slats as a function of ring angle.

Growth Ring Pattern Consideration In Computer Sawing Simulation.

by

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GROWTH RING PATTERN CONSIDERATION IN COMPUTER SAWING SIMULATION

I. INTRODUCTION

The lumber industry has responded to past increases in log prices by improving recovery, and great improvements have been made. However, since log prices are forecasted to continue in the same upward trend, optimization of quality is the next challenge for the forest product industry.

Several computer programs simulating log breakdown have been written and are currently used to increase recovery. However, none consider wood quality. One such measure of quality, the growth ring pattern, can be used as a criterion to classify boards and optimize the value. Such a classification would increase the quality by yielding the most appropriate ring angle or ring count in a board when needed. In lumber, growth ring angle and ring density are related to some of its properties and value. Any classification of boards prior to log breakdown according to these features is thus of interest in determining the best sawing pattern to yield the highest possible value out of the log. Such a classification is of great interest for P&M Cedar Products, a pencil stock manufacturer, and California Cedar Products, a pencil slat manufacturer, where ring angle and ring density are both important factors for determining a pencil slat's quality.

The model used in this study is a modified version of BOF (Best Opening Face), an existing program simulating log breakdown. Modifications were made to BOF in order to adapt to P&M Cedar's specific sawing pattern, and subroutines were added to BOF to classify boards according to their growth ring.

II. OBJECTIVES

The objectives of this study were twofold. The first one was to build a model considering the growth ring pattern in lumber when simulating log breakdown. The two features analyzed were ring angle and ring density. The second objective was to apply the model to pencil stock manufacturing to analyze the effects of sawing pencil stock with rectangular-shaped transverse sections instead of square-shaped transverse sections.

III. LITERATURE REVIEW

A. GROWTH RING CHARACTERISTICS.

A prominent feature of most of the wood growing in temperate regions is the growth ring. In these woods, the difference between the wood formed early in the growing season and that formed later in the growing season is important enough to produce distinct annual growth rings visible with a naked eye. Growth ring increments and the relative amount of latewood in a ring are not constant features and fluctuate greatly depending upon the species, site, individual tree, and even upon the position within a given tree (26). During a tree's life, the diameter growth rate will usually vary from fast when young to slow when older, thus producing wider growth rings in earliest years. The transition from wide to narrower ring width is gradual and irregular. As will be discussed later, this change is related to some modifications of wood properties.

A growth ring normally completely encircles the pith. However, in an old or suppressed tree, a ring can be interrupted and not completely surround the stem. These types of rings, called discontinuous rings, are not infrequently encountered in old trees such as redwoods. The causes of this anomaly are still subject to debate. One theory by Hartig(14) attributes discontinuous rings to a shortage of food mainly in the case of heavily suppressed crowns, whereas a more recent theory by Larson(18) relates discontinuous rings to a hormone deficiency. Another abnormal type of ring is called a false ring. In this case, more than one ring may be formed in the same growing season, but the boundaries within a growing season are not sharply defined. False rings occur when the growth of a tree is interrupted by drought, defoliation by insects, or late frost (26).

B. PROPERTIES OF WOOD AFFECTED BY RING PATTERN.

The physical characteristics or properties of wood are numerous. These include as reported in the Wood Handbook(40):

- appearance,
- moisture content and shrinkage,
- weight, density, specific gravity,
- working qualities,
- weathering,
- decay resistance,
- chemical resistance,
- thermal and electrical properties.

Most of these properties are, to a certain degree, influenced by the ring pattern, especially shrinkage and mechanical properties. Appearance is also directly dependent on the ring pattern, but this is more of a concern when hardwoods are used for things such as furniture. There, depending upon the direction a log is sawn or peeled, the growth increments will show a specific pattern.

1. Factors influenced by ring angle.

Logs can be sawn in two different ways, either tangent or radially to the annual rings, with each method yielding boards with specific mechanical and physical properties. Even though in practice boards are seldom sawn strictly perpendicular or tangent to the rings, they are commonly referred as being flatsawn or quartersawn according to their ring angle orientation. Flatsawn (also called plainsawn) lumber has growth rings that make an angle of 0 to 45 degrees with the widest surface of the board, while quartersawn has rings that make an angle of 45 to 90 degrees with the widest surface (40).

Both flatsawn and quartersawn boards have some advantages. Some of these as reported in the Wood Handbook (40) are:

flatsawn

- figure patterns are brought out more conspicuously
- less susceptible to collapse in drying
- shrinks and swells less in thickness
- easier to obtain

quartersawn

- shrinks and swells less in width
- less splits and surface-checks in seasoning
- wears more evenly
- some types of figure, such as rays, are brought out more conspicuously.

Depending on the end use of a board, a manufacturer may want to obtain the highest possible production in either flatsawn or quartersawn.

a. Mechanical properties. Depending on the species, the mechanical behavior of a board will be influenced by the angle existing between the stress applied perpendicular to the longitudinal direction of the board and the direction of the growth ring (40). Strength properties will be better in the radial direction than in the tangential direction. The modulus of elasticity is about twice as great in the radial direction than in the tangential direction. Young's modulus for Douglas-fir (Pseudotsuga menziesii) is for instance 0.1424 10^6 psi (pounds per square inch) in the radial direction and 0.0912 10^6 psi in the tangential direction. For incense-cedar (Libocedrus decurrens), young's modulus is respectively in the two directions

0.1110 10^6 psi and 0.0636 10^6 psi (4).

b. Drying properties. One of the factors most sensitive to ring orientation is the behavior of lumber as it is drying. Defects such as bow, cup, twist and crook are partially caused by the anisotropic shrinkages associated with wood drying (Figure 1). Hallock (11,12,13) in three studies on different species examined how warp in studs was affected by the sawing method. Even though ring pattern was not directly considered in these studies, it appears that the sawing pattern and board location in a log have a significant influence on warping, which makes it of interest to determine as accurately as possible the position of a board in a log. It is the large difference between radial and tangential shrinkage that is the cause of these distortions, with one side of the piece shrinking more than the other (34). The percent shrinkage in the tangential direction is about two times larger than in the radial direction. The ratio of tangential to radial shrinkage (T/R) is for instance 1.6 for Douglas-fir and incense-cedar (26).

Research has been done to try to model or quantify these deformations due to shrinkage. As early as 1945, Mc Lean (22) considered the growth ring angle in a board to develop formulas predicting the changes in lumber width and thickness during drying. More recently, Hsu and Tang (15,16) looked at the effect of the coefficient of shrinkage, the geometry of the board, and the location of the board in the log to quantitatively analyze the distortion of a piece of wood. Their results showed there was a relationship between the coefficients of shrinkage in the radial and tangential directions and certain types of warping. In a study on yellow poplar, Koch (17) found a strong correlation between crook and growth ring direction, ranging from a minimum in flatsawn boards to a

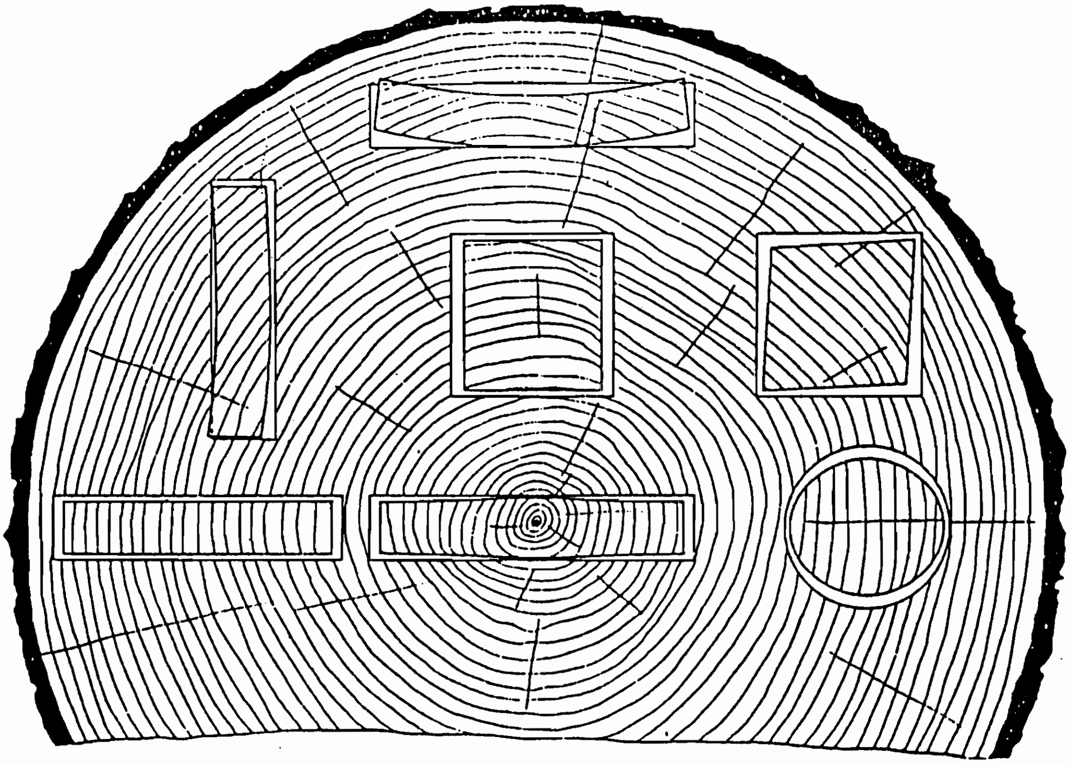

Figure 1. Example of how ring orientation in boards affects shrinkage distortions (from Wood Handbook (40)).

maximum in quartersawn boards. All this information leads to the conclusion that to know a board's position in a log, thus it's ring angle, and the shrinkage coefficients of the species can help predict certain distortion due to drying.

2. Factors influenced by ring density.

Specific gravity is an important characteristic of wood, affecting its strength, machinability, acoustic properties and wearability, and is often considered in determining the possible usage of wood. While it is now well accepted that strength and density in wood are related, a more controversial matter is the effect of the growth ring in this relationship. For a long time, the quality of wood was often assumed to be determined by the characteristics of its growth rings. Their width and the relative amount of latewood in them were the prominent features used to judge the quality of wood. Ring width and strength were assumed to be related so that wide rings meant low strength in softwood. According to Bamber (3), the only reason this might be true is that the wider rings occur in the juvenile wood near the pith, which has a lower density. Nevertheless, grading agencies take the rate of growth into consideration as means to classify certain type of boards. The Western Wood Products Association Grading Rules for instance classify Douglas-fir and larch (Larix occidentalis) into medium grain and dense, according to the average number of annual rings per inch (39).

The existence of juvenile wood also has an influence on some of the properties. Besides a lower density, it is also fundamentally unstable in seasoning and low in mechanical strength. According to Zobel (41), it should thus be recognized in the sawing pattern. Similarly the sapwood/heartwood boundary is an important characteristic to know when drying or treating with preservatives. Booker (5) noted that the radius of the heartwood/sapwood boundary in a board and the moisture content differences between heartwood and sapwood lead to different amounts of water needing to be evaporated during drying.

The change in ring density, the transition between juvenile wood versus mature wood, and sapwood versus heartwood boundary can be modeled in the sawing simulation. Thus, the amount of juvenile wood or sapwood in a board can be estimated during simulation the same way as a low ring count.

C. STUDIES DONE ON CALCULATING RING ANGLE AND RING DENSITY.

Until recently, there was no adequate system for recording annual ring orientation in boards. It was not until the 1980's that a few methods were proposed and applied to measure or evaluate ring angle and ring density. The development of computers and modern scanning methods increased the interest in such research in recent years.

A relatively simple method for quantifying and classifying growth ring orientation in lumber was developed by Olson in 1986 (25). The proportion of quartersawn and flatsawn in each board is found according to the position of the board in the log. The method used in this thesis' model is based on Olson's work and will thus be discussed in more detail further on. A more pragmatic method was given by Booker (5). This method records annual ring orientation in boards, where ring angles are defined by a radius and an angle. Based on a scaled transparent overlay, this method is designed for sawn boards and does not permit prediction of the ring pattern prior to sawing. In addition, the process is entirely manual and consequently not fitted for industrial usages. Such a method found application with Massey and Reeb (23) who wrote a computer program based on Booker's method to determine the amount of juvenile wood in boards. Again, the use of a scaled transparent overlay makes the method too slow to be economically used by the industry.

More sophisticated apparatuses have been used to measure ring density or to give the grain pattern. Among these, X-ray's have been used in several applications to measure the density. X-ray densitometry was used by Parker (27) in a study measuring ring width and ring density on red alder. Such a method could help in the future to forecast the ring density pattern in a board prior to sawing. In fact, Toghigi (36) used soft X-ray radiation to look at internal features of a log. Then with a computer, grain patterns were simulated on fictitious boards. As a result, one can determine the optimum sawing position to have the highest possible output of lumber of a given quality. Because this method requires special equipment and long computing time, it is not yet suited for industry purposes. On the other hand, the results are close to reality, and the grain pattern is given on all faces.

A faster and cheaper method consists of predicting the ring pattern when simulating log breakdown without measuring the internal defects. Such a method requires assumptions diminishing the accuracy of the results but can easily be applied by the industry.

D. COMPUTER SIMULATION OF LOG BREAKDOWN.

The lumber industry has long been interested in modeling the process of converting a log into lumber. The rapid development of computer technology has fostered various simulation approaches. The advantages of simulation are that it permits rapid development of data related to lumber production or the generation of sawing patterns for logs according to the lumber market. Without computers and simulation, these data must be obtain by expensive, and labor intensive means. Computer simulation makes it easier to assess the impact of changes in parameters such as saw kerf, sizes, or sawing variation. The variation of yield in response to log features such as taper can be investigated. Practices such as edging and trimming as well as offset or breakdown method can also be studied (2,7,8,35). All simulation models involve variables and parameters. In the lumber industry, model variables can include such things as log geometry, taper, the mix of possible board dimensions, sawing method, sawing variation, sawkerf, or edging and trimming methods (10,35). For instance, Hallock (7) showed the importance of taper and of the breakdown method (i.e., live or cant, split or full taper, offset or centered log) on recovery. There are neither required standards nor limitations regarding the variables to consider, and each program will have its own original set of variables.

Because they are more complex to model, only a few studies, take into account internal defects or characteristics. Many simulation studies on hardwood log breakdown have been undertaken (1,30,31,32,33,37), and most of them to a certain degree include defects, usually knots. Graphic simulations to help visualize defects have also been developed for hardwoods (24,29). Simulation programs for softwood log breakdown are also numerous and widely used. Several different approaches were made by Peter (28), Mc Adoo (21), Cummins(6) Airth and Calvet (2), and Wagner and Taylor (38) to simulate log breakdown.

Among the existing programs, perhaps the one most widely adopted by the lumber industry is the Best Opening Face (BOF) program developed by Hallock and Lewis in 1971 (9). The program selects the sawing pattern yielding the highest volume or value by calculating all possible solutions and comparing them. While a publication has been written about how BOF considers sweep and eccentricity (19), the computer program still has not been written[1]. How BOF works will be discussed in more detail later in this study since it is used as support for the model developed for this thesis research.

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[1] Danielson, J. 1990. Personal communication.
USDA Forest Service, Forest Products Lab, Madison, WI

IV. MANUFACTURING PENCILS

To better understand the interest of P&M Cedar and California Cedar Products in a study such as this, it is important to first have an idea of how pencils are manufactured. A brief introduction to P&M Cedar and California Cedar is given, followed by an overview of the whole process of manufacturing pencils. Pencil stock and its production are then described in more detail.

A. P&M CEDAR PRODUCTS INC. AND CALIFORNIA CEDAR PRODUCTS INC.

P&M Cedar Products Inc., a company based in Stockton, California, has mills in California and Oregon where incense cedar logs are sawn into pencil stock. Incense cedar (Libocedrus decurrens), also known as pencil cedar, has remarkable qualities for making pencils. Incense cedar is appreciated as a raw material for pencils mainly because of its uniformity in texture and in hardness between early and late wood which makes it easy to sharpen. Its resistance to abnormal shrinkage, its ability to hold paint, and its resistance to splitting are also properties that add to incense cedar's choice for manufacturing pencils. The major portion of the pencils made in the world today use incense cedar as raw material, which makes P&M Cedar a world leader in its field. P&M Cedar Products itself does not produce the finished pencil, but produces the majority of the world's pencil stock which are then shipped to slat manufacturers.

The range of products offered by P&M Cedar is not limited to pencil stock. Although pencil stock remains the main product, other lumber products such as moulding, siding, and paneling are also manufactured.

California Cedar Products, Inc., a company also based in Stockton, California, is mainly a pencil slat manufacturer (see process in Section IV-B). The majority of California Cedar Products' production is exported around the world to pencil manufacturers. Besides pencil slats, California Cedar Products also uses waste produced during the slat processing to manufacture fireplace logs.

B. PENCIL MANUFACTURING PROCESS.

The wood that will become a single pencil will go through three different mills between the time it is a log until it becomes a finished pencil ready to be used. As mentioned, P&M Cedar deals only with the first part of the manufacturing process, converting logs into pencil stock. California Cedar Products only deals with the pencil slat conversion process. Still, the whole process from raw log to ready to use pencils will be described, with more specific details given for pencil stock.

The logs are sawn into pencil stock at a P&M Cedar mill (Figure 2). Pencil stock is a 3.09 inch square piece of wood with a length ranging from 4 to 16 feet. The pencil stock is then shipped to a slat manufacturer where it is first dried, then trimmed into 7.25 inch long blocks. Prior to sawing slats, the blocks are manually oriented to obtain the most appropriate ring angle in the slats. The blocks are then sawn into slats, and the wood is impregnated with wax and stain and then redried. At this point, the slats are shipped around the world to pencil makers. There, several grooves are cut on one side of each slat, and rods of lead are laid in the grooves of half the slats. Next, a slat with lead is glued to another one with no lead, and the glued slats shaped into

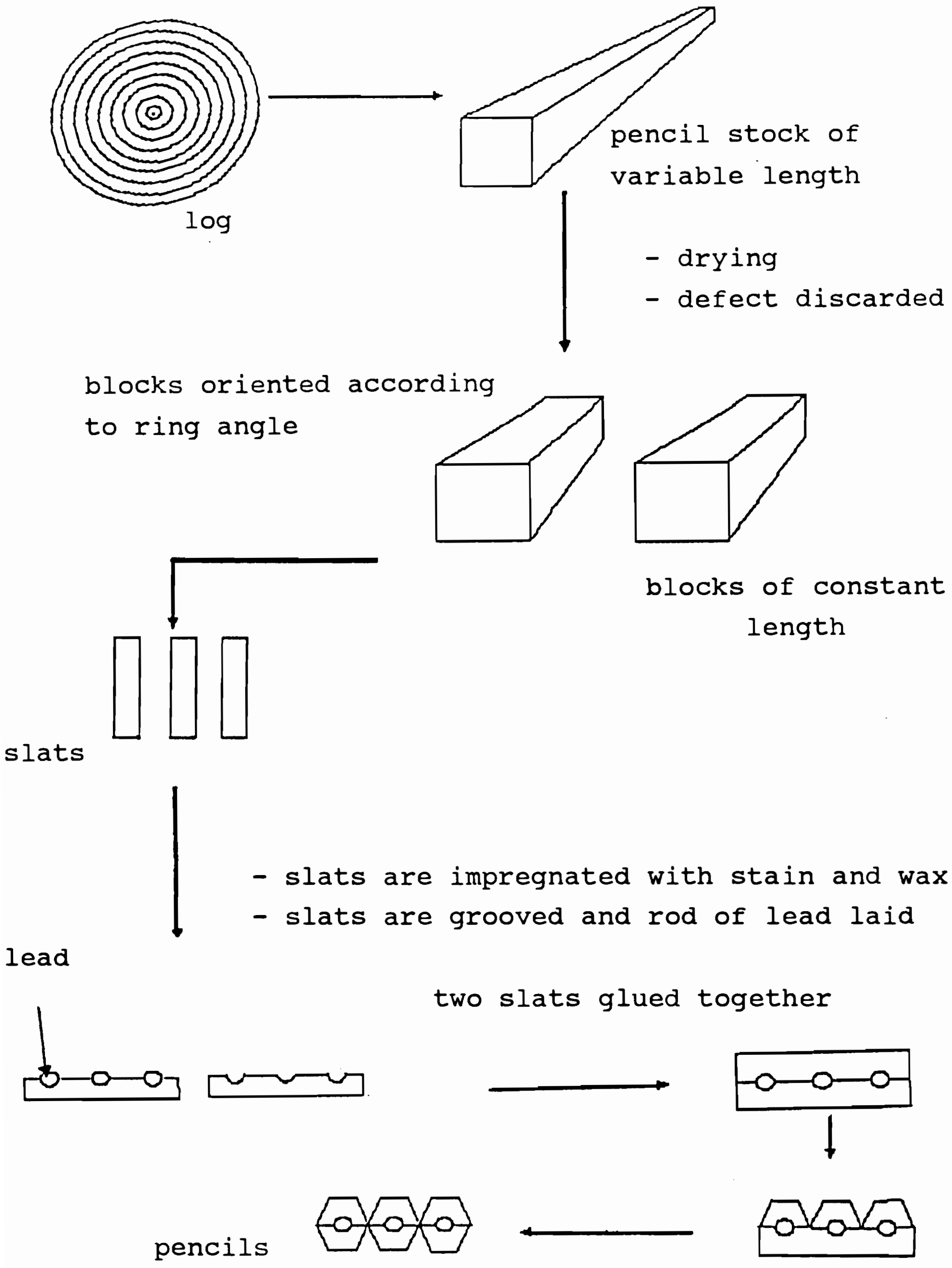


Figure 2. Process of manufacturing pencils.

series of pencils. Finally, pencils are finished with paint, and an eraser is added.

C. PENCIL STOCK.

As was just mentioned, pencil stock has square shaped transverse sections. In fact, it comes in three general classes of sizes: full-tally, two-thirds-tally, and one-half-tally. The definitions of these three categories are given by P&M Cedar's quality control policy and procedure manual.

- Full-tally is pencil stock with at least 3 inches, but less than 3-7/16 inches on all four sides (Figure 3a).
- Two-thirds-tally is pencil stock with either:
    * at least 2 inches but less than 3 inches in thickness, and at least 3 inches but less than 3-7/16 inches in width (Figure 3b), or
    * at least 3 inches but less than 3-7/16 inches on two adjacent sides with 1 inch or larger borders on the other two adjacent sides (Figure 3d).
- One-half-tally is pencil stock with at least 1-1/2 inches but less than 2 inches in thickness, and at least 3 inches but less than 3-7/16 inches in width (Figure 3c).

Historical data indicate that full-tally recoveries range from 80.4% to 87.8%, depending on the mill. Thus, a large amount of pencil stock has a square transverse section in the current process. The fact that pencil stock is square shaped enables blocks to be oriented according to their ring angle later in the process when they are sawn into slats. Ring angle orientation is an important factor in pencil quality. Thus, close attention is given to correctly orient a block before it is sawn

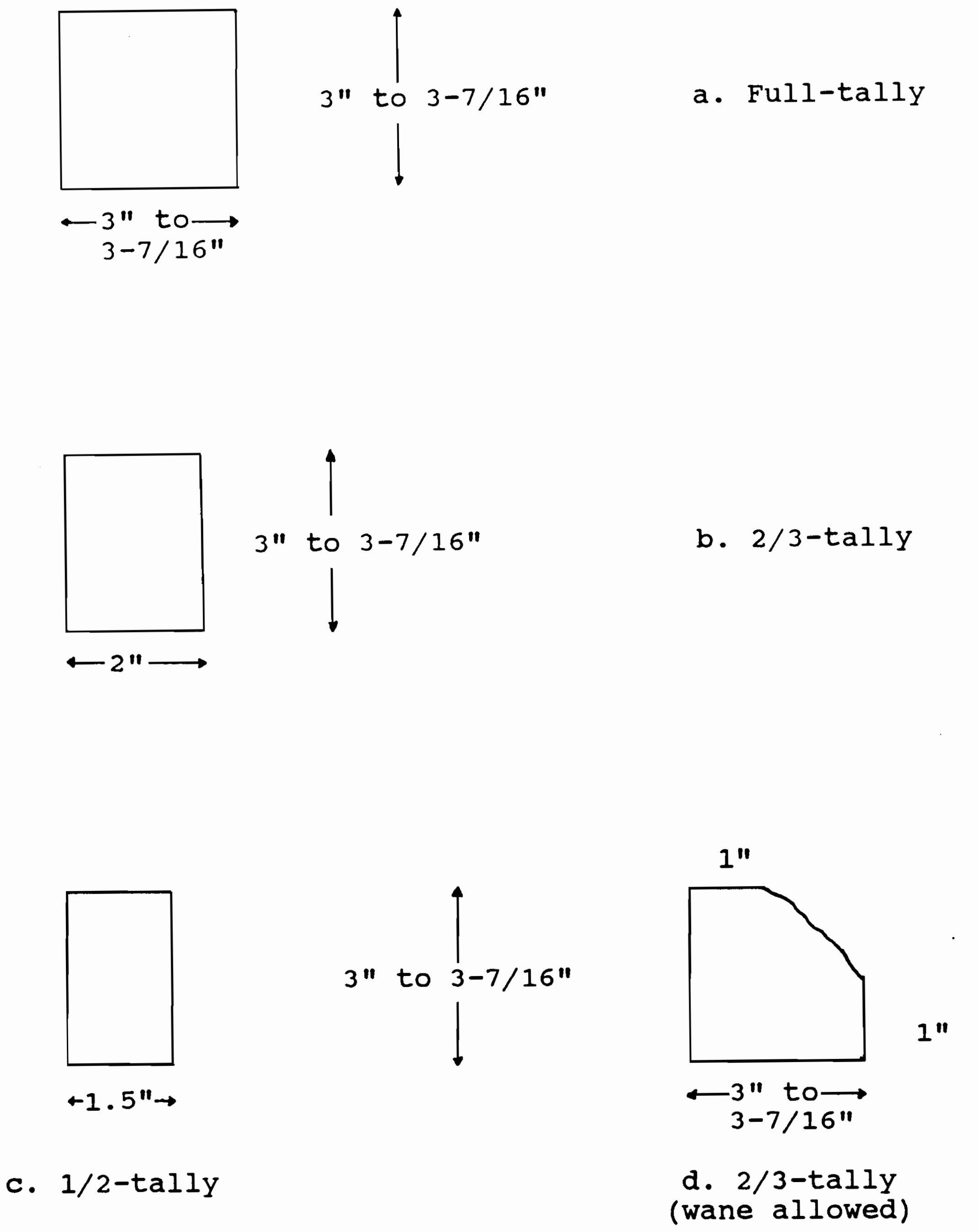


Figure 3. The three categories of pencil stock according to sizes.

into slats. Three categories of ring angle orientation are used:

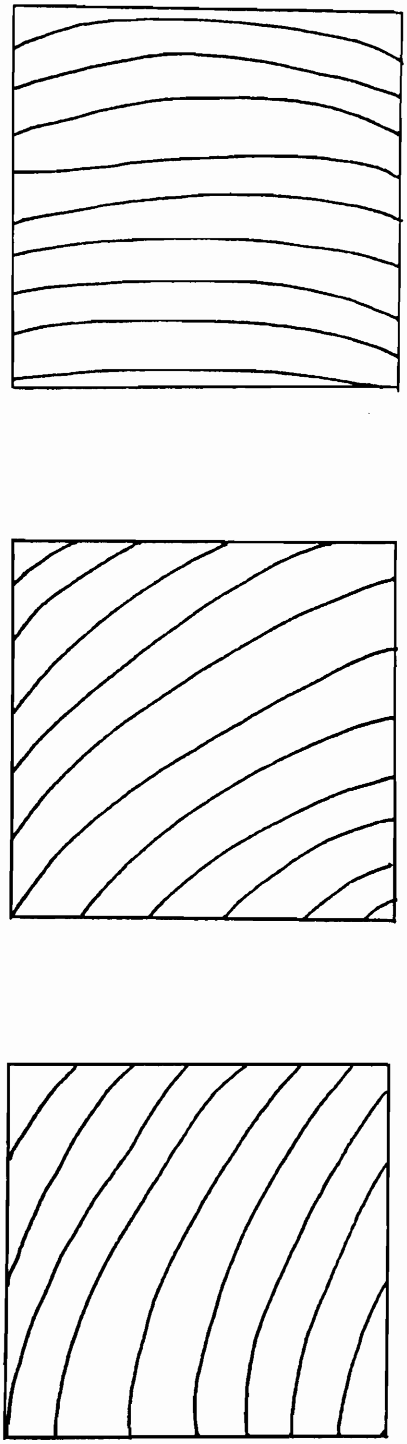
- The highest quality occurs when growth rings have an angle greater than 60° with the saw line orientation when sawing slats (Figure 4a).
- A medium quality slat is when the rings make an angle ranging between 30° and 60° with the sawline orientation when sawing slats (Figure 4b).
- The lowest quality slat is when rings have an angle less than 30° with the sawline orientation when sawing slats (Figure 4c).

During the rest of the discussion, these three categories will respectively be referred as grade 1 (highest quality), grade 2 (medium quality), and grade 3 (lowest quality).

When sawing full tally blocks into slats, dimensions requirements for slats are such that a block does not really need to have a square transverse section but could have a rectangular one instead. The reason for sawing squares instead of rectangles is explained by the fact that square pencil stock leave the flexibility of orienting blocks according to their ring angle. The rough green block dimension requirement to produce slats are:

- width	3.090 inches
- thickness	2.930 inches

These are company average target sizes and not actual target sizes. All the target sizes of P&M Cedar are different, varying by mill, machine center, and product. For simplification purposes, the analyses in this study were made using the rough green average dimensions listed in Table 1.



a. high quality, grade 1, angle greater than 60°.

b. medium quality, grade 2, angle between 30° and 60°.

c. low quality, grade 3, angle below 30°.

Figure 4. Three classes of pencil stock according to ring angle.

Table 1. Rough green dimensions of pencil stock used in this simulation study.

		width(in.)	thickness(in.) rectangles	squares
Full-tally		3.09	2.93	3.09
2/3-tally	no wane	2.00	2.93	3.09
	with wane	3.09	2.93	3.09
1/2-tally		1.50	2.93	3.09

By sawing squares with 3.09 inch sides instead of rectangles with 2.93 inch heights, a waste of 0.16 inches in thickness occurs in each block. The idea was thus to investigate what will happen if the thickness of the flitches was reduced during log breakdown. Raw material would be saved, and there would be an increase in recovery. On the other hand, the blocks would not be able to be oriented when sawing slats, thus resulting in a decrease in quality.

Besides sawing pencil stock, P&M Cedar also produces commercial boards. These boards are made out of the lower quality part of the log, parts which would not yield acceptable pencil stock. It usually corresponds to the central part of the log which contains more knots and juvenile wood. Some logs not suited for pencil stock manufacturing are also sawn entirely into lumber for products other than pencil stock. These types of logs were not considered in this study.

V. BOF SUPPORT OF THE MODEL

A. JUSTIFICATION.

The main reason for choosing the Best Opening Face (BOF) program as a basis for the present model was its popularity. Among the existing computer programs simulating log breakdown, BOF is certainly the most widely known and used by the American lumber industry. Its popularity most probably comes from its seniority; BOF was developed in 1970 at the USDA Forest Products Laboratory in Madison, Wisconsin, making it one of the earlier programs of its kind. Moreover, BOF belongs to the public domain, and thus is readily available to any interested party. Many of the sawing simulation programs that followed BOF's release used it as a foundation.

Even though BOF does not consider log defects or lumber grade, it remains a powerful tool to assess the impact of changes on recovery (sawkerf, taper, diameter class, sawing variation, sawing method...), and to provide the sawing pattern yielding the highest recovery factor. The two principal disadvantages of using BOF, not as a management tool but as a basis for new models, are its inability to handle complex log shapes as well as the lack of literature related to the program structure. The latter point makes it difficult and time consuming to work on when modifications are needed.

The following section gives an overview of how BOF works so it will be easier to understand why and how the modifications were made to BOF in this model.

B. OVERVIEW OF THE BOF PROGRAM.

The version of BOF used as the basis for this model is written in FORTRAN. It consists of a main program called "BOF" and several subroutines referred as "SAW", "RESAW", "EVAL", "INPUT" and "OUTPUT".

As its name indicates, the principle of BOF is to find the position of the first sawline, the opening face, yielding the highest value or volume based on the concept that the whole sawing pattern depends on that opening face. The program tries all possible opening faces, calculates for each of them the value or the volume, and retains the position yielding the best results.

The variables available in BOF leave a reasonable amount of flexibility in its usage. The following variables are in the version used for this model: taper, planing allowance, sawing variation, sawkerf, lumber sizes, shrinkage, log diameter and length ranges, setting increment capability of equipment, diameter measurement increment, shortest and narrowest piece allowed, and sawing method. Sawing method includes live or cant sawing, full taper or split taper sawing, and full length or trim back edging method.

1. Calculating rough green target sizes.

In order to find the green sizes to which lumber should be sawn, BOF adds to the finished size the dressing allowance, sawing variation, amount of shrinkage, and a quantity linked to the setting increment capability of the equipment. This last quantity is needed in order to have an integer number of setting increments between two sawlines. The nominal sizes available range from 3 inches to 12 inches in width and from 1 inch to 2 inches in thickness. When studs are sawn, only boards of 3 inches and 4 inches wide are recovered. As will be discussed later (Section VI-A-2-b), the model used in this thesis assumes pencil stock production is similar to stud production, and thus only considers the studs option henceforth. In a similar way, only split taper live sawing will be discussed.

2. Sawing pattern.

a. Starting opening face. BOF calculates the position of the first sawline yielding the smallest acceptable board from the log. Starting from that first sawline, successive cuts are made corresponding to the thickness of a flitch. For studs, the flitches have a constant 2 inches nominal thickness.

b. Edging and trimming. When sawing studs, BOF combines studs prior to sawing and then uses these larger boards in the edging process to find the number of studs that fit in a flitch. When combining studs, BOF takes into account the finished sizes, sawkerf, sawing variation, shrinkage, dressing allowance, and setting increment capability.

Two edging methods are available: full length edging and trim back edging. For sawing studs, only the full length edging method is of interest, since only one main width is available. This method finds the widest possible full length stud or the maximum combination of studs of 4 inches nominal width each fitting in the flitch. A narrower stud of 3 or 4 inches nominal width, depending on the operator's choice, may then be sawn from the remaining triangle if possible. This last piece is often shorter than the whole length of the flitch.

c. Recovery. The value and volume for this specific opening face are determined according to the pieces produced. The position of the opening face and the yield are then stored to be later compared to other solutions.

3. New opening face.

The opening face is then shifted toward the center of the log by an increment chosen by the operator at the beginning of the program. The sawing process is repeated and the new value or volume compared to the one previously saved. The best of the two yields is saved, and the whole process repeated until the first sawline has moved the thickness of a flitch. At this point, all possibilities have been tested. The position yielding the highest value or volume is then given as output.

VI. COMPUTER PROGRAM

This chapter is divided into five parts. The first part describes the sawing method used as well as the assumptions and constraints made in the process and in the model. Then modifications made to BOF in order to meet the new assumptions and constraints are developed, followed by a description of the calculation of ring angle and ring density in each board. The fifth part deals with the practical usage of the model: how the data are entered, and how results are presented.

A. ASSUMPTIONS AND CONSTRAINTS.

1. Process.

a. Sawing method. When manufacturing pencil stock, P&M Cedar uses different sawing patterns, depending mainly on log diameter. This study considered only the type of sawing pattern used for log diameters ranging from 13 to 25 inches. This sawing pattern is the one most commonly used by P&M Cedar's mills. To leave the opportunity to assess the effect of this type of pattern on larger diameter logs, the program was modified to allow logs up to 40 inches in diameter.

The split taper sawing method was used, which means that the headrig sawline is parallel to the log centerline. All logs were live sawn, producing flitches of constant thickness corresponding to a pencil stock's thickness. Jacket boards were not allowed. All the flitches, except the two nearest to the pith, were then sawn into a combination of full-tally, 2/3-tally, and 1/2-tally pencil stock to obtain the best recovery. The highest possible number of full-tally, full-length pieces of pencil stock were sawn based on the small-end of the flitch. In the remaining portion of the flitch, a full-length 1/2-tally piece was recovered when possible; otherwise a shorter, 2/3-tally piece was saved. If a full-length, 2/3-tally piece could be recovered prior to a 1/2-tally piece, it was given priority. A 1/2-tally piece and a 2/3-tally piece can not be recovered at the same time since their additive width would then exceed the width of a full-tally piece. While this hierarchy is arbitrary, it was estimated that this combination should be the closest to the optimum one. Ideally, all possible combinations should be made available, mixing full-tally with 2/3-tally and 1/2-tally in any amount. Such a flexibility in the sawing pattern would complicate the model and dramatically increase the running time. A pencil stock has a 3X3 nominal size when it is a full-tally piece; it has a 2X3 nominal size when it is a 2/3-tally, and a 1.5X3 nominal size when it is a 1/2-tally piece.

The two flitches closest to the center of the log followed a slightly different sawing pattern. They were sawn partly into commercial boards and partly into pencil stock (Figure 5). The centers of these two flitches, which contain the pith area and juvenile wood, are sawn into commercial boards 6 inches or 8 inches wide depending on the demand. Each commercial board is then sawn into two nominal 6/4 X 6 or 6/4 X 8 boards. The latter breakdown was not considered in this study, and the commercial boards were treated as nominal 3X6 or 3X8 boards to compute values.

The edging was done following the full length edging method as describe in section V-2-b.

b. <u>Log sizes</u>. Log sizes ranged from 6 to 16 feet in length and from 13 to 40 inches in diameter. Pencil stock lengths ranged from 4 to 16 feet.

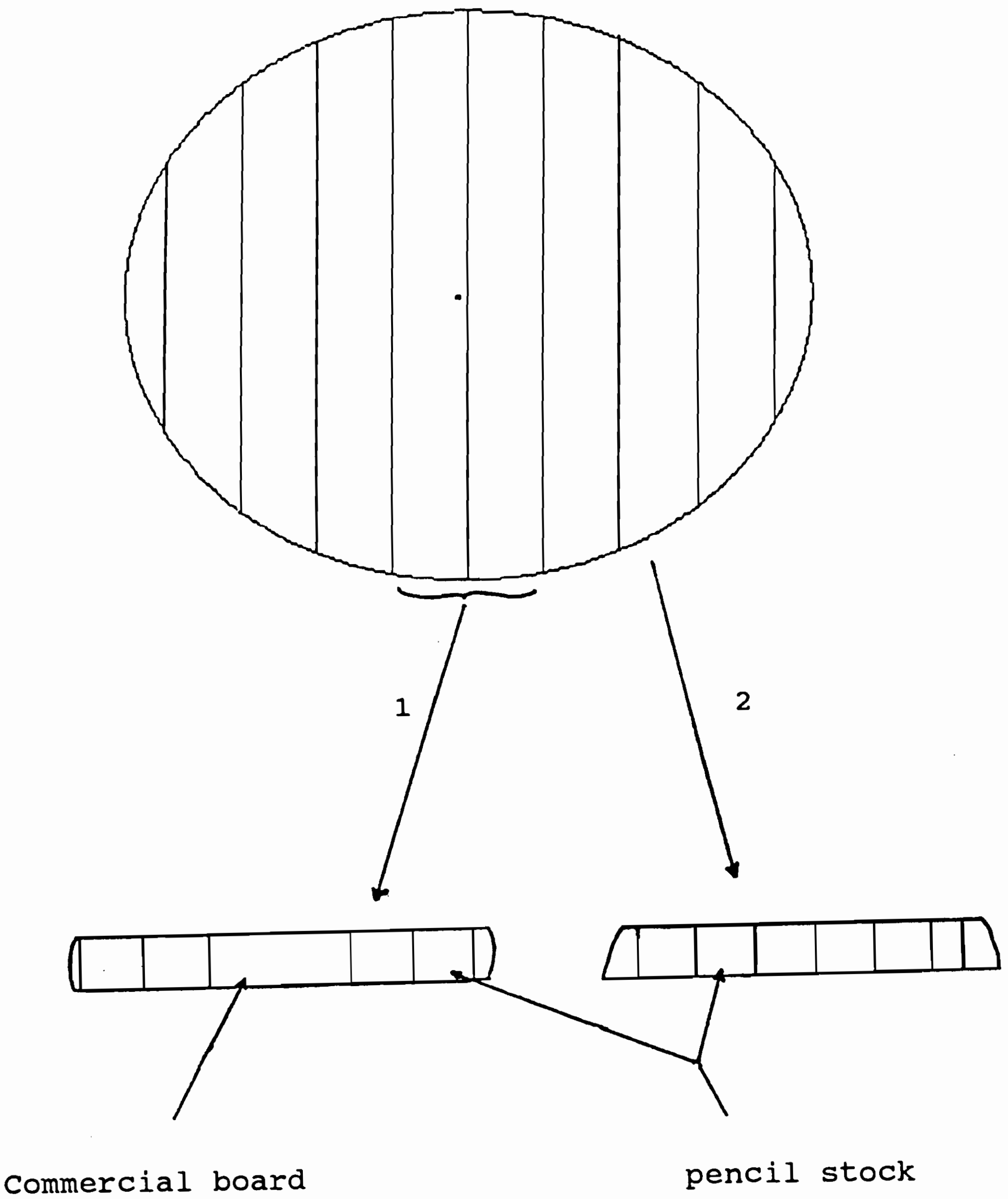


Figure 5. Sawing patterns. The two center flitches are sawn according to pattern 1. All other flitches follow pattern 2.

2. Model.

a. Log. As in the original version of BOF, the logs in this model are treated as truncated cones, with no internal or external defects. Because false rings and discontinuous rings are not common features in incense cedar, each growth ring was also assumed to be a truncated cone following exactly the shape of the log, and no false rings or discontinuous rings were allowed.

b. Sawing. Sawing full-tally pencil stock is the same thing as sawing studs, except that the target sizes and nominal sizes are different. In both cases, boards in a flitch have the same sizes, except for one extra narrower shorter board that can be saved from the remaining area of the flitch. In the specific case studied here, a 1/2-tally piece can also be recovered as explained in VI-A-1-a. Pencil stock were thus treated as studs, the nominal size being changed in the program from a 2X4 to a 3X3. As previously noted, commercial boards were present only in the two flitches closest to the center of the log. Within those flitches, the commercial boards need to be as centered as possible. Because logs have taper and sawing of the flitches are made parallel to the edge, a commercial board can not be centered over the whole length of the log. In this model, the commercial boards were positioned according to the large end of the log where the ring angle and density are measured. P&M Cedar combines the use of a headrig and resaw for the breakdown of logs into flitches. Since BOF only simulates a headrig, the resaw characteristics for P&M Cedar were assumed to be the same as those for the headrig.

c. Wane. The wane allowed in BOF corresponds to 25% of the width and thickness of a board. P&M Cedar allows its 2/3-tally pieces to have up to 66% wane on two adjacent sides of pencil stock. To leave some flexibility in the amount of wane allowed, the percentage of wane was made a variable to be entered by the operator. Because pencil stock containing wane has its nominal size decreased, it is important to position the first sawline in a flitch so as to have a minimum number of pieces containing wane.

d. Ring angle and density. Even though the three classes of ring angle used by P&M Cedar are well defined (Section IV-C), the angle limits in each class were left as variables to allow for more versatility. Each class is not given a fixed price, but rather a factor corresponding to its relative price, and those factors are used to compute value. When a flitch is edged in BOF, the sawlines are parallel to the flitch's edge and not to its center line. Thus, the ring angles are not uniform for the full length of the board and the classification depends on the position considered. Therefore, ring angles were measured at the large end of the flitch, which gives the more conservative (lowest) value angle. Because pencil stock is then trimmed into shorter blocks, the angle in each block will be different. Classification according to ring angle in blocks from the two extremities of a pencil stock could thus differ.

Two growth rate classes were made available. The change between the two growth rates in a log was assumed not to be progressive, but rather to take place at a given distance from the center of the log. This distance was left as a variable. This leaves the possibility of using these two classes not only for ring density, but also for anatomical features such as sapwood/heartwood or juvenile wood/mature wood where the boundaries are treated the same way.

For both ring angle and ring density calculations, a board containing more than one class of angle or density was automatically placed in the class with the lowest value. It was assumed that a visual grader would not be able to see accurately a small percentage of lower grade in a board to downgrade it as the computer would do it. Therefore, an option was added that requires a certain percentage of the board to be in the lower class before downgrading the whole board.

B. MODIFICATIONS TO B.O.F.

The work done on the B.O.F. program was divided into three distinct steps. Step one involved the deletion of BOF subroutines no longer needed because of the specific production application. Step two consisted of modifications done to the original version of the BOF program to meet the specific assumptions of this study. These included changes in the log diameter range, lumber sizes, wane, sawing pattern, and volume and value computation. In some instances, modifications were more than just mere changes of limits, but rather totally new procedures such as for the calculation of the amount of wane in a flitch. The third step involved addition of the subroutines calculating ring angle and ring density and are discussed respectively in Sections VI-C and D.

1. Subroutine deletions.

Before even starting any modifications, parts of the original program were removed due to new assumptions that did not require these features. Because the trim-back edging method, the cant sawing method, and the existence of a jacket board were not considered as alternatives in the sawing pattern, all parts dealing with these variables were deleted. Also the subroutine RESAW, that sets the subroutine for sawing the cant, was of no use since only live sawing is considered and was thus deleted.

2. Log diameter range and lumber sizes.

Log diameter range and lumber sizes are closely related since the diameter in BOF is limited only by the maximum width of a flitch, which in turn is a function of the number and width of boards allowed to fit in a flitch. In the case of stud production, a maximum of 6 boards of 4 inches nominal width can be obtained from a flitch, plus an additional narrow piece of either 4 inches or 3 inches depending on the input. This combination only allows logs with a maximum small-end diameter of 28 inches to be processed in the original program.

As the present model dealt with 3 inches nominal width and the logs were to reach 40 inches in diameter, a combination of up to 13 full-tally pencil stock pieces plus one 2/3-tally board was made available in a flitch. Using the nominal sizes of 3 inches wide for full-tally pencil stock, and 2 inches wide for 2/3-tally, the above combination allows logs around 41 inches in diameter to be simulated. However, no precise limit can be given since the actual sizes differ from the nominal sizes, and parameters such as saw kerf or sawing variation were not taken into account at this point. In fact, the largest flitches come from the center of the log, where the commercial boards of nominal 6 inch or 8 inch width are cut. Therefore, in the case of flitches containing commercial boards, only 11 full-tally pencil stock are necessary to fulfill the diameter requirements.

As mentioned before, studs are grouped together to form large fictive flitches prior to sawing (Section V-B-2-b). Henceforth, the term flitch will refer to these boards made out of a combination of studs. In the original program, the maximum number of studs allowed in a flitch was 6, which is far less than the 13 allowed in this study. Because of this increase in the maximum number of studs in a flitch, changes had to be made in the arrays using this number. Those arrays were SAWVAR(I), SIZES(I), GREEN(I), ALLOW(I), PRICE(K,I,M), LUMBER(I,M), and PIECES(K,I,M), where I represents the width, K the length, and M the thickness.

Other sizes that also had to be added included the commercial boards and the 1/2-tally boards. The 2/3-tally pieces were treated as the "narrower shorter" pieces of the original program, under the variable name PX. A total of 18 sizes are carried along in the program. They include 13 stud flitches (those flitches containing from 1 to 13 studs), 1 thickness, 1 size for the 1/2-tally, 1 size for the 2/3-tally, and 2 commercial boards. The dimensions of arrays SAWVAR, SIZES and GREEN were thus all increased from 8 to 18. Other arrays whose dimensions also are a function of the thickness and the length will be explained in more detail in Sections VI-B-2-e, f and g.

a. Thickness. The thickness was reduced from 2 choices to a single one, since the model does not consider jacket boards. This was done in subroutine INPUT by changing the number of thicknesses allowed, variable MAXTHX, from 2 to 1. The only other change made was in subroutine SAW where the variable TX representing the thickness used at the time was also changed from 2 to 1.

b. Sawing variation. Sawing variation is an array whose elements must be entered by the user. Nevertheless, because its dimensions were increased, the way it is entered was changed. Among the 18 data that are needed, 13 are merely a combination of studs all of which are the same size. Therefore, to make it easier for the user, only the 6 independent data necessary for determining the sawing variation are used in the READ statement. In subroutine INPUT, the array to be read was changed from SAWVAR to SCIVAR. SCIVAR has a dimension of 6 and represents the sawing variation data in the following order: thickness, 1/2-tally, 2/3-tally, full-tally, 6 inch commercial boards, and 8 inch commercial boards. SAWVAR is kept with the new dimension of 18 as explained in Section VI-B-2. The passage from SCIVAR to SAWVAR is done in the subroutine INPUT by matching the values as follows:

SAWVAR(1) = SCIVAR(1)
SAWVAR(2) = SCIVAR(2)
SAWVAR(3) = SCIVAR(3)

$$\left.\begin{array}{l}\text{SAWVAR(4)}\\ \cdot\\ \cdot\\ \cdot\\ \text{SAWVAR(16)}\end{array}\right\} = \text{SCIVAR(4)}$$

SAWVAR(17) = SCIVAR(5)
SAWVAR(18) = SCIVAR(6)

The advantage of using SAWVAR as defined instead of SCIVAR was to avoid major changes in statements involving the sawing variations. The other change concerning SAWVAR was made in the subroutine INPUT when SAWVAR is checked for any error (negative value). The loop's upper limit was changed from 8 to 18, corresponding to the new dimension.

c. <u>Sizes</u>. The array SIZES represents the finished dimension requirements for the lumber. For the same reason as mentioned for SAWVAR, the elements to be read were changed from SIZES to MES, which has a dimension of 6. The passage from MES to SIZES also follows the same pattern as for SAWVAR. The widths of flitches were computed according to the same principal as the original program. Only the limits of the loop used to compute the flitch were changed to a minimum of 5 for 2 studs and a maximum of 16 for 13 studs. The 1/2-tally and 2/3-tally boards are not options but rather are always computed. If not desired, a value of zero can be entered as their sizes.

The array GREEN, whose dimension was also increased to 18, represents the green finished sizes of the boards. The elements of GREEN are computed from the elements of SIZES and the shrinkage factor. The only change made was in the main program, BOF, where the upper limit in the loop used to compute the elements of GREEN was changed from 8 to 18.

The array ALLOW represents the amount to be added to the target size in order to meet the requirements due to the setting increment capability of the machine center. The sawlines have to be on a setting increment and can not be in between. The dimension of ALLOW is the same as for GREEN but increased by one. This extra element is half the allowance on the thickness and is used for the flitches from the side of the log which contain the first and last sawlines. The dimension of ALLOW is thus changed from 9 to 19. The board to which each of its elements correspond is the same as for SIZES up to 18 and in addition ALLOW(9) becomes ALLOW(19).

d. Length. The smallest lumber length allowed was decreased from 6 feet to 4 feet. This forced the dimensions of the arrays LENGTH and LOGS to increase from 13 to 14. It also required adding the constant 4 in the DATA statement defining the array LENGTH in the subroutine SAW as well as the array LOGS in the subroutine OUTPUT. The array LOGS and the format arrays

FOR46, FOR47, FOR92, and FOR93, are used for printing tables that include length. They also had their dimensions increased from 13 to 14 to consider the 4 foot lumber.

Because the minimum length for lumber was reduced, changes were made to avoid ending up having null or negative values for some variables. In subroutine INPUT, the variable MNLENX being a function of SHORT, itself a function of MINLEN (minimum length), meant the relation:

MNLENX = SHORT-3

was changed to:

MNLENX = SHORT-2

resulting in a value of one for MNLENX when the shortest lumber allowed is 4 feet. In a similar way, in subroutine SAW the variables JX and PX are a function of the lumber length and were defined as being J-2 instead of J-3. Because of the changes made to MNLENX, a number of additional changes were required to be done in subroutines OUTPUT and INPUT. In these two subroutines a DO statement is used several times to have all the lumber length that can be found in one specific log from the shortest lumber length allowed to the total length of the log. Because a modification was made on the shortest lumber length MNLENX and none was done on the log length, one unit had to be added to the log length MXLOGX in the DO statement in order to reach the correct number of lumber lengths. The variable LOGLEN, which is the total number of lumber lengths available, had to also be increased by one in the subroutine OUTPUT. Variable LX, which is a function of the log length LOGX, is used twice in a loop related to lumber length. It thus had to be increased by one for the same reason as mentioned above.

e. Prices. Because there were more sizes available, the arrays PRICE, PIECES, and LUMBER had to undergo certain modifications. The dimensions of PRICE were changed to PRICE(14,17,1) (length from 13 to 14, width from 6 to 17, and thickness from 2 to 1 as defined in Section VI-B-2). In fact, PRICE has only the five following widths when read: 1/2-tally, 2/3-tally, full-tally, and 6 inch and 8 inch commercial boards. To read those five widths in subroutine INPUT, the variable WIDEX, which is a function of the number of widths available, was given a constant value of 5. The number of elements in PRICE is then increased to 17 widths by giving all 13 flitches, those flitches made of different combinations of studs, the same price per thousand board feet. The FORMAT statement was also increased by one from 13 to 14 corresponding to the new number of lengths available. The change in the width dimension was made as follows:

- the 1/2-tally was changed from the 1st to the 17th element of the array,
- the 2/3-tally was changed from the 2nd to the 1st element,
- the full-tally flitches were changed from the 3rd element to the elements ranging from 3rd to 14th,
- the 6 inch commercial board was changed from the 4th to the 15th element, and
- the 8 inch commercial board was changed from the 5th to the 16th element.

The array DIMEN, used to print tables of lumber nominal sizes in the subroutine OUTPUT, was given new values in the DATA statement. These nominal sizes are 3x1.5, 3x2, 3x3, 3x6, and 3x8.

f. Lumber. The array LUMBER deals with the nominal sizes of the boards, and is used to compile their volumes and values. The specific case in this study of pencil stock required modification of the nominal sizes previously fixed in BOF. Under the DATA statement in subroutine INPUT, the variable BDFT was given new nominal sizes corresponding to the volume in board feet of a one foot long board with dimensions: 3X2, 3X3, 3X6, 3X8, and 3X1.5. Their respective volumes are 0.5, 0.75, 1.5, 2, and 0.375 board feet. The dimensions of BDFT were changed accordingly to five widths and one thickness. The dimension for LUMBER was changed from 6 widths to 17 widths as defined in section VI-B-2 and from 2 thicknesses to a single one. Also, a lower limit zero for the width is given with a value zero for the corresponding element. This initialization is necessary since it does happen that a value zero is given to the width when calculating the flitch's value. The values of the elements of LUMBER are calculated from BDFT using the following equations:

flitches	LUMBER(J,1)=(J-1)*BDFT(2,1) (with J varying from 2 to 14)
2/3-tally	LUMBER(1,1)=BDFT(1,1)
6 inch commercial	LUMBER(15,1)=BDFT(3,1)
8 inch commercial	LUMBER(16,1)=BDFT(4,1)
1/2-tally	LUMBER(17,1)=BDFT(5,1)

g. <u>Pieces</u>. This array is used to give the piece count of each lumber size in the final printout. Its dimensions were changed in the same way as array PRICE to PIECES(14,17,1). The different number of widths available as compared to the original program required modifying the limits where the width is involved. In the subroutine OUTPUT, the two statements:

```
DO    K = NARROW,6
```

were changed to:

```
DO    K = NARROW,17
```

For the printout, the pieces table shows the nominal sizes. These sizes, given in the array DIMEN, were change in the statement DATA to the new nominal sizes: 3X1.5, 3X2, 3X3, 3X6, 3X8. Before printing the data, the number of width elements in PIECES was reduced from 17 to 5. The 5 widths are: 2/3-tally, full-tally, 6 inch commercial, 8 inch commercial and 1/2-tally. The WRITE statement is such that in the final table the widths are represented in that order.

h. <u>Test</u>. The elements of the array TEST are used to determine the number of pencil stock pieces recoverable in a flitch. TEST does not include the 1/2-tally pieces because they are considered directly when simulating the sawing of the flitches. The elements of TEST are combinations of boards creating a fictitious large board that is all one piece. These large boards are henceforth just referred to as boards. For stud sawing in the original program, two ranges of elements existed in TEST: the boards containing only nominal 4 inch wide studs, and the boards containing in addition to the nominal 4 inch wide studs, either a 3 inch wide stud or a 4 inch wide stud depending on the operator's choice. The second range of elements is used to find if an extra, shorter piece can be recovered from the flitch. In the present model, the same pattern is kept but with new limits because of the higher number of studs allowed in a flitch and the fact that commercial boards were also considered. New elements were added to TEST representing a combination of boards made out of one commercial board of either 6 inches or 8 inches plus a number of full tally boards and 2/3-tally boards in some instances.

TEST is a two-dimensional array. The row defines the combinations of widths, and the column defines where the board's width is measured. It can be measured on the face of the board, TEST(I,1), which means that there is wane to be considered; or it can be measured full width from edge to edge, TEST(I,2). The first width is henceforth called face width and the latter called edge width. When only full-tally pencil stock are in the flitch, the elements of TEST(I,2) are computed as in the original program, but with just the upper limits of the loop being changed to 14. Because the boards used in TEST are symmetrical (the same amount of wane on both sides of the board), TEST considers only half the sizes. To compute the face width from a 2 stud board to a 13 stud board, the amount of maximum wane allowed is subtracted from the edge width. The boards containing a 2/3-tally board, or only one full-tally board are different since no wane is allowed on a 2/3 tally board by definition and that only half the wane can be subtracted on each side of the 1 stud board. Thus, in these two cases, it is equivalent to having half the wane on each side. Thus, the face width is the edge width decreased by only half the maximum width of wane allowed on a full tally board. In the second set of elements of TEST, an extra 2/3 tally is added to the above combinations. The procedure is the same as in the original program except for the limits of the loop which were changed from a minimum of 14 and a maximum of 24 to a minimum of 16 and a maximum of 28. The first element represents a flitch made only of a 2/3 tally board. The elements from 2 to 14 represent fourteen flitches made exclusively of full-tally boards. The fifteenth element is given any value large enough to exceed the maximum log diameter allowed in order to stop the search for the widest flitch in the subroutine SAW. The value 100 was given in this case.

The same procedure is used to compute TEST for flitch containing commercial boards; only the limits are changed (Table 2). The flitch in this case has one commercial board plus anywhere from 2 to 11 studs

Table 2. Values of the elements of the array TEST.

element	number of full-tally boards	number of 2/3-tally boards	commercial board sizes
0	0	0	0
1	0	1	0
2	1	0	0
.	.	.	.
.	.	.	.
.	.	.	.
14	13	0	0
15	0	0	0
16	1	1	0
.	.	.	.
.	.	.	.
.	.	.	.
28	13	1	0
29	0	0	0
30	2	0	6"
.	.	.	.
.	.	.	.
.	.	.	.
39	11	0	6"
40	0	0	0
41	2	0	8"
.	.	.	.
.	.	.	.
.	.	.	.
50	11	0	8"
51	0	0	0
52	2	1	6"
.	.	.	.
.	.	.	.
.	.	.	.
61	11	1	6"
62	0	0	0
63	2	1	8"
.	.	.	.
.	.	.	.
.	.	.	.
72	11	1	8"
73	0	0	0

(Section VI-B-2). When passing from elements representing flitches that do not include commercial boards, to elements representing flitches that include commercial boards, an element is skipped in TEST and given a value 100 for the same reason as previously described.

The dimensions of the array TEST were modified according to the new range of widths it is dealing with. The row's lower limit is set to zero and the element associated with it given the value zero. This initialization is needed in subroutine SAW where the element 0 can appear. The row's upper limit is increased to 73 to include all the elements related to commercial boards.

3. Wane.

Numerous changes were made concerning the wane, from converting it to a variable to considering the alternatives between allowing some wane or none at all on the pieces of a given flitch.

a. Wane as a variable. The fixed value of wane given in BOF under the statement DATA was deleted, and a READ statement in the subroutine INPUT was added. Since the elements of WANE are given as percentages, only two values are needed; one is for thickness, and the other one is for the width.

b. Wane at the first sawline in a flitch. Before checking whether the wane can be avoided on at least one side of a board, it is useful to know precisely how the board can be positioned within the flitch. When testing which widest board can fit in a flitch, two boards' widths are tested. The face width TEST(I,1), which has wane is compared to the flitch's width FACE. The edge width TEST(I,2), which is free of wane, is compared to the flitch's width EDGE, which is the width when the maximum wane on the thickness is present

(Figure 6).

Either of the two widths can be the limiting factor for the number of pieces and their positions in the flitch. Depending on the position of the flitch in the log, the thickness can have the maximum wane allowed and the width very little wane or vice versa. To determine which one is the limiting factor, the distance X, representing the amount of wane on the face, is evaluated (Figure 7). If this value is lower than the wane allowed in a stud, then the flitch's width EDGE is the limiting factor. In such a case, the variable PLUS is given the value 2. Otherwise the flitch's face FACE is the limiting factor, and PLUS is set at 1. PLUS is then used to properly position the board within the flitch for checking the presence of wane on both sides, for adding 1/2-tally pieces, and for calculating ring angle and density.

c. Wane on one side. In some instances, wane can be present on only one side of the board, leaving the other side clear of any wane. For all boards the hypothesis is made that there is wane on only one side. The difference between the width of such boards and the TEST value is TRANS. If TRANS is greater than zero, then the hypothesis is true. In this occurrence, the variable PERTE is given the value 1; otherwise, PERTE is set at 0. The way the widths of these boards and the value of TEST are measured depends on the variable PLUS. When PLUS is 2, the flitch's edge width, EDGE, is the limiting factor and the maximum width of a board containing wane on one side is EDGE + FACE. For reasons of symmetry, EDGE, FACE and TEST correspond to half the width of a flitch or a board. Because the flitch is considered from edge to edge, the board width from edge to edge is TEST(I,2) (Figure 8). When PLUS is 1, the flitch's face width,

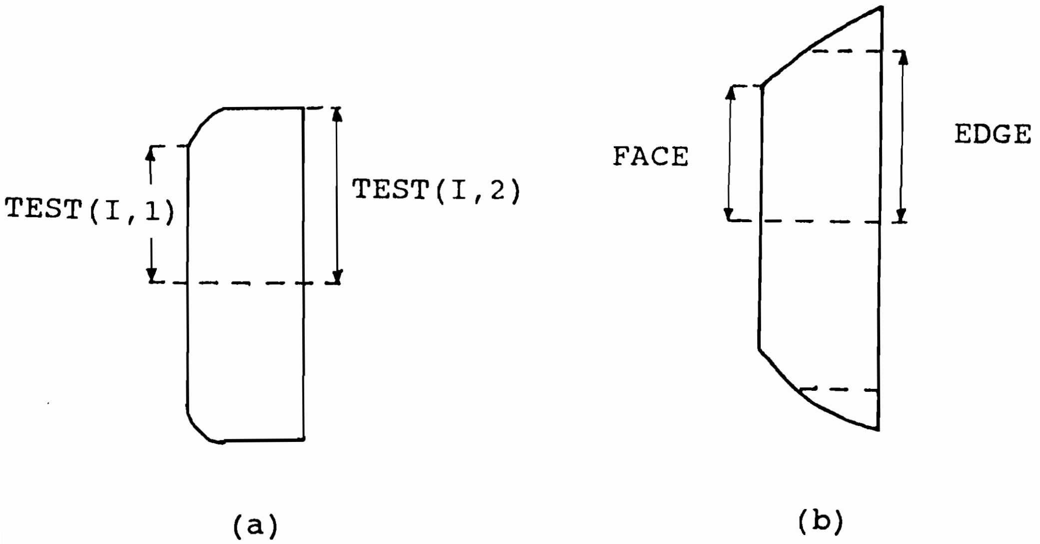


Figure 6. (a) Board with the two width measures TEST(I,1) and TEST(I,2).
(b) Flitch with the two width measures FACE and EDGE.

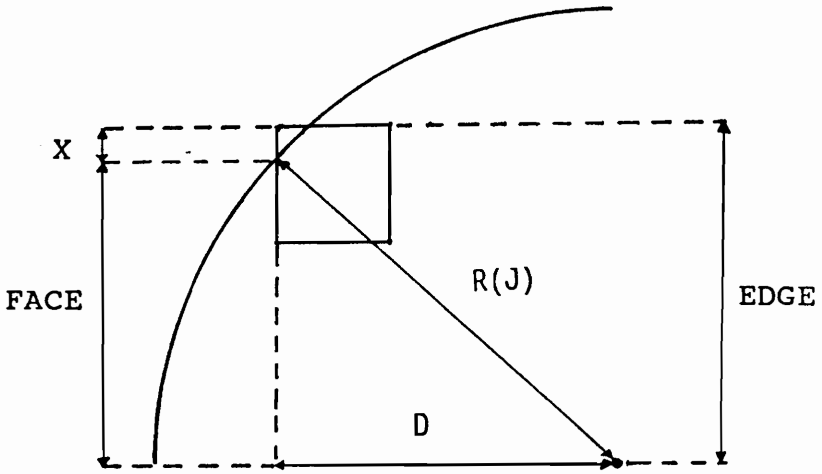


Figure 7. Illustration showing how the amount of wane on the width is computed. R(J) is the radius of the log. D is the distance of the flitch's face from the pith.

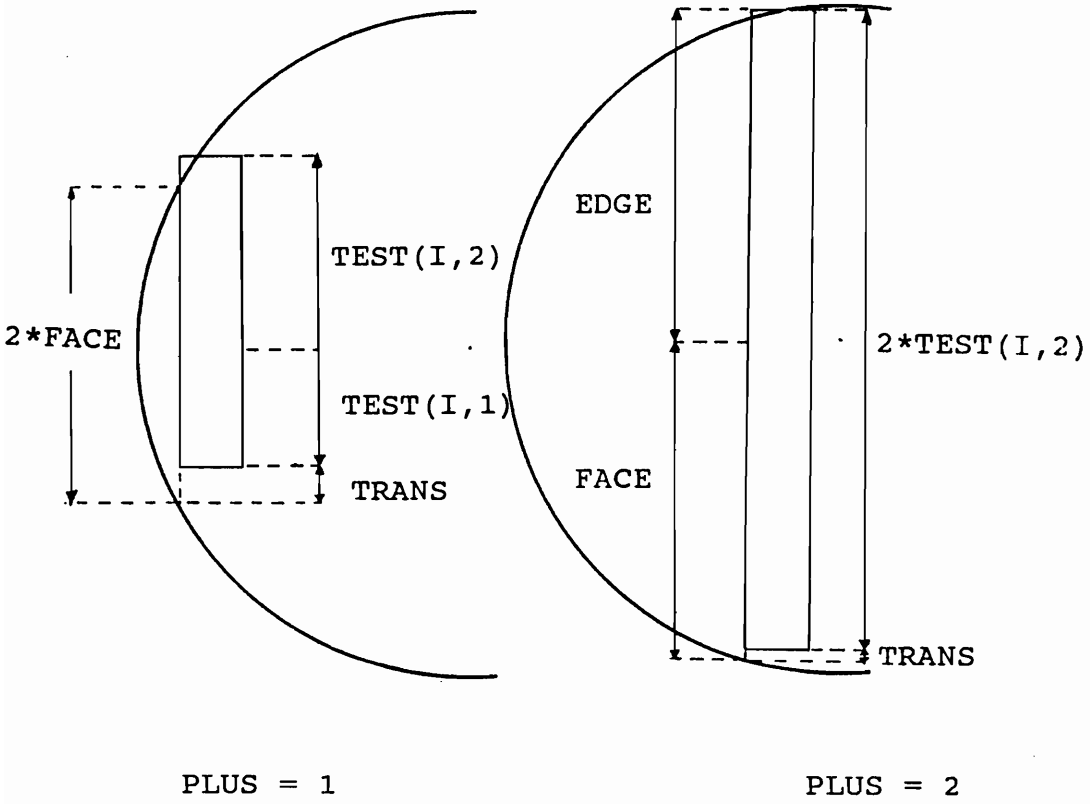


Figure 8. Illustration of the calculation of TRANS to estimate if there is wane on 1 or 2 sides of the flitch. When:
PLUS=1, FACE is the limiting factor to position the board in the flitch or
PLUS=2, EDGE is the limiting factor.

FACE, is the limiting factor, and the flitch's total face width is 2*FACE. The element of TEST for the whole board's face is the sum of the element TEST(I,1) (corresponding to the half containing wane) and of the element TEST(I,2) (corresponding to the half containing no wane) (Figure 8).

PERTE is then used when computing the volume and piece count. The presence of a 1/2-tally piece or of a 2/3-tally piece does not change the results of PERTE, since by definition these boards do not contain any wane.

d. No wane. When it is possible to fit all the full-tally pieces in the flitch with no wane on either side, two alternatives are tried and compared. In a first trial, wane is present as well as possibly a 2/3-tally and/or a 1/2-tally. Results are then compared to results of a second trial where no wane is allowed.

The variable TUT describes the situation when wane can be absent on both sides of the board. Initially, TUT is set to 0 and takes the value 1 when the flitch's width, FACE, is greater than the board's testing width, TEST(I,2), corresponding to the edge width. This means that the whole board can fit within the limits of the flitch's FACE. This situation is more likely to occur in the flitches close to the center of the log where the log's curvature is smaller and where the width of FACE and EDGE are not far apart.

When TUT is 1, there are two options. In the first option, the board is positioned in the flitch so that wane is present on the flitch, and the presence of a 1/2 or 2/3-tally board is checked as is done in the regular procedure. The variable PASSER, which is initially set to 0, is now set to 1, and the subroutine COMPARE called. In COMPARE, the value of the board is computed and saved. This computation is done by first looking at the 2/3-

tally (PX), then the 1/2-tally (SKY), and finally the full-tally pieces as well as commercial boards when present. When PASSER is 1, the board contains one and only one pencil stock with wane since the board could fit entirely in the flitch without any wane. Also, by definition the 1/2 and 2/3-tally pieces do not contain wane.

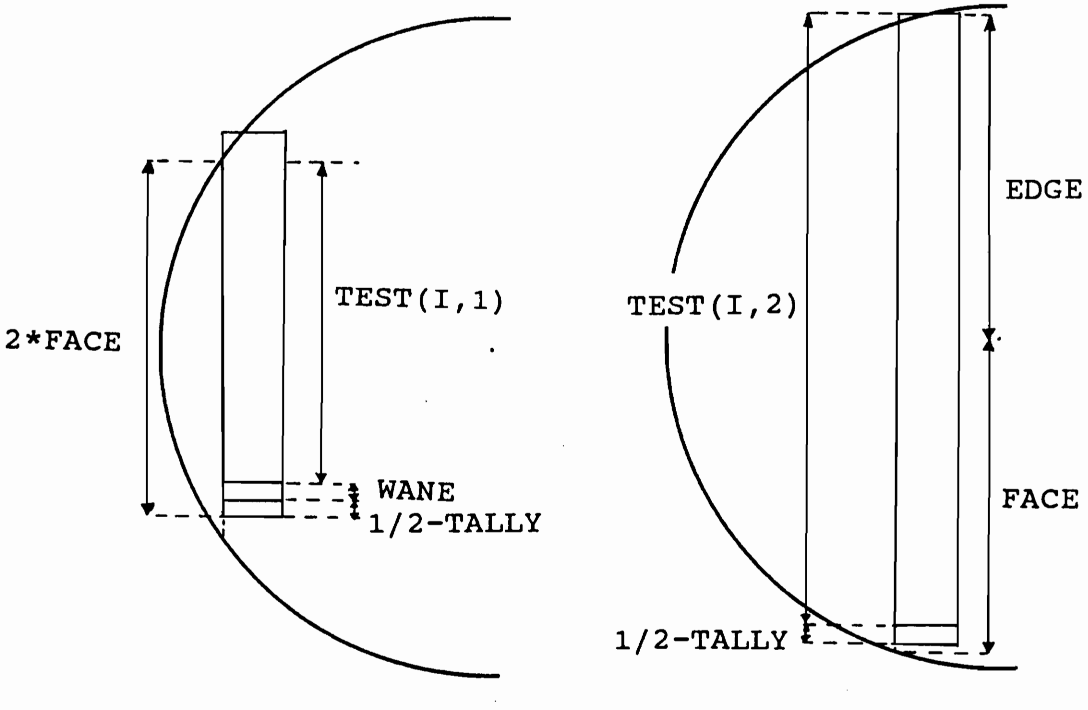
Once the value is obtained, the program returns to the subroutine SAW to calculate a new board for the same flitch, only this time no wane is allowed. For this case, the variable EDGE is given the value of FACE, which makes the flitch equivalent to a rectangle with no wane in which the board has to be sawn. The number of full-tally pieces remains the same since the width data are the same, but a change can occur in the presence of a 1/2-tally and/or a 2/3-tally. The variable PASSER is set to 2 for this second case, and the value of such a board is computed in the subroutine COMPAR. The variable SCIE characterizes the most profitable of the two boards, with SCIE=1 representing the board with wane and SCIE=2 the waneless board. The program returns to the subroutine SAW to obtain and save the necessary data for the selected board. During this third passage PASSER is set to 3 indicating that the options for this specific flitch are both done and that the next flitch may be processed.

4. Sawing pattern.

The two modifications discussed in this section are the additions of a 1/2-tally piece and of commercial boards present in the central flitches. The 2/3-tally pieces are computed the same way as the "narrower shorter" board of the original BOF program and thus needed very little modification.

a. Sawing pattern — no: a. 1/2-tally piece. To assess if a 1/2-tally piece can be added to an existing board, the exact position of the board in the flitch must be known. Thus, the usage of PLUS as defined in section VI-B-3-b is required. If PLUS is 1, the width FACE is the limiting factor. Then to have a 1/2-tally piece, the flitch's total width, 2*FACE, must be greater than or equal to the sum of the board's face width TEST(I,1), of a 1/2-tally piece's width, and of the amount of wane allowed on a full-tally piece's width. This latter value can be explained by the fact that no wane is allowed on a 1/2-tally piece, and that the TEST value for the face assumes wane on both sides of the board. Thus the wane must be subtracted from one of the extremities (Figure 9a). When PLUS is 2, the width EDGE is the limiting factor, and the amount of wane on the board's face is smaller than the maximum wane allowed. Since the edge is the limiting factor, the element of TEST used to estimate the presence of a 1/2-tally piece must represent the edge which is TEST(I,2). The edge width of a flitch with wane allowed on one side only and the other side containing a 1/2-tally piece free of wane is EDGE plus FACE. If a 1/2-tally piece is to fit in a flitch as limited above, the flitch's width must be greater than or equal to the sum of the board's edge width, TEST(I,2), and of the width of a 1/2-tally piece (Figure 9b).

If neither of the two inequalities is true, no 1/2-tally piece can be recovered, and the variable SKY representing the 1/2-tally piece is left at 0. If a 1/2-tally piece can be recovered, the presence of a 2/3-tally piece must first be checked prior to saving the 1/2-tally piece. At this point, no 2/3-tally pieces were considered in a flitch. Their presence and length are computed during a second passage as in BOF's original program. The assumption was made in Chapter IV that if possible, a 2/3-tally piece is recovered prior to a 1/2-tally piece.



(a)   (b)

Figure 9. This figure shows how the presence of a 1/2-tally board is estimated, depending on the value of PLUS.
(a) PLUS=1
(b) PLUS=2

It must thus be checked that the presence of a 1/2-tally piece does not prevent a 2/3-tally piece from being recovered prior to it at the small-end of the log. The width of a 2/3-tally is computed and saved as TOTH. The two cases PLUS=1 and PLUS=2 are treated as for the 1/2-tally piece, except for the width of the 1/2-tally piece which is changed to the width of the 2/3-tally piece. If one of the two inequalities is true, than a full length 2/3-tally piece is recovered instead of 1/2-tally piece. It should be noted that a full length 2/3-tally and a 1/2-tally piece have no reason to appear at the same time since their combined width is greater than a full-tally piece which would then be sawn instead. When it is found that a 1/2-tally piece can be recovered, the variable SKY takes the value 1, otherwise it stays at 0.

In some instances, when PASSER is 1 or SCIE is 2 (Section VI-B-3-d), wane is avoided on both sides of the board. The computation for the presence of a 1/2-tally piece is then slightly different since the total width available will be smaller due to less wane. In such a case, the width EDGE is changed to the width FACE. In the inequalities described above, when PLUS is 2 things work the same with the total width of the flitch turning out to be 2*FACE. When PLUS is 1, things are different since the flitch's width FACE needs to be compared to the edge width TEST(I,2) instead of the face width TEST(I,1), since no wane is permitted.

b. <u>2/3-tally piece</u> . During the computation of a possible 2/3-tally piece, the presence of a 1/2-tally piece must be considered. It has been noted that a 1/2-tally piece and a full length 2/3-tally piece can not be recovered from the same flitch. On the other hand, a shorter 2/3-tally piece may be recovered even if a 1/2-tally piece has already been recovered. The test for the existence of a 2/3-tally piece is done exactly the same way as for a 1/2-tally piece by taking into account the 1/2-tally piece width, if there is one, and by considering the values of PLUS, PASSER and SCIE.

c. Commercial boards. A characteristic of the commercial boards is that they are present only in the two central flitches, and within these flitches they need to be as centered as possible. The existence of commercial boards required the creation of new elements for TEST which gave flitches' face and edge widths (Section VI-B-2-h). The flitches closest to the pith are determined in the subroutine SAW, and the position within the flitch is found in the subroutine ANGLE; the latter will thus be discussed in Section VI-C-6.

The choice between a 6 inch and a 8 inch wide commercial board is made in the subroutine INPUT and is entered under the variable COM as 0 for no commercial, 1 for 6 inch commercial and 2 for 8 inch commercial board. In order to use an arithmetic IF statement, these values were decreased by one to obtain either a negative, a null, or a positive number. COM becomes respectively: -1, 0, 1.

The variables used to determine the two central flitches in the subroutine SAW are MU, NU, TROP, and CFLIT. All of them are reset to 0 for each new opening face. Of the two flitches containing a commercial board, only one contains the pith of the log. The second one must have its inside face not farther than one half the thickness of a flitch from the log's pith. It can be either of the two flitches on each side of the flitch containing the pith.

The variable giving the position of a flitch in a log is TD, the distance from the log's perimeter to the outside face of the flitch. TD must be increased by the thickness to obtain the inside face of the flitch. The limit, as described above for a flitch with a commercial board, is thus the distance TD increased by one thickness and a half. The radius of the log at the small-end is DMIN + HALFBD by definition. Therefore, if the equation TD + THICK*1.5 <= DMIN + HALFBD is true, the flitch is too far from the pith and does not contain a commercial board. In the opposite case, the variables CFLIT and NU are both set to 1; KX, which is used to define the element in TEST, is initialized in order to reach the correct range of values in TEST corresponding to a board containing a 6 inch or an 8 inch commercial board. If 6 inch commercial boards are sawn, then KX is 30; if 8 inch commercial boards are sawn, then KX is 41 (Table 2, page 40). The regular procedure used for studs is then resumed.

When the center of the log is reached, the flitch which includes the pith will automatically contain a commercial board. Two situations may be present. In the first situation, the flitch previous to the central flitch was close enough to the pith to contain a commercial board. Therefore, the central flitch is the second and last flitch to contain a commercial board. MU is set to 1, and CFLIT and NU are left at 1. In the second situation, the central flitch is the first one to contain a commercial board, and thus the next flitch also contains one. Then MU is set to 2, CFLIT to 1 and NU left at 0. Also the variable DMIN, which is a function of the radius, is set to 100 inches which indicates that the center of the log has been passed. The program then computes the number of studs, in addition to the commercial board, that the flitch contains according to the regular procedure.

During this computation, if NU and MU are both equal to 1, the variable TROP is set to 1. This indicates that this flitch is the second one containing a commercial board and that the next flitch should then contain only pencil stock. If NU is 0 and MU is 2, the number of pencil stock in addition to the commercial board is computed. NU and MU are set to 1 so that the flitch following this central flitch is considered during the next passage as being the second and last one containing a commercial board (Figure 10).

d. Offset positions. In the original version of BOF, the sawing pattern is such that if no offset is allowed, the log is centered on the cant and therefore, the pith is in the middle of the cant. For the present program, no cant is sawn, but the two flitches containing a commercial board must be as centered as possible. If no offset is allowed, the pith should fall in between these two flitches, which together can be formed into a cant. The variable CENTER represents the distance from the pith to the face of the flitch when there is no offset. CENTER is a function of HALF, which represents half of the thickness. For a pith falling between the two flitches to be included in a cant, CENTER becomes a function of 2*HALF, which represents two halves of the cant which is in fact a whole flitch. The variable OFFSET represents the distance from the pith to the center of the cant when there is some offset. It is a function of HALF, and thus in the same way as CENTER and HALF was changed to 2*HALF.

5. Volume and value.

The way the value of a board and of a log is computed does not change when compared to the original BOF, but there is an increase in the variety of boards which required slight modifications. Three new types of

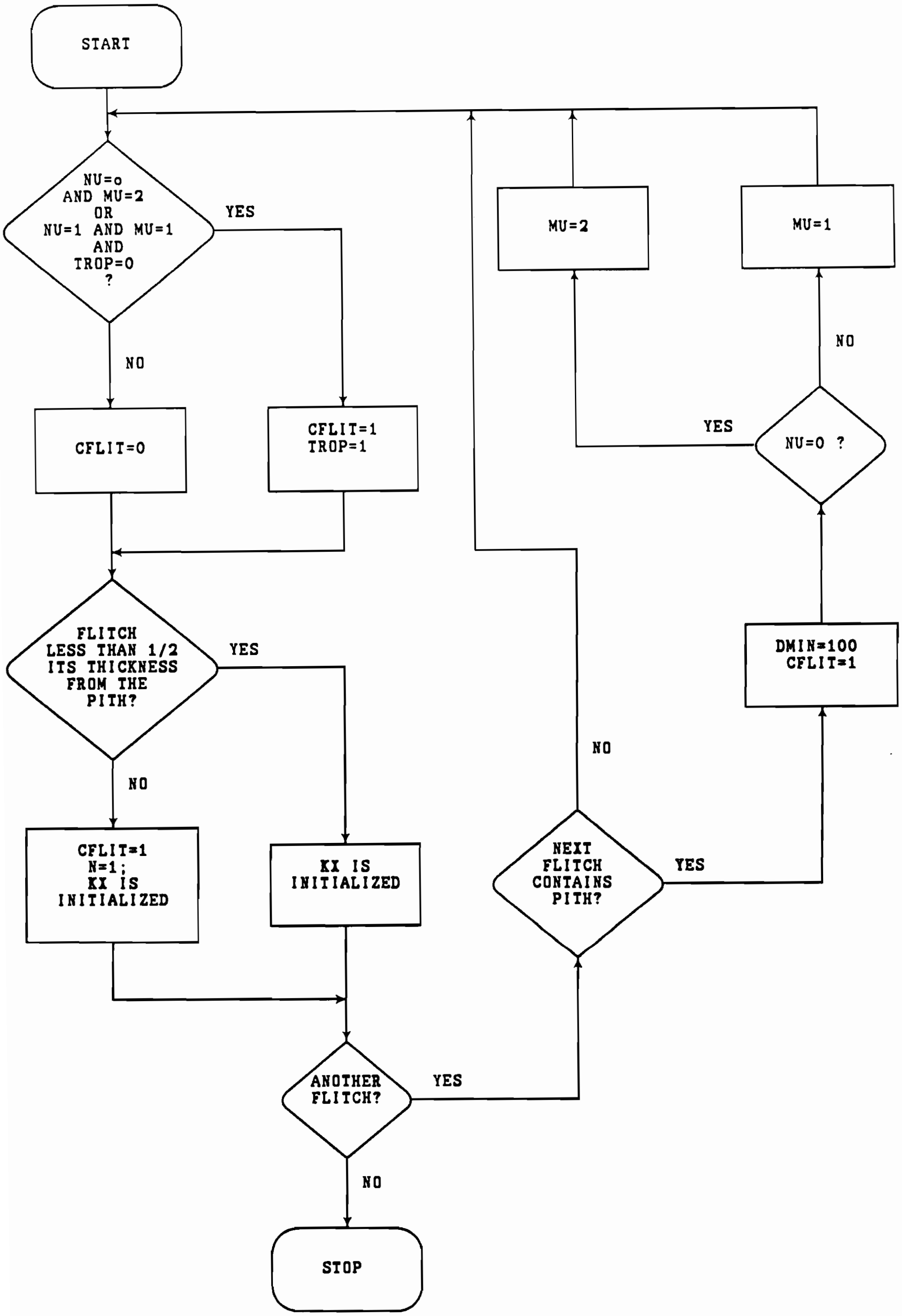


Figure 10. Flowchart showing how the two flitches closest to the log's center are determined.

boards exist: the 1/2-tally pieces, the commercial boards and the full-tally pieces with wane which have a nominal value lower than their counterparts free of wane. The piece count is also done when computing the flitches' values, and new types of piece counts were added especially to increase the information given in the output. Besides the regular piece count that keeps track of the length and width of each board, the number of pieces in each category of pencil stock is saved. These include full-tally free of wane, full-tally with wane, 2/3-tally and 1/2-tally, respectively named TFT, NWP, NSP and NNP. The value of each board is also multiplied by two factors given in subroutines ANGLE and DENSITY. These factors are functions of the board's angle and density categories. Their computations are explained in detail in the sections where subroutines ANGLE and DENSITY are discussed (Sections VI-C-1 and VI-C-2).

The value and piece count of a 1/2-tally piece are computed the same way as for a 2/3-tally piece. A 2/3-tally piece is itself computed as the "extra narrower" piece of the original program. For both types of boards, the piece count for the board category and the factor corresponding to the angle and the density class were added. For the 1/2-tally piece, NUMS represents the angle factor and NUMSD the density factor. For the 2/3-tally piece, the variables are respectively NUML and NUMLD.

When a commercial board is present in a flitch, its value is computed separately from the rest of the studs but with the same procedure. When COM is 0, the commercial boards are 6 inches wide and the variable KX representing the width in the arrays LUMBER, PRICE and PIECES is set to 15. If COM is 1, then the commercial boards are 8 inches wide, and KX is set to 16 (Section VI-B-2-e), the variable characterizing the number of studs and the presence of a commercial board in a flitch is WIDE. The values of WIDE are the ones defined in the array TEST (Section VI-B-2-h), they belong to three distinct ranges of values corresponding to solely studs, studs and a 6 inch commercial board, or studs and an 8 inch commercial board. To compute the studs' values when a commercial board is in the flitch, WIDE must be decreased by a certain amount in order to be in the TEST range representing boards containing only studs. In the array TEST, the 30th element represents a flitch containing a 6 inch commercial board and two studs. To consider only the studs, WIDE must be reduced to 27 in order to have a value 3 corresponding to a flitch with two studs (Table 2). The same amount of 27 must be subtracted when more studs are present. In the same way, 8 inch commercial boards start with the 41st element in the array TEST, and WIDE must be reduced of 38 in order to have a value 3.

The new variable representing only the number of studs in a flitch is LX. In fact, since a value one for LX represents a full length 2/3-tally piece (Table 2), then a value of LX greater than one represents the real number of full-tally pieces in a flitch plus one. The volume of all the studs in a flitch is first computed. For this, it must keep track of studs with wane. If the variable WANE was entered as 0 by the operator or if SCIE is 2 (Section VI-B-3-d), then no wane is allowed on any studs. Also, if LX is 1, then the flitch contains only a full length 2/3-tally piece with no wane by definition. When all of the above conditions are not fulfilled, the variable KLX takes the same value as LX, and MUL, representing the number of studs with wane, is 2. If PERTE is 1 then there is wane on two studs in the flitch. There is an exception when only one stud fits in the whole flitch. Then LX is 2, and since only one stud can have wane, MUL is set at 1. Also if LX is 3, there are only two full-tally pieces, both containing wane; thus KLX must be set to 2 so that the element of LUMBER representing the full-tally pieces is 0.

The flitch's volume, BOARD, is the product of the board's transverse section and length. The transverse section of a stud with wane is LUMBER(1,1), representing a 2X3, times MUL, which is the number of pieces with wane. The area of the full-tally pieces is LUMBER(KLX-2,1), where KLX-2 represents the total number of studs in the flitch minus the two studs containing wane. If LX is 2 or 3, then in both cases KLX is equal to 2 as explained above. If PERTE is 0, there is wane on only one stud in the flitch. Then to compute BOARD, the factor MUL is not needed since it is equal to 1, and KLX-2 in LUMBER becomes KLX-1.

Once the volume is computed according to the above conditions, the value is obtained by taking into account the stud's price and the value factor function of the angle and density class (respectively, WANGLE and WDENS). The piece count is done following the same scheme as for computing the volume. When adding the number of full-tally pieces of a flitch to the number of pieces of the previous flitches, the variable LX is used. When 2 studs have wane, the numbers of studs free of wane is LX-3. When 1 stud has wane, the numbers of studs free of wane is LX-2. When all studs are free of wane, then the number to be added is LX-1.

C. ADDITIONS TO BOF.

As stated in the objectives section, the changes being made to program BOF have been to facilitate the inclusion of ring angle and density analysis in the log breakdown optimization process. Many similarities will be found between the way ring angle and ring density are computed. While the equations are different, most of the algorithms are alike, and the general patterns are the same. Once the boards in a flitch are defined in subroutine SAW, they are sent first to subroutine ANGLE and then to subroutine DENS. There, a factor is given to each board within the flitch according to the angle or density category. If the angle or/and the density options are not set, the subroutines are not called.

1. Angle calculation.

The angle classification process can be divided into several distinct steps (Figure 11). Board width is computed at the small-end of the log; ring angle and ring density are then computed at the log's large-end. Therefore, the positions of the boards at the large-end need to be computed. This is the first step after setting the variables to their default values, and then the ring angle of each board in the flitch is computed. If squares are sawn, boards can be oriented and are classified in only two categories. A special part deals with this aspect. When a certain amount of lower grade is allowed in a board without it being downgraded, the program looks at the possibility to upgrade each board before saving its angle class. If present, the commercial board is then positioned correctly within the flitch. The 2/3-tally and 1/2-tally boards are then classified, and for both cases the possibility of upgrading is checked as for the full-tally board. The central flitch when sawing rectangles in subroutine ANGLE is considered separately, since all boards there will have the lowest angle and thus fall in the lowest class.

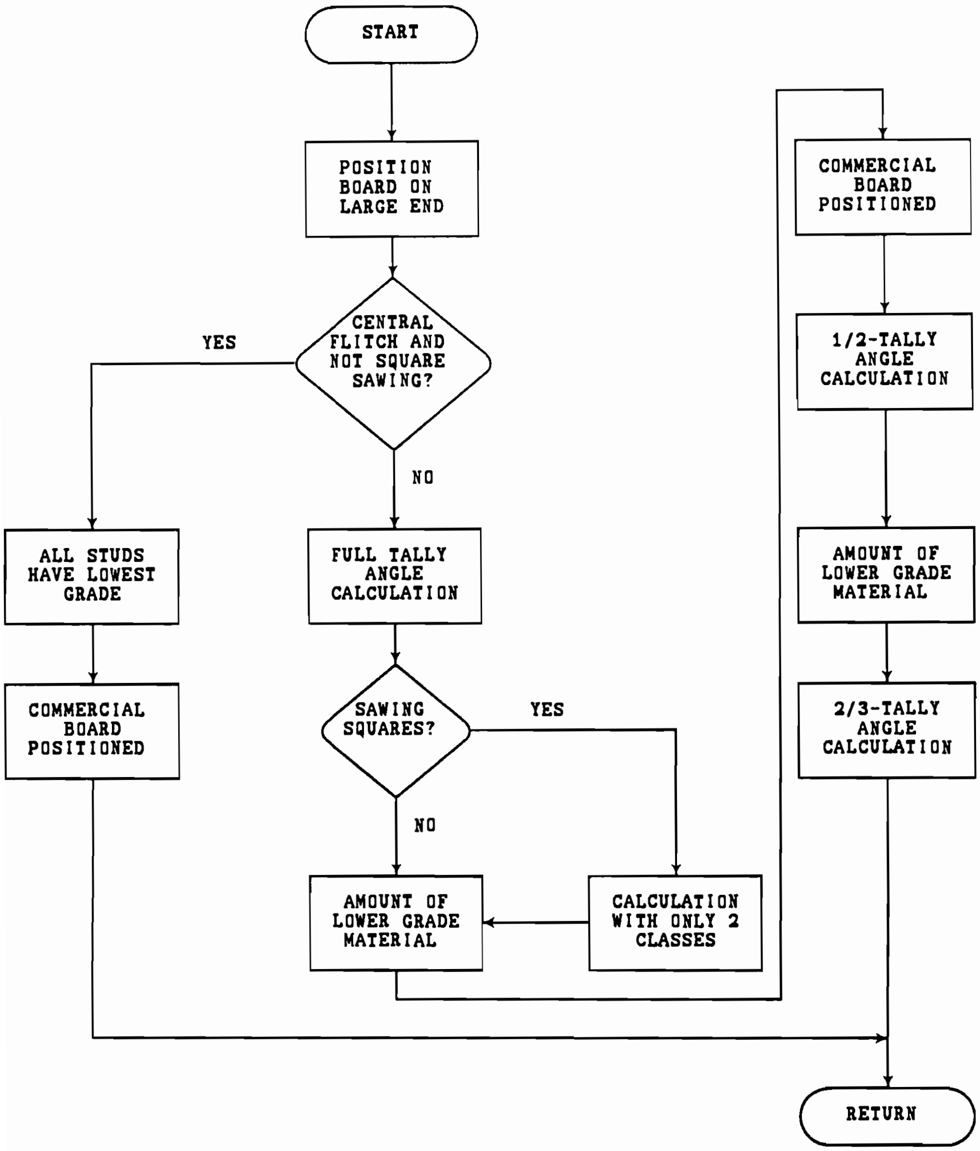


Figure 11. Overall flowchart of subroutine angle.

a. <u>Starting subroutine ANGLE</u>. Subroutine ANGLE is called from subroutine SAW after finding the widest board fitting in the flitch and before computing the value of the board. ANGLE is called only if the variable ANG is 1. ANG itself is defined in the subroutine INPUT and depends on the values of ALPHA and BETA. These two variables are entered by the operator; they represent the angle limits for each category. ALPHA is the limit between first and second class while BETA is the limit between second and third class. ALPHA and BETA are entered in the subroutine INPUT in units of degrees but are immediately changed into radians. When at least one of the two variables ALPHA or BETA is different than 0, then ANG is 1 and the subroutine ANGLE called.

b. <u>Position of the board at the log's large-end</u>. The variables REDGE and RFACE have the same values as the variables EDGE and FACE which are measured at the small-end in the subroutine SAW as defined in Section VI-B-3-b. The reason for using REDGE and RFACE is that once the widest flitch fitting in the log's small-end is found in subroutine SAW, investigations are made to find if a shorter 2/3-tally board could also be recovered. The values of FACE and EDGE change accordingly to represent wider flitches. However, the board was positioned within the flitch according to the log's small-end. Thus the small-end widths are needed also to position the board at the large-end. In subroutine ANGLE, the variable EDGE is used again and is given the small-end flitch's width, REDGE. If PLUS is 1, then the flitch's face width is the limiting factor (Section VI-B-3-b); thus, the flitch's edge width is the face's width added to the maximum amount of wane allowed:

```
EDGE = RFACE + GREEN(4) * WANE(2)
```

When the board is free of wane on both sides, then EDGE has already been given the value of FACE in subroutine SAW and thus no changes are needed (Section VI-B-3-d).

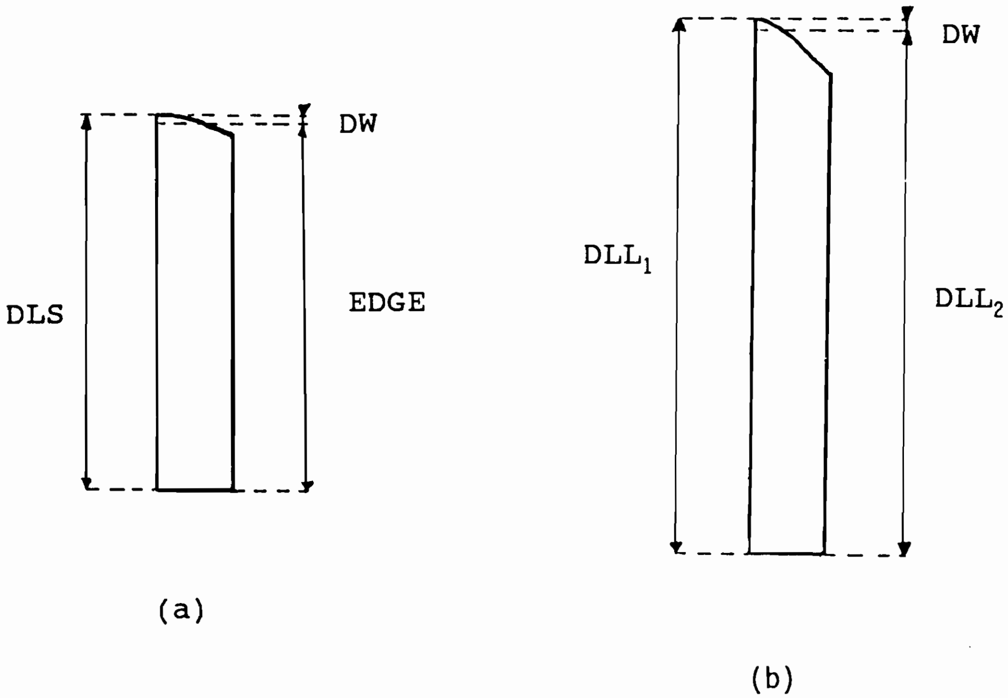
The distance of the flitch to the center of the log, D, is given in subroutine SAW considering the outside face of the flitch. Because the ring diameters get smaller near the pith, the inside face closest to the center is needed to compute the ring angle. The distance from the pith to the inside face of the flitch is D increased by the flitch's thickness, THICK. The sawkerf, KERF, must be subtracted from THICK which includes the sawkerf by definition:

$$D = D - THICK + KERF$$

At the log's small-end, the boards were positioned in a flitch according to the value of PLUS (Section VI-B-3-b). Once a board is positioned, the distance of the first sawline from the fence must be kept constant over the whole length of the board. DLL is the half width of the flitch at the large-end; DLS is the half width of the flitch at the small-end. The distance from the edger's fence to the first sawline is DW, and is the same for both the small-end and large-end (Figure 12). However, the variables used to calculate DW depend upon which end is being analyzed. The value DLL (Figure 12) of all flitches is saved in the array SADL for later use in drawing the log.

c. <u>Angle</u>. The case where rectangles are sawn and the flitch contains the log's center is treated separately in VI-C-1-i.

1'. <u>Principle of calculation</u>. Olson (25) developed a method for calculating the amount of quarter sawn material in a board according to its percentage. The difference between his application and this model is that a board must be free of lower grade material in order to



(a)

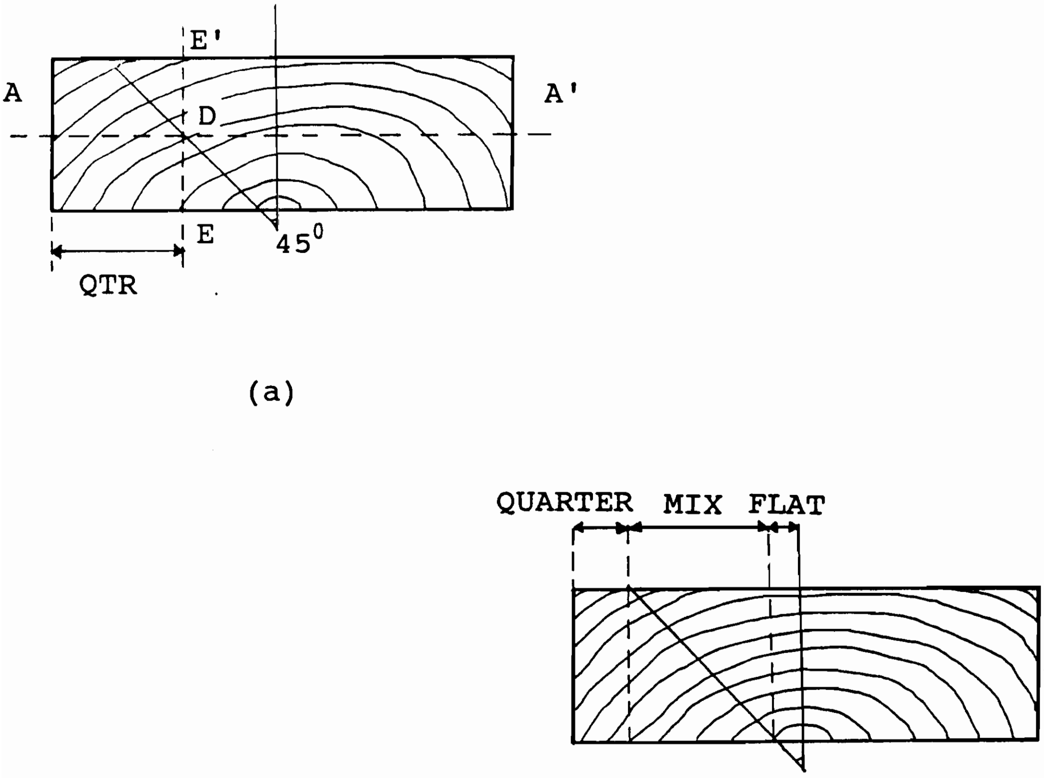
(b)

Figure 12. The distance DW from the fence to the first sawline is the same at the log's small-end (a) and large-end (b).

be classified in a higher grade. Olson draws a line perpendicular to the growth ring with a 45° angle being the limit between quarter sawn and flat sawn material. The intersection of this line with a line representing the mid-thickness of the board represents the limit of quarter sawn material in the board (Figure 13a). This is equivalent to an area. Some quarter sawn material is found beyond that point and some flatsawn material is found before that point, both of which are incompatible with the requirements of this study. To have the real width of the board free of quarter sawn material, the line perpendicular to the ring must intercept not the flitch's center line but its inside face. This point of interception defines the boundary between two classes of boards. For this study, the highest grade pencil stock are the ones closest to flatsawn (Figure 4). The board's face to be considered is the one closest to the center of the log. In the opposite case, where quarter sawn material would have more value, the face farthest from the pith should be considered (Figure 13b).

There are two angle limits for the model, and they are left as variables. An example is given in Figure 14 for only one angle limit, but the two angle limits follow exactly the same principles. Figure 14a shows a flitch at a distance D from the center of the log of half width DLL. The angle a ring makes with the face of the flitch closest to the pith is α . Class 1 has an angle greater than α ; class 2 has an angle smaller than α . In this case, class 1 would have a higher value than class 2.

Knowing D and α , the width of the portion of the flitch that contains class 1 can be found and is called DA1. DAK, it's complement, is the width of the flitch containing class 2. Once the proportions of class 1 and class 2 are known, the flitch is sawn into pencil stock



(a)

(b)

Figure 13. Calculating ring angles.

a. Olson's method (23) gives the percentage of quarter sawn material.
   - AA' is the center line
   - D is the intersection of a 45^o line with the center line
   - Some flatsawn material is at the right of the line EE'

b. The model in this thesis requires each board be free of lower grade material. Therefore, the limit is the intersection with the flitch's face.

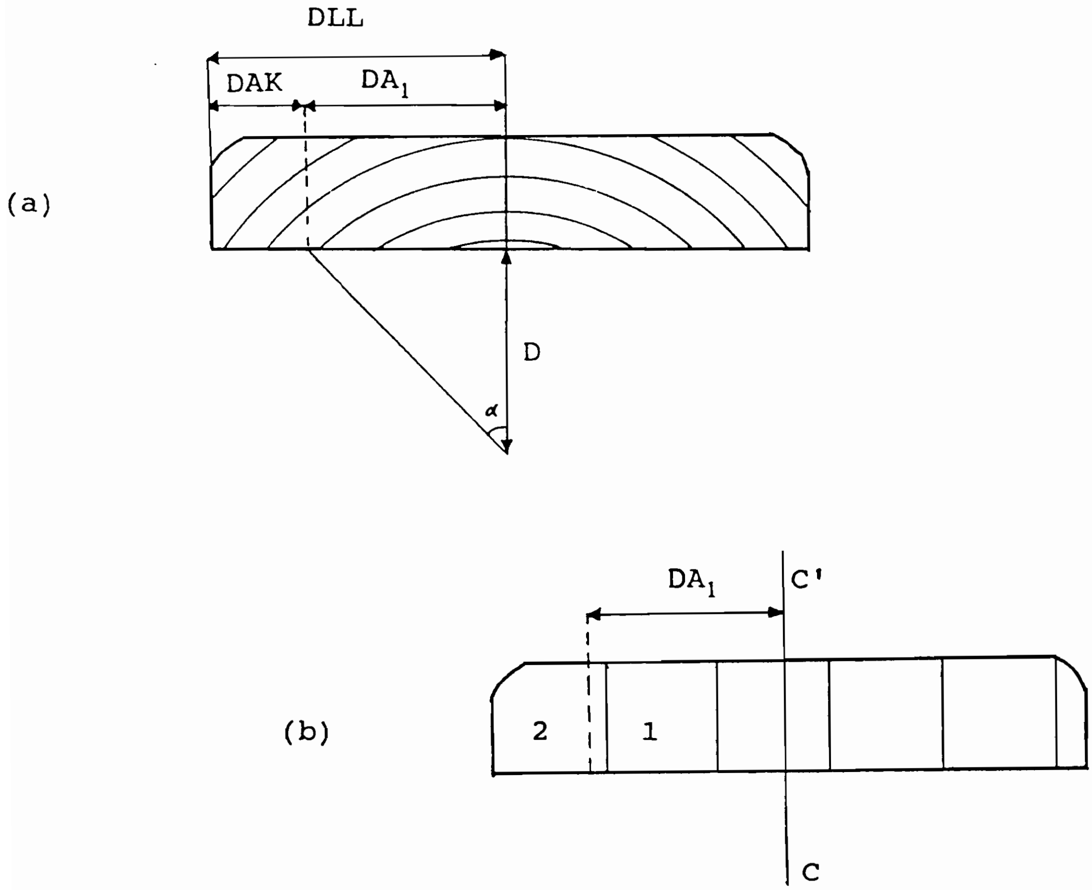


Figure 14. Ring angle classes.
a. Principal of determining the ring angle in a board.
.Alpha is the angle limit
.D is the distance from the pith to the flitch's face closest to the center.
.DLL is half the flitch's width
.DA1 is the width of class 1 material
.DAK is the width of all other material
b. If a board overlaps a class's limit, it takes the lowest class value.
.Because DA1 is half the width of the flitch containing only class 1 material, the second board will contain both class 1 and 2 material but will be considered to be class 2.

(Figure 14b). Each board can be classified according to its distance from the center line C-C'. If one board overlaps the limit between the two widths DAK and DA1 (Figure 14b), it will be classified in the category having the lowest value.

2'. Algorithm. Ring angles in pencil stock are measured between the growth ring and whichever edge is in the direction of the slat's sawline. In the example described in Section VI-C-1-c-1', the angle was measured between the growth ring and the flitch's face (Figure 14). Using the same procedure, the width of class 1 in a flitch is:

DA1 = D * TAN(PI/2-ALPHA)

and the width of class 2 when not considering class 1 is:

DA2 = D * TAN(PI/2-BETA)

The first pencil stock considered is on the flitch's edge used to position the board at the log's large-end. The first value of DAK is the distance from the board's edge DLL to the limit of class 2, DA2 (Figure 15). K, which defines the class of a pencil stock, is first set at 3 at the beginning of each flitch. A value of 3 represents the lowest class and 1 the highest. A negative value for DAK means that the limit of class 2 is outside the flitch; thus, no class 3 will appear in this flitch. Then K is set to 2, and DAK now represents the distance from the board's edge DLL to the limit of class 1, DA1. Once again, if DAK has a negative value, then the limit of class 1 is outside the flitch. All the boards in this flitch would then fall within the limits defining class 1 and thus be saved in the highest category, with K set at 1 (Figure 16). When DAK is positive in either of the two cases, the position of the pencil stock is compared to the limits defined by DA1 and DA2.

The distance from the pencil stock's edge farthest

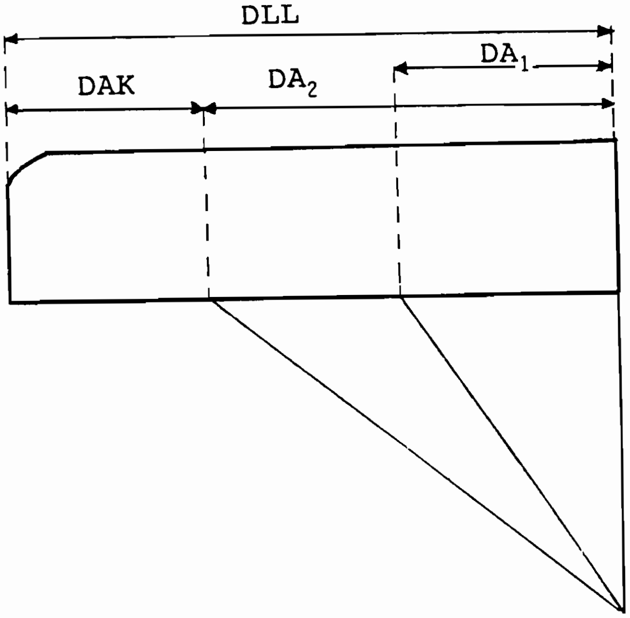


Figure 15. Widths DA1, DA2 and DAK for half a flitch.
DA1: limit of class 1
DA2: limit of class 2
DLL: half the flitch's width
DAK: distance from the limit considered to the flitch's edge.

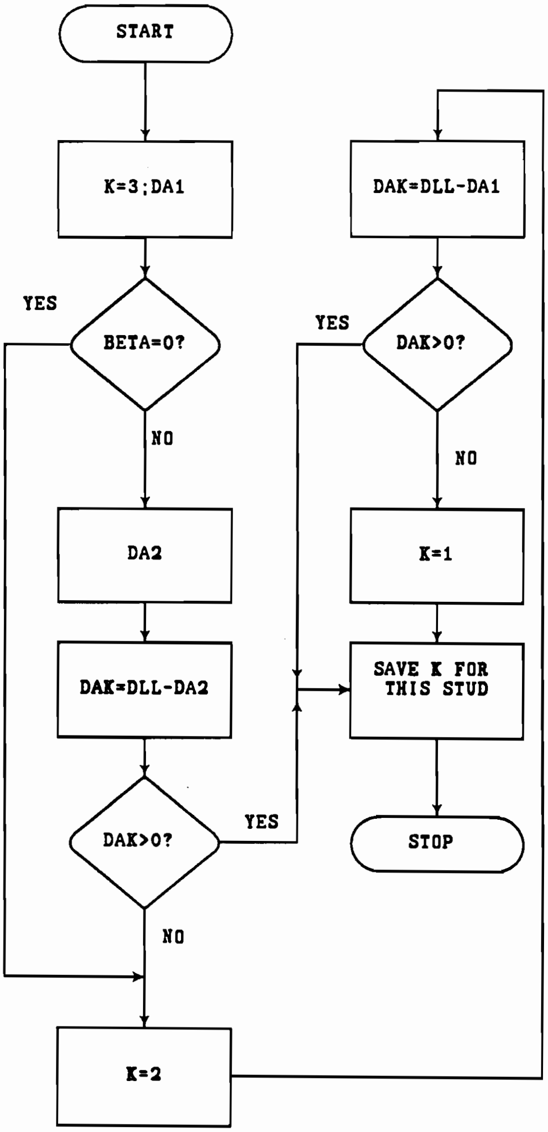


Figure 16. Flowchart giving the correct class K.

from the center to the flitch's edge is ESTEST (Figure 17). The variable ESTEST is a function of TEST as defined in section VI-B-2-h. TEST is renamed RTEST in subroutines ANGLE and DENSIT because its value may be changed during the computations in these two subroutines. When a flitch contains a commercial board, the width ESTEST of the boards before reaching the commercial board is a function of TEST with no commercial board. Once the commercial board is reached, the variable JIL has the value 1, and ESTEST becomes a function of TEST with a commercial board (see Table 2). Since RTEST is the distance from the flitch's edge to the pencil stock's second edge, the width of a full pencil stock must be subtracted from RTEST to find ESTEST when the flitch's center has not yet been reached. The center of the flitch is passed when NSENS has the value 1 (Section VI-C-1-f); when this is the case, then ESTEST is just equal to RTEST. When ESTEST is less than DAK, then the last pencil stock represented in ESTEST is at least partially within the limit of the angle class limited by DAK. The last pencil stock takes the value of K associated to this class. If ESTEST is greater than DAK, then the value of K is reduced by one, which means a higher grade. The width DAK is then given the value corresponding to the limit defined by the next angle class. Three cases may occur: the value of DAK can be lower than, equal to, or greater than the flitch's half width DLL. When DAK is lower than DLL, the width DA2 and then DA1 must be subtracted from DLL. When DAK is equal to DLL, the width DA1 must be added to DLL. When DAK is greater than DLL, the width DA2 must be added to DA2. This progression gives a constantly increasing value for DAK to which ESTEST is compared (Figure 18). When the flitch is close enough to the pith, it may occur that the width DA1 is close to 0. In this case, if DAK is equal to

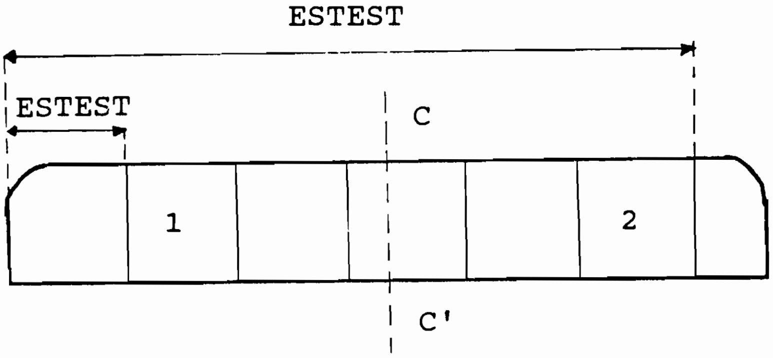


Figure 17. Illustration of the distance ESTEST for a board when the board is before the center line CC' (1) or after the center line (2).

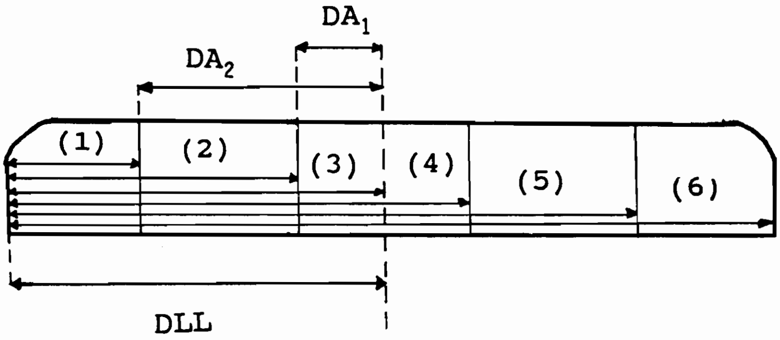


Figure 18. An example showing the different values of DAK.

(1)	DAK=DLL-DA2	class K=2
(2)	=DLL-DA1	K=1
(3)	=DLL	K=1
(4)	=DLL+DA1	K=1
(5)	=DLL+DA2	K=2
(6)	=DLL+DLL	K=3

DLL, the value DA2 should be added to DLL instead of DA1 to avoid having an endless loop. If DA2 also has a value close to 0 for the given flitch, then the whole flitch has the lowest class value 3 (Figures 19a and 19b).

d. Squares. The option of sawing squares instead of rectangles is the choice of the operator. The variable SQUAR set at 1 indicates that square, full-tally pieces are sawn. If SQUAR is not set, then rectangles are sawn. It is necessary to indicate which types of full-tally pieces are sawn in order to classify them appropriately. When squares are sawn, only two angle classes are used. A board of class 3 with the rectangle classification process can not merely be changed to a class 1 board if squares are sawn. A board that contains just a small amount of class 3 and the rest in class 2 would then be changed to a class 1 even though it contains some material of class 2. This is not possible according to the assumption made that a board must be free of lower grade material.

Such boards are thus classified in a different way than were the rectangles. Any square material is first classified as if it was a rectangle. Then, only if the option SQUAR is set to 1 and if the board has an angle class of 3 does a modification occur. Any board in class 1 or 2 does not change class. For squares, the highest grade in a flitch beside the boards closest to the flitch's center will be situated in the boards farthest from the center. For these boards, the edge closest to the flitch's center and on this edge the corner farthest to the pith must be considered. The edge closest to the center is given by RTEST before the flitch's center is reached and by subtracting the width of a full-tally piece from RTEST once the center is passed.

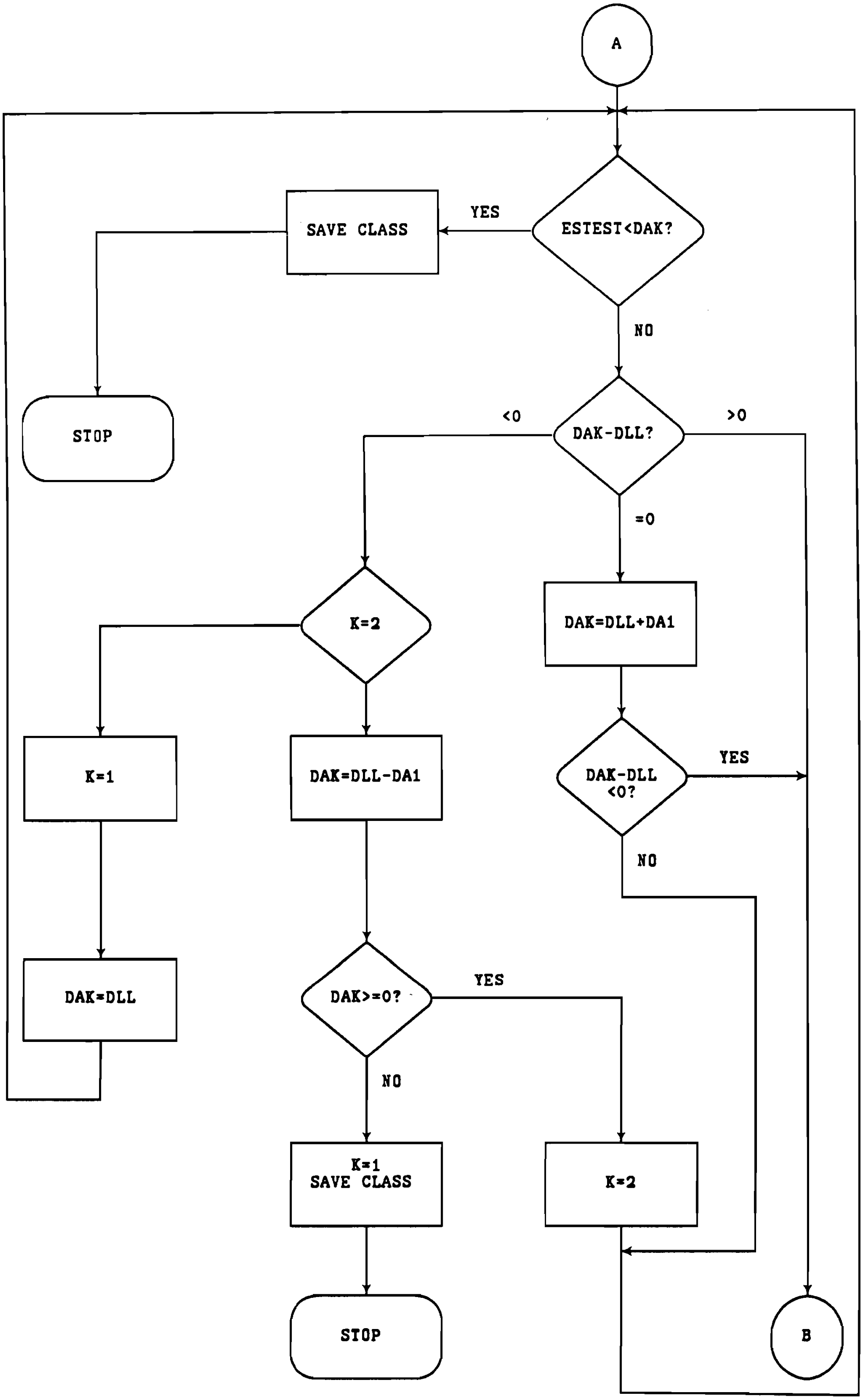


Figure 19a. Flowchart of the class computation.

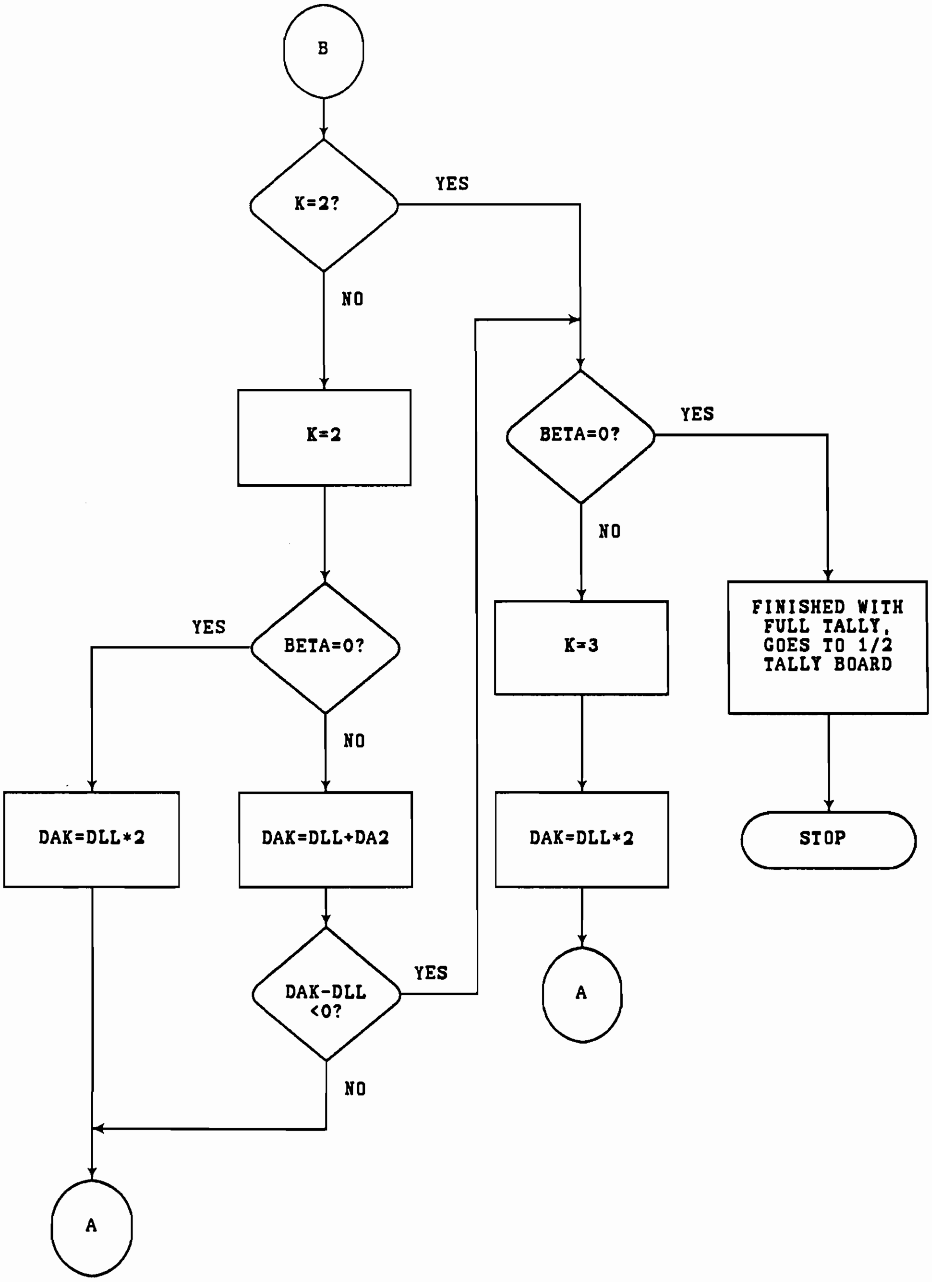


Figure 19b. Flowchart of the class computation (continued).

This is opposite from what is done when rectangles are sawn. The limit DAK is given for the flitch's face closest to the pith. However, the board's width to consider here is the one on the flitch's opposite face. To be able to compare both on the same basis, the value MOINS is added to the board's width ESTEST. The variable MOINS represents the base of a triangle whose height is the thickness of the flitch, THICK, and of angle BETA (Figure 20). It enables the comparison of both DAK and ESTEST on the same face. The distance DAK is given from the flitch's edge to the limit between class 2 and 3. If ESTEST is greater than DAK, then the last board in the flitch considered has some material in class 2 and is thus given an angle class of 2. Once the flitch's center is passed, the variable MOINS is subtracted instead of added to ESTEST. In this case, if ESTEST is smaller than DAK, then the last stud in the board considered has some material in class 2, and is thus given an angle class of 2 (Figure 21).

The central flitch containing the pith is a special case. In this flitch, for square sawing, the distance D from the pith to the flitch's face is given directly for the farthest face from the pith. DA2 is thus also given for the farthest face, and MOINS is set to 0.

It was pointed out that the classes of boards are first computed as for rectangles. A board is first given the class value of the previous board, and this value then is decreased (or increased if NSENS is 1) according to the value of DAK. In the case of squares, a board of class 1 may be followed by a board of class 2 when NSENS is 0. The number of the class is thus increased instead of decreased, which is incompatible with the algorithm.

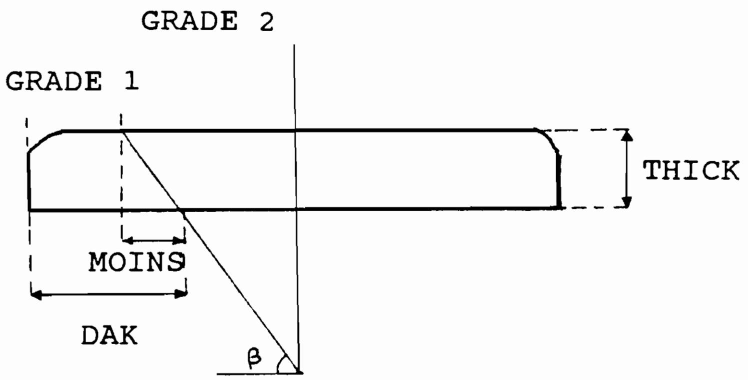


Figure 20. The variable MOINS is used when squares are sawn. The flitch's face considered must be the external face.
MOINS = THICK/TAN(BETA)
THICK: thickness of a flitch
BETA: angle limit between class 2 and 3.

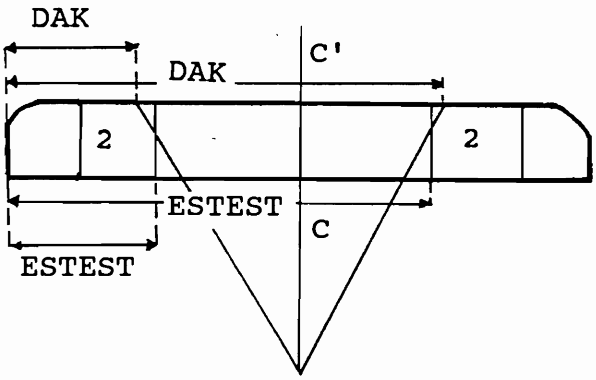


Figure 21. Classification of squares on both sides of the central line CC'. At right, if ESTEST>DAK, the stud's class is 2. At left, if ESTEST<DAK the stud's class is 2.

Thus, each board that is first classified as a class 3 prior to being treated as a square is characterized by the variable PERM which is set to 1. When the next stud is analyzed, a value 1 for PERM indicates that the class search must start with a value 3 for K.

e. Area. This option allows a certain amount of lower grade material to be present in a board before downgrading it. The maximum amount of such material allowed in a board is entered by the operator as a percentage of the board's transverse section and is given the name PER. Given the width and thickness of a board, the end area, SURF, of lower grade material allowed is found.

The actual end area of lower grade material in a board is then computed for comparison to SURF unless K equals 1. In that case, the whole board is in class 1 grade and can thus be saved as is. Otherwise, the actual end area of lower grade material is calculated in one of four ways, depending upon the values of PERM and MOINS as well as whether the boards being sawn are squares (Figure 22) or rectangles (Figure 23). Figures 22 and 23 illustrate the calculation of BASE, which is the maximum width of the lower class area in the board. In these examples, the boards overlap classes 2 and 3. The same equations are valid for boards overlapping classes 1 and 2 if DA1 is substituted for DA2.

The area of lower grade material is the triangle defined by the width BASE and the angle BETA (or ALPHA), and is calculated using the equation

AREA = (BASE**2) * TAN(BETA)/2.

It may happen that the base of the triangle exceeds the width of a board or that the height of the triangle exceeds the thickness of a flitch. Such occurrences take place when the amount of material in the lower grade

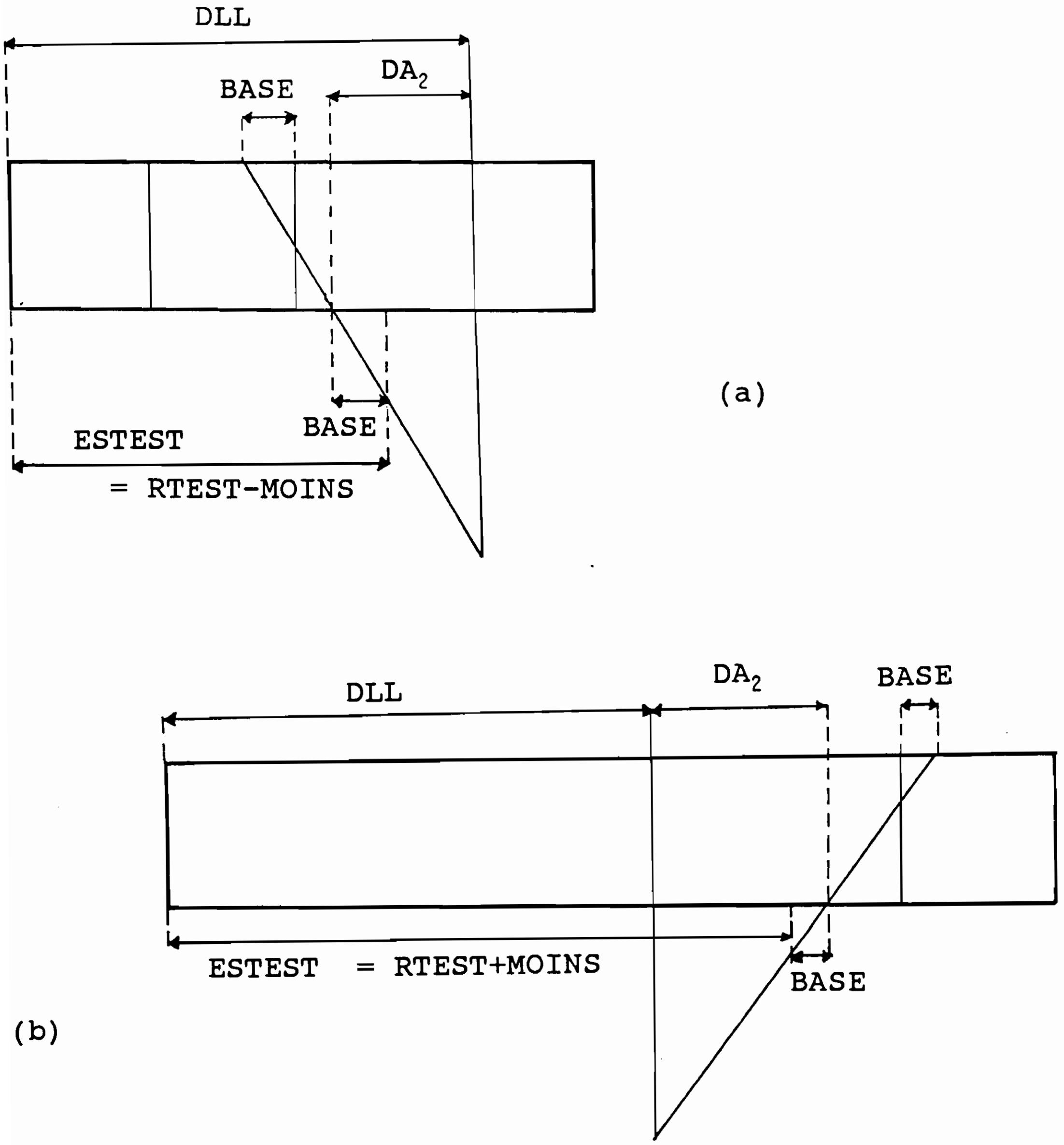


Figure 22. Computation of BASE, the maximum width of the board in the lowest class when sawing rectangles.

a. MOINS=0 so the board is before the center and BASE = ESTEST + DA2 - DLL.

b. MOINS=1 so the board is after the center and BASE = (DLL + DA2) - ESTEST.

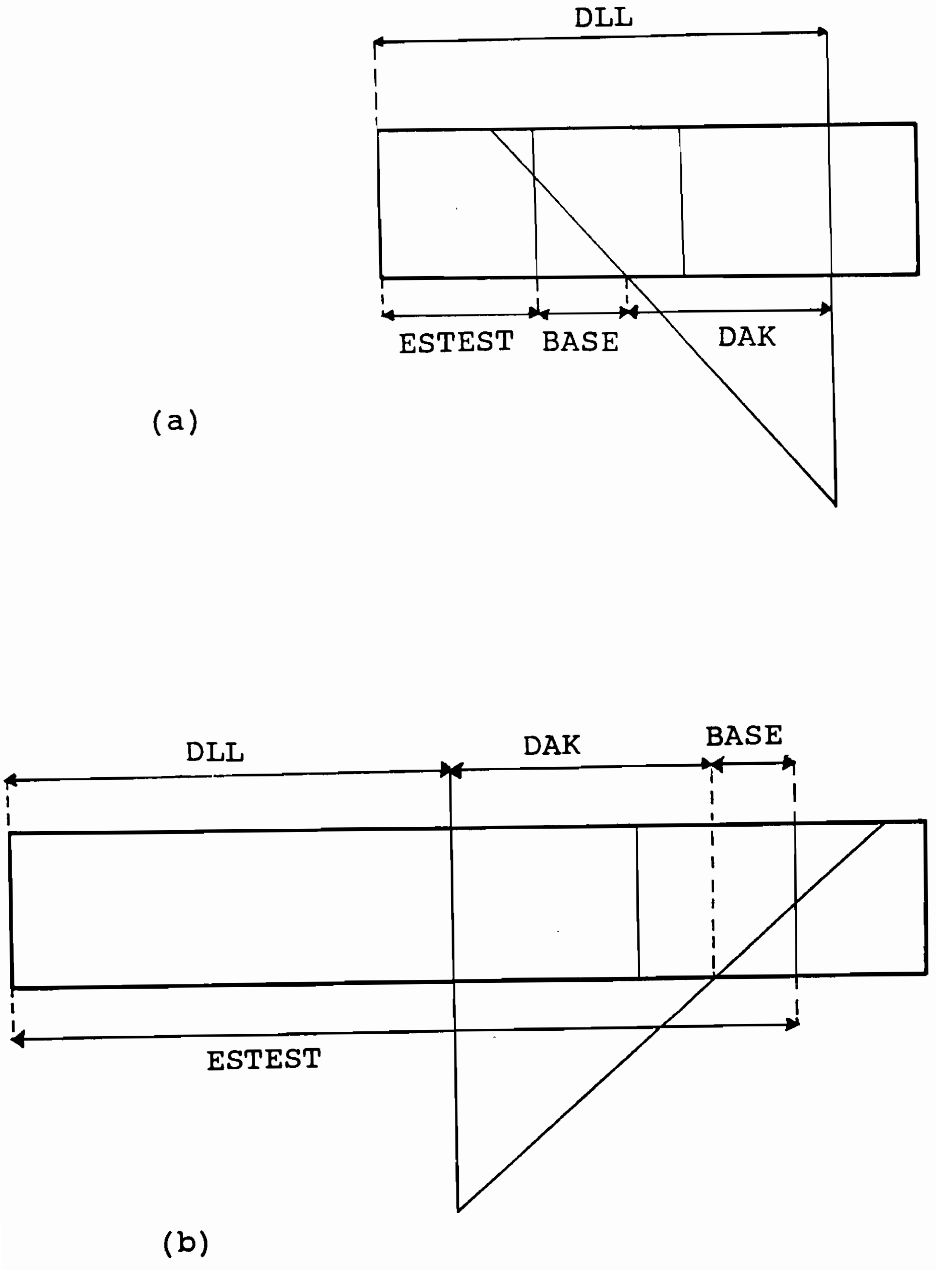


Figure 23. Computation of BASE, the maximum width of the BOARD in the lowest class when sawing squares.

a. MOINS=0 so the board is before the center and BASE = DLL - DAK - ESTEST.
b. MOINS=1 so the board is after the center BASE = ESTEST - DLL - DA2.

greatly exceeds the limits used for this study. These types of boards remain in the lower class.

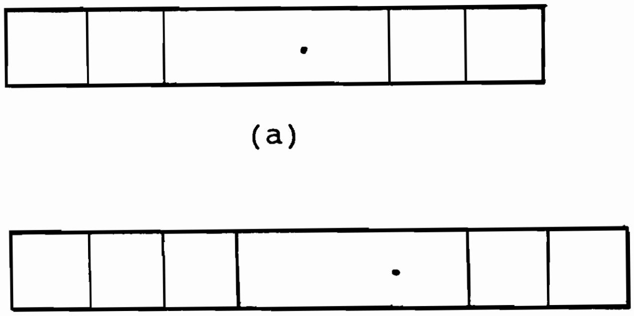
If the computed AREA is less than the SURF allowed, then the board is given a better class by subtracting 1 from K. The class of the board is then used in two places. It is used in the calculation of the number of boards of that particular class in a flitch, NUM(K), which in turn is used to compute the flitch's value. The other place it is used is in the printout of the class of all the boards in the log. This is done by keeping track of the flitch and board in array ORDER(FLI,COMP), where FLI is the flitch number and COMP is the board number.

f. Commercial boards. Flitches containing a commercial board were determined in subroutine SAW which was discussed in section VI-B-4-c. The position of a commercial board, which was of no use until now, was left unknown. Even though a commercial board is not classified according to its ring angle, its position is now critical in determining the positions of all the other boards so that their ring angles can be determined. The program starts looking at the board on the flitch's edge and then successively adds a new board to the previous ones once the ring angle class is found. On flitches without a commercial board, the process continues until all the boards of the flitch are classified.

The process is more complicated when a commercial board is present in a flitch. It is the same until the commercial board is reached, at which point the whole width of a commercial board must be added to the previous width and the process resumed by again adding successive boards. However, the commercial board must be centered as much as possible on the log's large-end. To start with, a good approximation when the total number of studs in the flitch is even is to have the same number of boards on both sides of the commercial board. However, if this total is an odd number, the side where the ring angle computation is started has one more stud than the other side (Figure 24). This choice was made since the boards and commercial boards are positioned according to the log's large-end diameter but the number of boards in a flitch depends on the log's small-end diameter. At the large-end, all the boards will have the tendency to be shifted to one side. This combination of boards on both sides of the commercial board is just a starting point to look at the commercial board's position. High taper or long logs may require shifting some boards from the flitch's second half to its first half. The distance from the commercial board's edge to the flitch's center is checked to be sure it is in the most centered position. Otherwise, a board is moved from one side of the commercial board to the other side, its angle computed, and the process started again.

If COM is less than 0, then no commercial board is present in the log, and the whole section dealing with commercial boards is skipped. In a similar way, if CFLIT is not 1 then the flitch studied contains only boards, and the section is skipped as well. Also, a value of 1 for CENT indicates that the commercial board has already been positioned, and there is no need to go through the same section again.

When none of those three conditions mentioned is satisfied, then the commercial board is considered. The variable SKX is a function of the number of boards in a flitch. When a commercial board is also present, SKX takes on a higher value (Table 2, page 40) based on the width of the commercial board. To keep track of the number of boards remaining on one side of the commercial



(a)

(b)

Figure 24. Position of the commercial board according to the number of boards in a flitch where
(a) has an even number and (b) an odd number of boards around the commercial board.

board, the variable BSKX is calculated by subtracting from SKX either 27 for 6 inch commercial boards or 38 for 8 inch commercial boards. If the number of boards already classified, J-1, is less than or equal to half BSKX, then half the studs have not yet been considered. The program then classifies the next board, and this continues until at least half of them are classified. When half the boards of a flitch are classified, CENT takes the value 1, indicating that the commercial board is reached. JIL, which represents the number of the piece treated, is then J-1.

The array CTEST, which is used to draw the log's sawing pattern, is also then computed. CTEST is the width from the flitch's edge to the end of the commercial board. It is the sum of the width of the boards previously classified and the commercial board's width. The sawkerf and sawing allowance are also added as was the case when computing the elements of TEST in the main program BOF.

The program then verifies whether the commercial board is well centered. The absolute value of the distance from the commercial board's edge to the center is compared to the absolute value of the distance from the center if one more board is added to that side (Figure 25). If the former distance is greater than the latter distance the commercial board would be better centered if the extra board is added before the commercial board. Obviously, it must also be checked that the total number of boards fitting in the flitch is then not exceeded. When these two conditions are simultaneously present, the variables CENT, JIL, and CTEST are reset to 0, indicating that the commercial board has not yet been positioned. If one of the two conditions is not true, then the position of the commercial board is saved (Figure 26). The class given

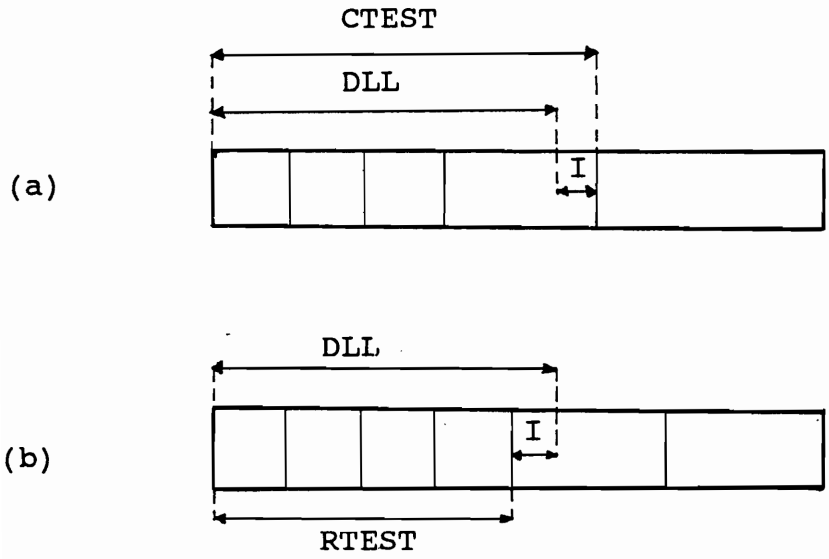


Figure 25. Distance I from the log's center to the commercial board's edge before (a) and after (b) one more board is added to one side of the flitch.

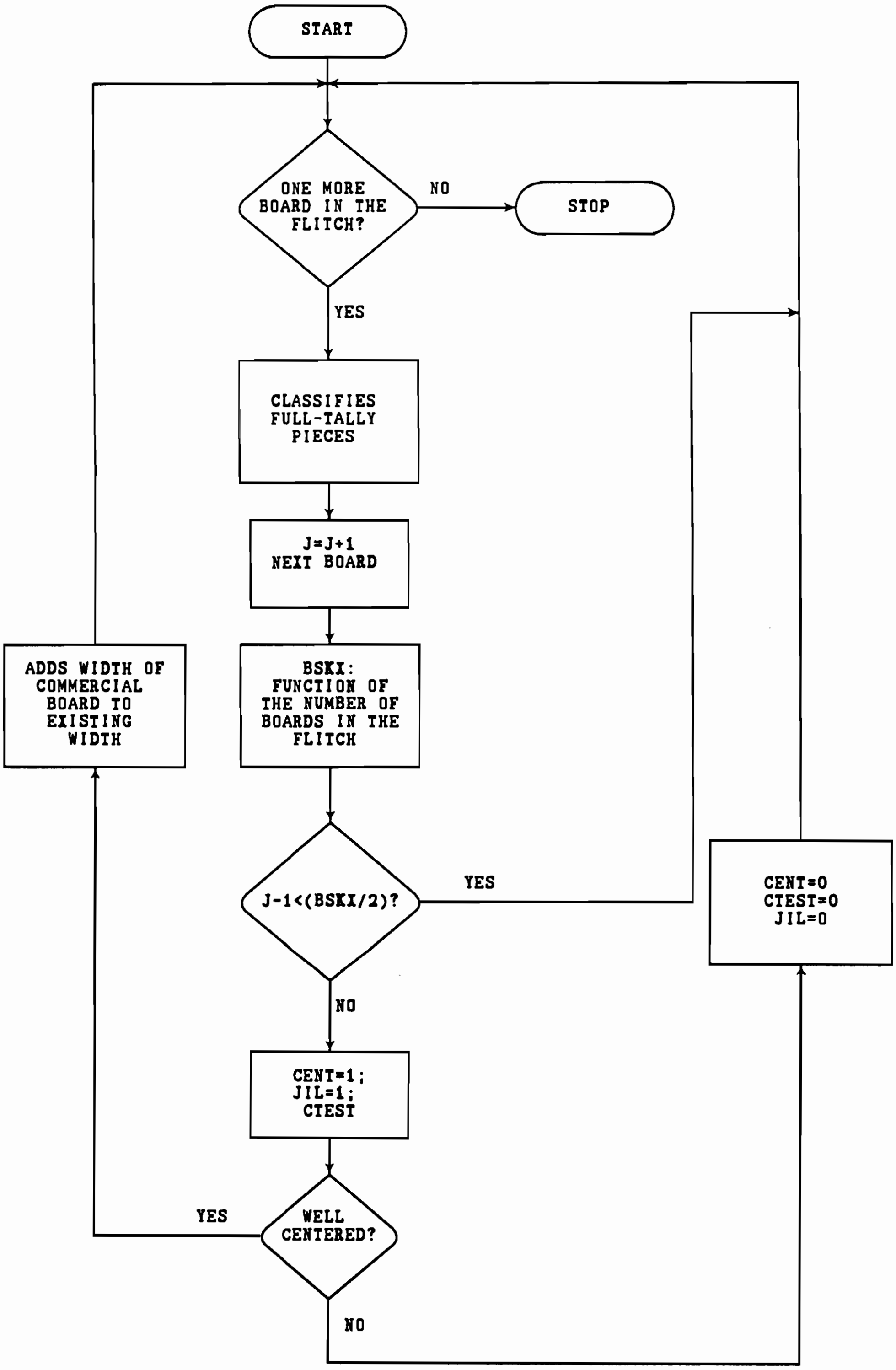


Figure 26. Flowchart for positioning the commercial board.

for printout purposes is 0, indicating the presence of the commercial board. The commercial board may overlap several of the points defining the limits between angle classes. This may disturb the regular procedure for classifying the next boards, which requires a regular progression in the value of DAK and of K. Since the flitch's center is passed, DAK and K are reinitialized as if starting from the center.

g. Passing the flitch's center. As for a commercial board passing through the flitch's center, a board that encompasses the flitch's center may overlap several of the points defining the limits between angle classes. Such a case occurs when the last board's edge is past the flitch's center which makes it also the first board on the right side. Passing of the flitch's center is indicated by the value of NSENS. It is an important feature, since it changes the way the measures are made to calculate the angle class. The default setting of NSENS, before the center is passed, is 0. When the edge of the last board classified passes the center, NSENS takes the value 1. When the flitch contains a commercial board, then the commercial board's edge must be past the center to have NSENS equal to 1. Also, when the edge of the last board is less than one half the width of a full-tally board from the center, then the next board has most of its width past the flitch center, and NSENS is set to 1.

h. 1/2-tally and 2/3-tally boards. Once the full-tally boards of a flitch have been classified, the program then classifies the 1/2-tally and the 2/3-tally boards if there are any. As for full-tally boards, these pieces are classified as rectangles. The square option is not considered for these boards which always have rectangular shapes. The amount of material in the lower grade is then compared to the maximum amount allowed, if any, to check for potential upgrading.

1'. <u>1/2 tally boards</u>. A value of 1 for SKY indicates the presence of a 1/2-tally board in the flitch. If SKY is not set at 1, then the program goes directly to the section classifying 2/3-tally boards. The width of the board from the flitch's edge to the 1/2-tally board included is the sum of the width of all the full-tally boards and of the 1/2-tally boards. The sawkerf and sawing allowance are also added as was the case for TEST in the main program BOF. If NSENS is 0, then the width is measured from the opposite edge of the 1/2-tally board to determine ESTEST. Once ESTEST is found, it is compared to the value of DAK. Exactly the same procedure as for the full-tally boards is then followed (Figure 19, page 71).

The area option is also treated the same as for the full-tally boards. However, the variable SURF, defining the maximum amount of lower grade material to be present in a board, is given as a function of the sizes of a 1/2-tally board. The class is saved in the array ORDER for the printout, in the variable NUML to compute the flitch's value, and in the array ANGLES to print out the total number of pieces in this class.

2'. <u>2/3-tally boards</u>. The presence of a 2/3-tally board is characterized by the variable PX with a value greater than 0. In the array TEST, the variable characterizing the range of value corresponding to a board that included a 2/3-tally piece is WIDTH1. It is computed in subroutine SAW, and is used in array TEST(I,J). The variable I takes the value WIDTH1, except when SKX is equal to 1, in which case I becomes 1. This particular case characterizes a flitch containing only a 2/3-tally board (Table 2, page 39). The width ESTEST is computed as for a 1/2-tally board, but with the addition of a 1/2-tally board if it is present. When SKX is 1, the section of the program calculating if the flitch's center was passed and giving NSENS was skipped (Section VI-C-1-g). Thus, the variable ESTEST must directly be compared to the width of half the flitch in order to know if the flitch's center is passed, and to compute the correct value of ESTEST. If ESTEST is smaller than DLL, then the center has not yet been passed. Once ESTEST is found, the area option is treated as for a 1/2-tally board, and the class value saved in ORDER, NUMS and ANGLES.

i. Central flitch. The central flitch, which includes the log's pith, is treated separately since all the growth rings in it will at one point make an angle of zero degrees with a sawline perpendicular to the flitch's face, and will thus have the lowest grade possible (Figure 27). If there are only two classes entered by the operator, BETA is 0 and the class K is fixed at 2; otherwise, K is fixed at 3. If the flitch does not contain a commercial board, all the studs take the value of K, and their class's saved in the array ORDER. If a commercial board is present, its position needs to be determined. As in section VI-C-1-f, the variable BSKX, which is a function of only the number of boards in the flitch, replaces SKX which is a function also of the commercial board present. The commercial board is then positioned following the same procedure as for a regular flitch. The commercial board is first positioned when half the boards have already been classified. If this position is not close enough to the center, another board is added on the same side before trying to position the commercial board again. Once the commercial board is correctly positioned, the rest of the boards are classified. The 1/2-tally and 2/3-tally boards, if

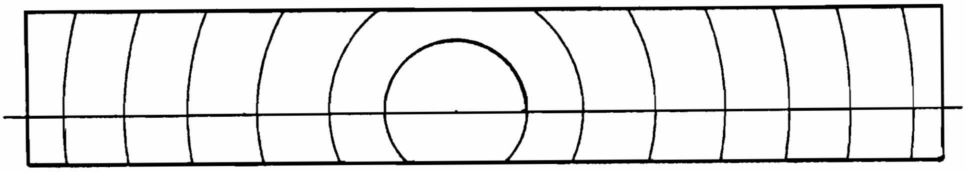


Figure 27. In the center flitch, all the rings make at one point an angle of zero degrees with a sawline perpendicular to the flitch's face. In this case, all boards are in the lowest class.

present, are then also given the same lower class value.

j. Results saved. Up to now, the results were saved in the array ORDER so that they could be printed out in a table showing the classes of all the pieces of the log. The full-tally boards were also saved in NUM(K) as a piece count per class per flitch used to compute the flitch's value. The values of the elements of the array ANGLES are functions of the values of FACTOR, which are the relative values of classes 1, 2 and 3 entered by the operator. NUML and NUMS for 1/2-tally and 2/3-tally boards are also a function of FACTOR, and are used in subroutine SAW as a multiplicative factor to compute the 1/2-tally and 2/3-tally boards' values. The cumulative sums of all boards of all sizes and classes in a log are saved in the array SANGLE which is used simply for print out. For the full-tally board's value, a weighted average of all the full-tally boards of all classes is computed as WANGLE. If there are no full-tally boards, then WANGLE is set at 1 corresponding to the angle class of a full-length, 2/3-tally board. These boards, if not in a flitch containing full-length pieces, can be found only together with a commercial board. The 2/3-tally boards cannot be oriented and thus are always in the lowest angle grade value zone when found in the center flitch.

2. Density calculation.

As was mentioned in section VI-C-1 which dealt with the angle calculation, the overall pattern of the density calculation subroutine, DENSIT, is close to that used in subroutine ANGLE (Figure 28). Still, a few features are particular to each subroutine. The square option is useful only when computing ring angle. When looking at ring density, the board's shape has no importance so squares and rectangles are treated alike. Also, the central flitch is computed separately in subroutine ANGLE

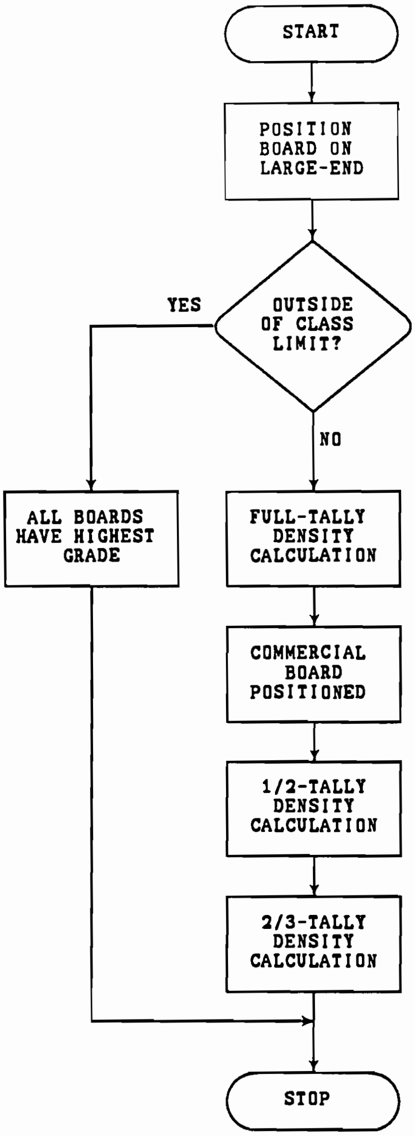


Figure 28. Overall flowchart of subroutine DENSIT.

but in DENSIT is treated just like the other flitches since both classes will be present in such a flitch. On the other hand, a flitch that is entirely outside the boundary between the two ring density classes is treated separately in subroutine DENSIT. In these flitches, all boards have a high ring count and are classified in the best class. The amount of lower grade material in a board is also not computed in subroutine DENSIT. This value was used in subroutine ANGLE to upgrade a board that contained less than a user specified percentage of lower grade material. Because of the grading rules, this feature is less useful for the ring density. Indeed, the limit between the two ring density classes is given as a percentage of the log diameter, which is especially useful when studying a whole range of log diameters (see section VI-C-2-a). Because there is a progressive change between the two classes in a real log, the use of a log diameter percentage makes the limit used here very simplistic. Therefore, the computation of the "exact" amount of lower grade material would not have much meaning. To offset the inability of a human grader to see small amounts of lower grade material, a more efficient method than calculating the "exact" amount would be to reduce the percentage of the log diameter defining the lowest class.

a. Starting the subroutine DENSIT. The boundary between the two ring density classes is defined by a circle whose diameter is a percentage of the log's large-end diameter. This percentage is entered in the subroutine INPUT under the name CHANGE. The advantage of using a percentage is that a whole range of log diameters can be investigated without having to enter the exact diameter of the boundary between classes for each diameter. Subroutine DENSIT is called from subroutine SAW once the ring angle computation is completed. DENSIT is called even if the subroutine ANGLE was not called, as long as the variable DENS has a value of 1. The variable DENS is set at 1 when the value of CHANGE is greater than 0.

b. <u>Ring density</u>. The position on the large-end of the flitch is found exactly as for the angle computation (see section VI-D-1-b). Nevertheless, the computation is redone in case ring angles were not computed, and subroutine ANGLE not called. The value REDGE, RFACE, D, DLL and DW are the same as in subroutine ANGLE.

1'. <u>Principal of calculation</u>. When computing ring angles, the boundaries between classes were straight lines defined by angles. For ring density, the boundary is the perimeter of a circle. All material falling in this circle has a theoretical lower ring per inch count and thus a lower grade, while all material falling outside this boundary has a higher ring count and grade. As for ring angle, the flitch's face to be considered is the one closest to the log's pith. The intersection point of this face with the density boundary can be found when the distance D from the pith to the flitch's face and the circle's radius are known. The intersection point can be characterized by its distance from the flitch's center (Figure 29). Knowing the boundary between high and low grade material in the flitch, each board in it can be classified according to its distance from the center. As was done for ring angle, a board overlapping both types of grade is automatically classified in the lowest class (Figure 30).

2'. <u>Algorithm</u>. The boundary between the two classes is a percentage of the log's large-end diameter. The radius of the boundary is thus the product

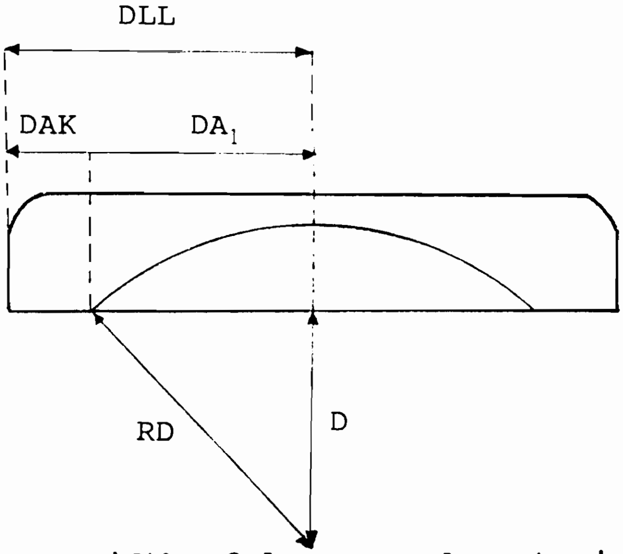


Figure 29. Width of lower grade material DA1, and of higher grade material, DAK, in a flitch of half width DLL.
D is the distane of the flitch to the log's center and
RD is the radius of the circle defining the boundary between limiting the classes.

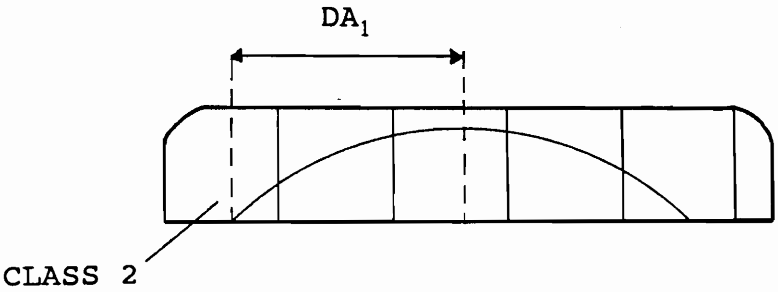


Figure 30. If a board overlaps the class boundary, it is assigned the lowest class value. DA1 is the width of class 2 material.

of the percentage CHANGE and of the log radius. The width of class 2 material in the left half of the flitch shown in Figure 29 is given by the relation

DA1=SQRT(RD**2-D**2).

When the flitch containing the log's center is considered, then the value of D is negative since the flitch's face has passed the center. DA1 is given the radius' value RD.

The width DAK is first set as the distance from the board's edge to the boundary of class 2, which would be DLL minus DA1 in this case. K, which defines the class of a board, is first set at 1. The highest class is chosen to start the search since the high grade material is farthest from the log center; the first board studied in each flitch is compared to the limits defined by DA1. Contrary to the angle computation, the edge of the board to be considered for computing the ring density class is the edge closest to the flitch's center. This difference is also due to the fact that the high grade material for ring density is farthest from the flitch's center.

The variable ESTEST in this subroutine represents the distance from the flitch's edge to the board's edge closest to the center of the flitch. Before the flitch's center is reached, the value of ESTEST is equal to the value of RTEST corresponding to the board being classified at that moment. Once the flitch's center is passed, when ESTEST is greater than DLL, NSENS is set to 1. The width of a full-tally board must then be subtracted from RTEST in order to have the board's edge closest to the center (Figure 31).

When ESTEST is less than DAK, then the last board represented in ESTEST is in the density class limited by DAK. The last board takes the value of K associated to this class. If ESTEST is greater than DAK, two cases may

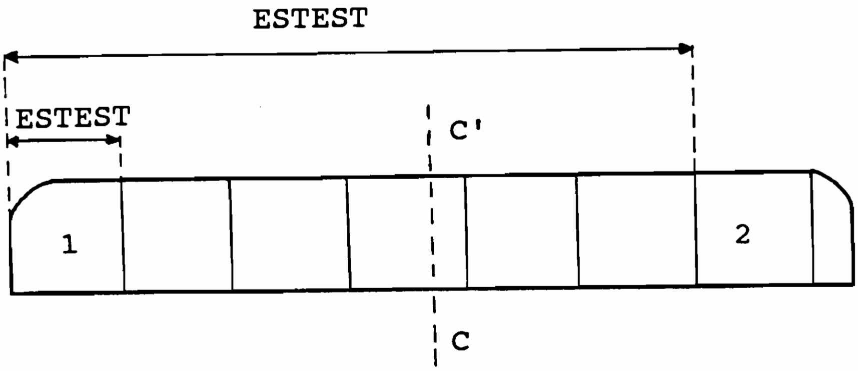


Figure 31. Distance ESTEST for a board when the board is before the center line C-C' (1) or after the center line (2).

occur: (1) the distance DAK is less than the flitch's half width DLL, or (2) it is greater than DLL. When DAK is less than DLL the center has not yet been reached and the next portion of the flitch considered is in the section of lower grade material. K is set to 2, and DAK represents the distance from the flitch's edge to the second class limit (Figure 32). On the other hand, when DAK is greater than DLL, the zone of lower grade material has been passed. The remaining boards in the flitch are all in the highest class. K takes the value 1, and DAK represents the whole flitch's width. Once the changes have been made to DAK, ESTEST is again compared to it as described above, until ESTEST becomes smaller than DAK. Then the value of K corresponding to this DAK is saved as the class for the board being considered (Figure 33).

Two special cases may occur. When both edges of a board fall outside the boundary between the grades, and the board still contains some lower grade material, the board must have a class 2 even though ESTEST falls in the class 1 zone. Such a case occurs when the center of the flitch is passed (Figure 34). The second case also occurs when the board contains the flitch's center. The value of NSENS is still 0, but the edge considered may fall in class 1 (Figure 35). Since such a board also contains low ring count material, it is classified in class 2. The difference from the first case is that one edge is in class 2 which means that the previous board in that flitch was in class 2 and DAK was set for it. In the first case, the previous board was in class 1, and DAK was still defining the first limit.

c. <u>Other changes</u>. The position of a commercial board in a flitch is computed exactly the same way as it was done in subroutine ANGLE. The commercial board's position found in both subroutines will be exactly the

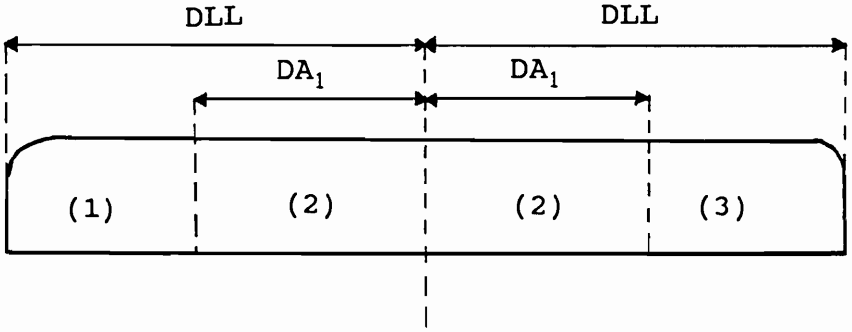


Figure 32. The different values of DAK.
(1) DAK=DLL-DA1 K=1
(2) DAK=DLL+DA1 K=2
(3) DAK=DLL*2 K=1

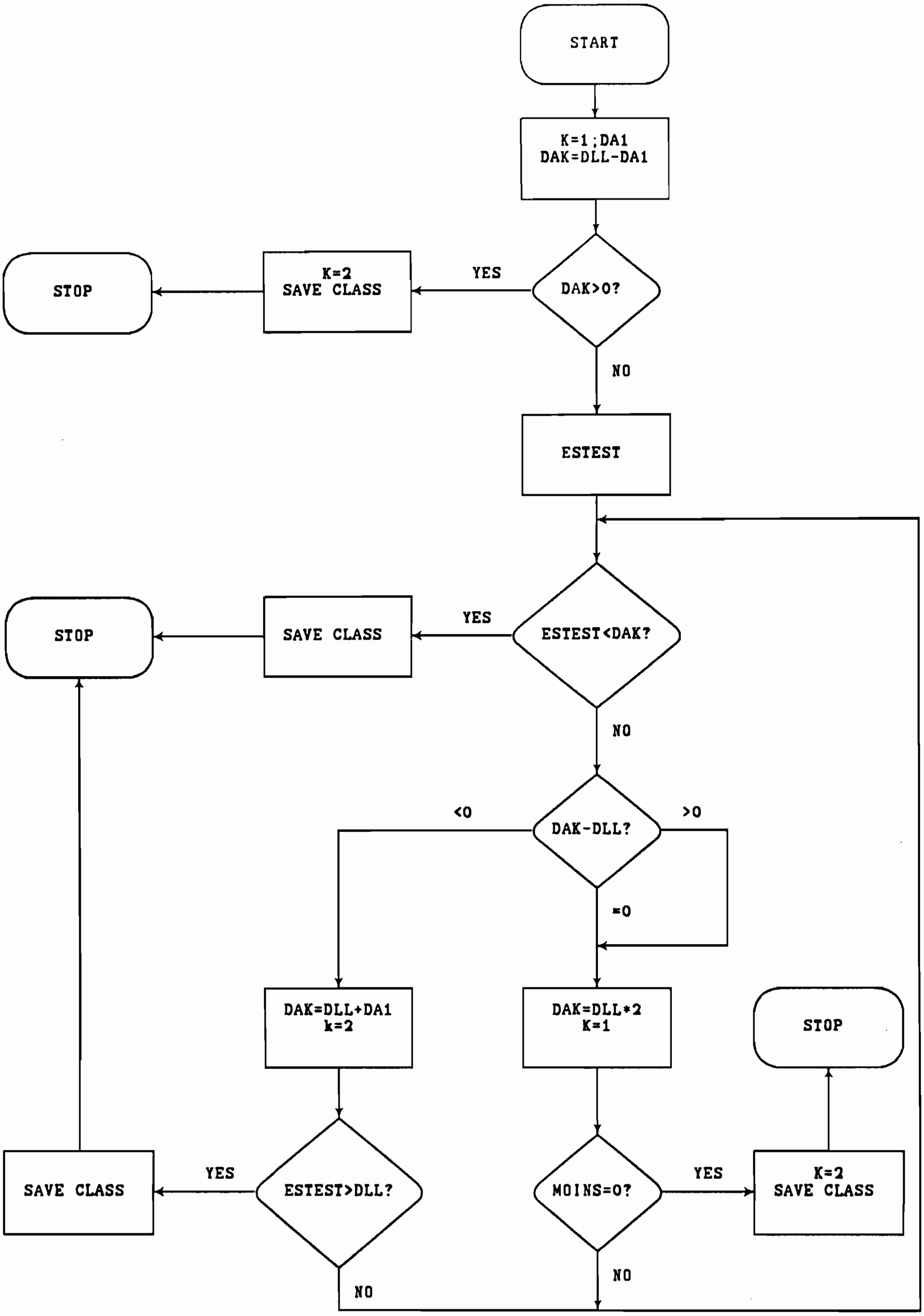


Figure 33. Flowchart of density class computation.

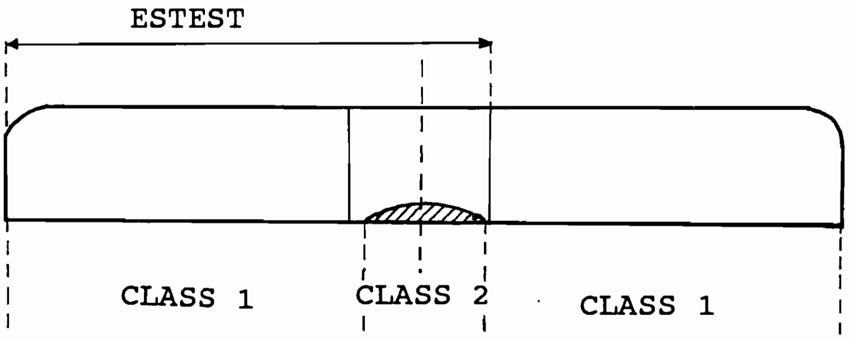


Figure 34. Both edges of the board being considered are in class 1, but the board still contains some class 2 material.

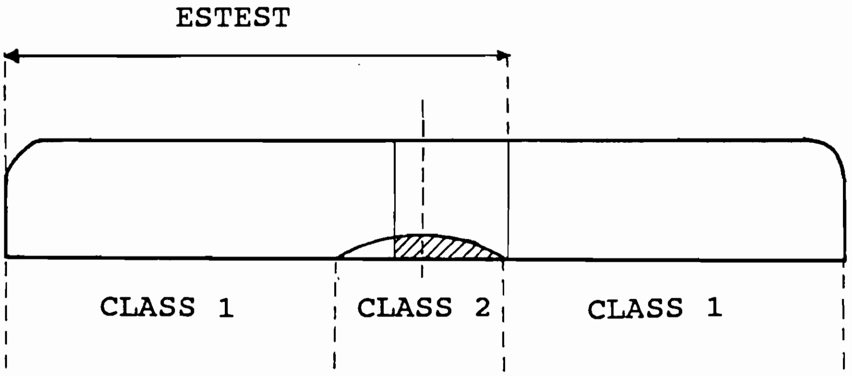


Figure 35. The board's edge being considered is in class 1, but the board still contains lower grade material.

same. However, this computation is done in the two subroutines since runs can be made looking only at ring orientation, which means that subroutine DENSIT will not be called, and vice versa. Then the classes of 1/2-tally and/or 2/3-tally boards are computed, also following the same pattern as for the ring angle. Only the values of ESTEST are computed differently to consider the board's face closest to the flitch's center as was done in section VI-C-2-b-2'. The flitches entirely outside the boundary between classes, which is the case when the distance D is greater than the radius RD, have all their boards in class 1 (Figure 36). No commercial board will appear in these flitches so the section dealing with it was not incorporated. All results are saved as they are in the subroutine ANGLE.

3. Using the program.

Because of the many changes made to the original BOF program, it was renamed BOFRING. As previously stated, every effort was made to keep BOFRING similar to BOF to aid users in understanding the new model. However, as would be expected, the input and output formats needed to be modified.

a. Input. The input format for BOFRING is very similar to the format for BOF (Figure 37 and Appendix A). As in BOF, certain information is required while other information is optional.

1'. Options. The specific characteristics of the program BOFRING require that some of BOF's options be fixed to avoid input error. They are:

1) Flag 2 was set to always have live sawing,
2) Flag 4 was set to always optimize the value,
3) Flag 8 was set to have full length edging,
4) Flag 10 was set to saw boards 3 inches wide,

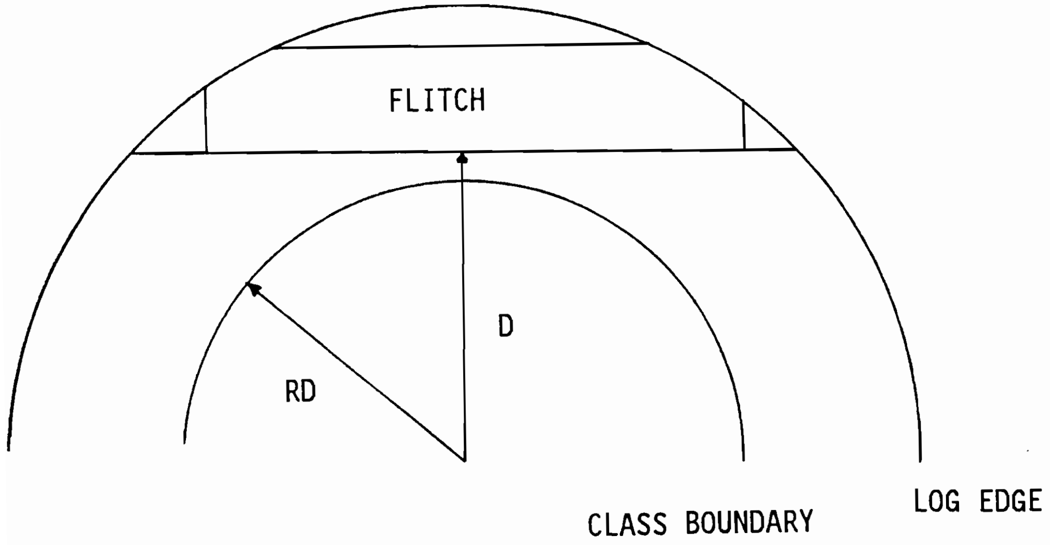


Figure 36. The flitch is entirely outside the limit between classes. The flitch's distance from the log's center D is greater than the class limit radius RD. All boards are classified in class 1.

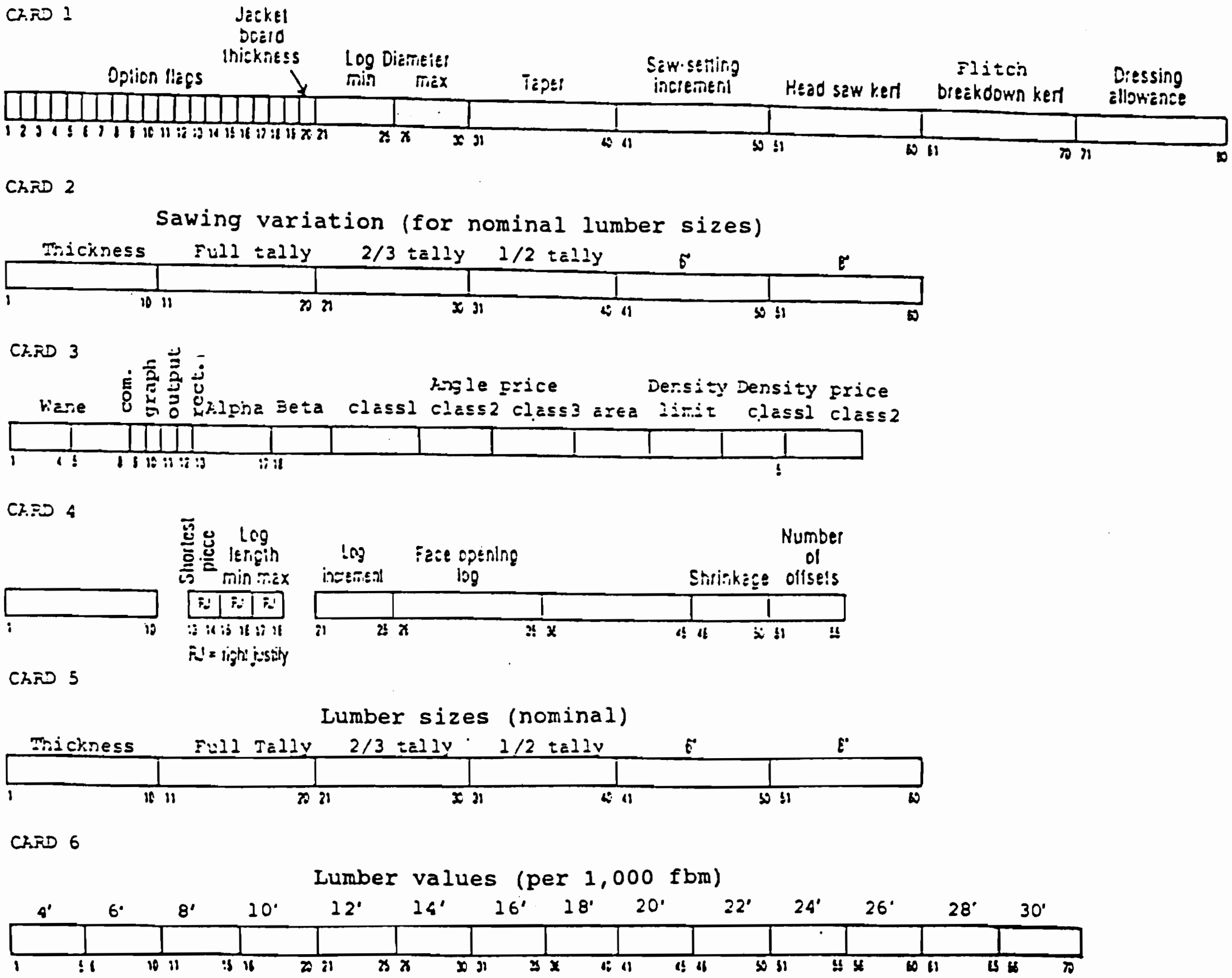


Figure 37. BOFRING input data format as modified from the BOF USER's guide

5) Flag 18 was set to always have to enter lumber dimensions,
6) Flag 19 was set to have split taper log breakdown, and
7) Flag 20 was set to have only one thickness available (Figure 37).

Other options, such as the ones concerning cant breakdown, are of no concern since only live sawing is used. Options 5,6,7 and 16 are thus of no interest here. The options available are listed in Table 3, which was taken from the BOF user's guide (20) and modified.

2'. Required information. Log diameter- the minimum small-end diameter allowed will depend on the commercial board option (Section VI-C-3-a-3'). If no commercial board is sawn, the smallest log can have a diameter almost as small as the size of the smallest lumber size. If commercial boards are sawn, logs must have a small-end diameter of at least 13" in order to be correctly sawn. This limit may vary with the lumber sizes and is given here for pencil stock sizes. Logs with small diameters yield mostly commercial boards and little pencil stock under the assumptions made. The maximum log diameter was fixed at 40 inches in the assumptions. Taper is the difference in diameter between the log's small and large-ends over a length of 16 feet. Saw setting increment is the minimum amount that a log can move with respect to the saw. Log increment is the increase in diameter between two consecutive logs when a range of logs is sawn. The face opening log (card 4) is the shift in the opening face position between trials. The number of offsets (card 4) is the number of positions that a log may be shifted from the pith. When no shift is allowed a 1 must be entered. When n shifts are allowed, the number to be entered is n+1.

Table 3: Various BOF options still available in BOFRING as modified from the BOF user's guide (20).

Options	Action	
	not set	set
1. processing control	BOF solution	1=table only 9=end of control set
3. Lumber sizes	dry	green
9. Piece count	not printed	1=offset,sequence printed 2=all table printed
11. Shortest piece allowed(ft.)	8	(Must enter)
12. Minimum and maximum log length(ft)	8 to 16	(Must enter)
13. log diameter increment(in.)	0.1	(Must enter)
14. Log opening face increment(in.)	0 .05	(Must enter)
15. Shrinkage(pct)	5.0	(Must enter)
17. Offset positions	variable	1=selected position only

3'. <u>New information needed</u>. The model modifications also required that new information be entered. These new data are entered in card 3.

- The percentage of wane allowed has to be entered as 0.25 for 25%. Thickness and width wane allowances are entered.
- The commercial board must be set to:
  0 if there are no commercial boards,
  1 if 6 inch commercial boards are sawn, or
  2 if 8 inch commercial boards are sawn.
- A graph option was created (see Section VII-A-3. for details). It must be set to:
  0 if no graph is desired or
  1 if graphs are desired.
- The output option must be set to:
  1 if BOF's tables are needed or
  2 if the analysis format is needed.
- The square option is set to:
  0 if rectangles are sawn or
  1 if squares are sawn.
- The angle limits between classes 1 and 2 (alpha) and between classes 2 and 3 (beta) are entered in degrees.
- The percentage of lower grade material allowed in a board is entered as a percentage of the lumber's cross-sectional area.
- The change in ring density is entered, for instance as .5 for a limit with a radius that is 50% of the log's radius.

b. <u>Output</u>. Two choices for the output were mentioned in the previous section. Either tables that are similar to BOF's output can be produced, or the output can be given in a format more suited to ring angle and density analysis.

1'. _Tables_. Only additions to BOF's tables will be discussed here (see Appendix A for a complete set of tables). Tables now include the volume of full-tally, 2/3-tally, and 1/2-tally boards produced in a log. Two values specific to the pencil industry are also given. The first is the value of the log considering only the boards' dimensions and not taking into account price factors relative to ring pattern. This value is given in dollars per log and corresponds to what the pencil stock manufacturer would get out of a log. The second value is the log's value considering only price factors for the angle and density classes. Since only relative values are used in the computation of this number, it does not reflect the actual value of the log but can be used for comparison purposes. This value is from the viewpoint of the slat manufacturer. Note that the amount given under lumber value in the standard BOF table is the combination of the two values mentioned above. It is this value, which summarizes the whole process from log to slats, that is optimized in the program. This also is a relative rather than an absolute value since slat production costs were not considered. An example of information concerning ring patterns is given in Appendix A.

2'. _Analysis format_. This format for output is best suited when further manipulation of the data is needed. Each log has all it's information given on one line (Appendix A).

VII. RESULTS AND DISCUSSION

A. VERIFICATION OF THE MODEL.

Four different procedures were used to validate the model:

1) results were compared to solutions given by BOF,
2) hand calculations were made to assess the precision and accuracy of the output numbers,
3) graphic means were used in order to assess the correct classification of lumber according to ring angle and density, and
4) all values of all opening faces during a run were recorded in order to confirm the choice of the optimum solution.

1. Comparison with BOF.

Similar data were entered in both programs; runs were made and the results compared. The same results can not be expected between the two programs since important modifications were made in BOFRING that affects the overall volume recovery. The value of each sawing pattern will thus differ, and a different sawing pattern may be selected in each program as being the best. The input data were chosen in order to be similar for both programs. For example, the effects of angle and density calculations were nullified by giving a value of one to all classes' factors. The commercial board option was set to have no commercial board in the log. The percentage of allowed wane was set at 25% to match the amount used in BOF. The minimum lumber length was set at 6 feet to be the same as in BOF.

The sizes were given the same value in each program so 4 inch boards and full-tally boards had the same size, 3 inch boards and 2/3-tally boards had the same size, and

1/2-tally boards were given the same size as 2/3-tally boards. This corresponds in BOF to the possible existence of a full-length 3 inch board.

Also, in order to have equivalent nominal sizes, changes was made in BOFRING. In the subroutine INPUT, the DATA statement defining the nominal board feet, BDFT, was given the value .5 for 1/2-tally and 2/3-tally boards and 0.666 for full-tally boards. These values correspond to the ones given in BOF. The offset position option was set to allow maximum offset. This is an important factor, since if no offset position was allowed it would greatly increase the difference between the two results. In BOF, the log's center would be in the middle of the central flitch, whereas in BOFRING it would be in between the two central flitches, resulting in an important shift of the opening face (see Section VI-B-4-d).

Three runs were made with both programs. Each of the runs considered logs with diameters ranging from 13 to 21 inches. The tapers and lengths used in the runs were a taper of 6 inches and length of 16 feet in run 1, 4 inches and 12 feet in run 2, and 2 inches and 10 feet in run 3. The taper as expressed here and during the whole discussion, corresponds to the increase in diameter over a length of 16 feet.

The model constantly yielded a lower value per log than did BOF, but the curves representing the log's value function of the diameter were similar (Figure 38). Such a result was expected, and can mainly be explained by the different nominal sizes given to a full-tally board containing wane. The main changes in the model that affected the volume recovered from a log were

1) full-tally boards with wane were counted as 2/3-tally boards, and thus had a lower volume and value,

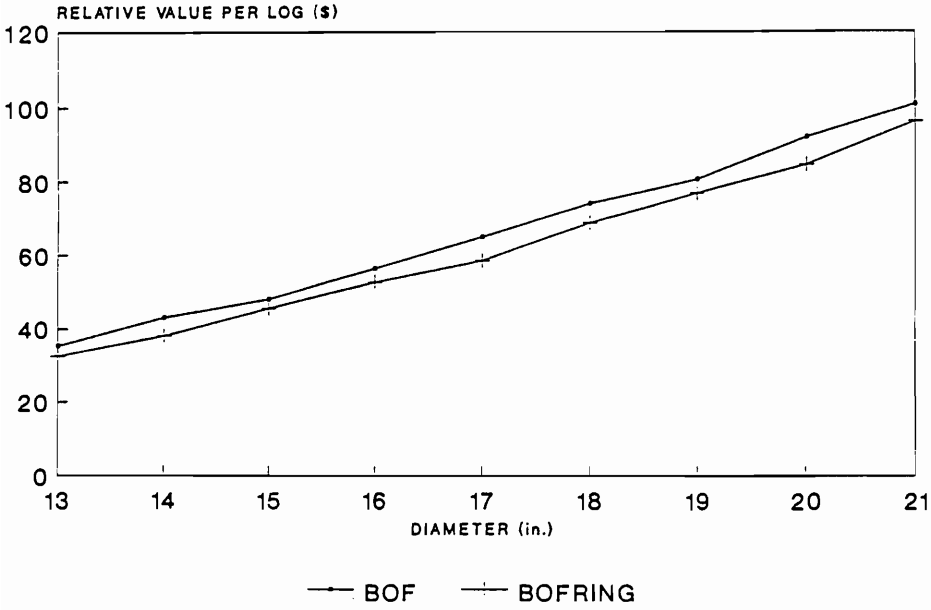


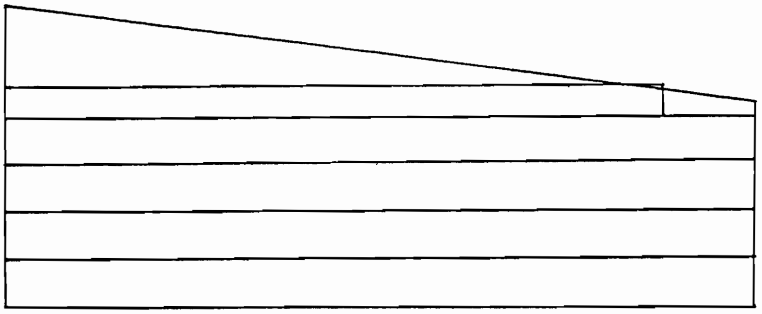
Figure 38. Relative value per log using BOF and BOFRING.

2) 2/3-tally boards could not contain wane, which could yield shorter pieces (Figure 39), and
3) the first sawline in the flitch could be shifted in order to have fewer pieces with wane in a flitch yielding a higher value (Figure 40).

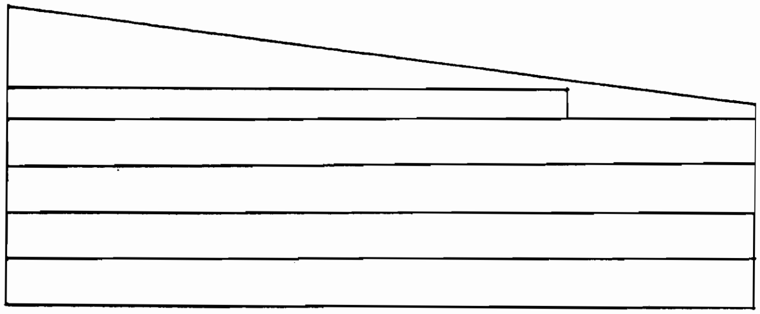
To illustrate the difference in sawing patterns that appeared between the two programs, graphs that show the logs from small-ends were plotted. Figure 40 represents a log 16 feet long, 16 inches in diameter, and with a taper of 6 inches. The number of full-length, full-tally boards, including the boards containing wane, was the same with either model. However, in BOFRING three of the flitches had their first sawlines shifted to have boards free of wane. Only one flitch then contained two full-tally boards with wane. Using BOF, four full-tally boards had wane which in BOFRING would be counted as 2/3-tally boards. The change in sawing pattern entails a different best opening face which yields the best solution under the new conditions. This difference in opening face also allowed BOF to recover one more short flitch than did BOFRING (Figure 40). These results do not infer that the sawing pattern found was the one yielding the optimum recovery, but rather states that it was in line with BOF.

2. <u>Checking the computation</u>.

The assessment of the accuracy of all the computations was done by hand calculating the different values and volumes. The sawing patterns used were the ones given as output by BOFRING. The product mix was found by combining information given in the output and on the graphs (see Section VII-A-3 for more details of the graphs). This way, the type of lumber produced was determined as well as the ring angle and ring density of each unit. These data were then combined with the nominal lumber sizes, relative lumber prices, and factors



(a)



(b)

Figure 39. Sixteen feet long flitch containing a 2/3-tally board.
(a) Using BOF, the board contains wane and is 14 feet long.
(b) Using BOFRING, the board contains no wane and is 2 feet shorter than with BOF.

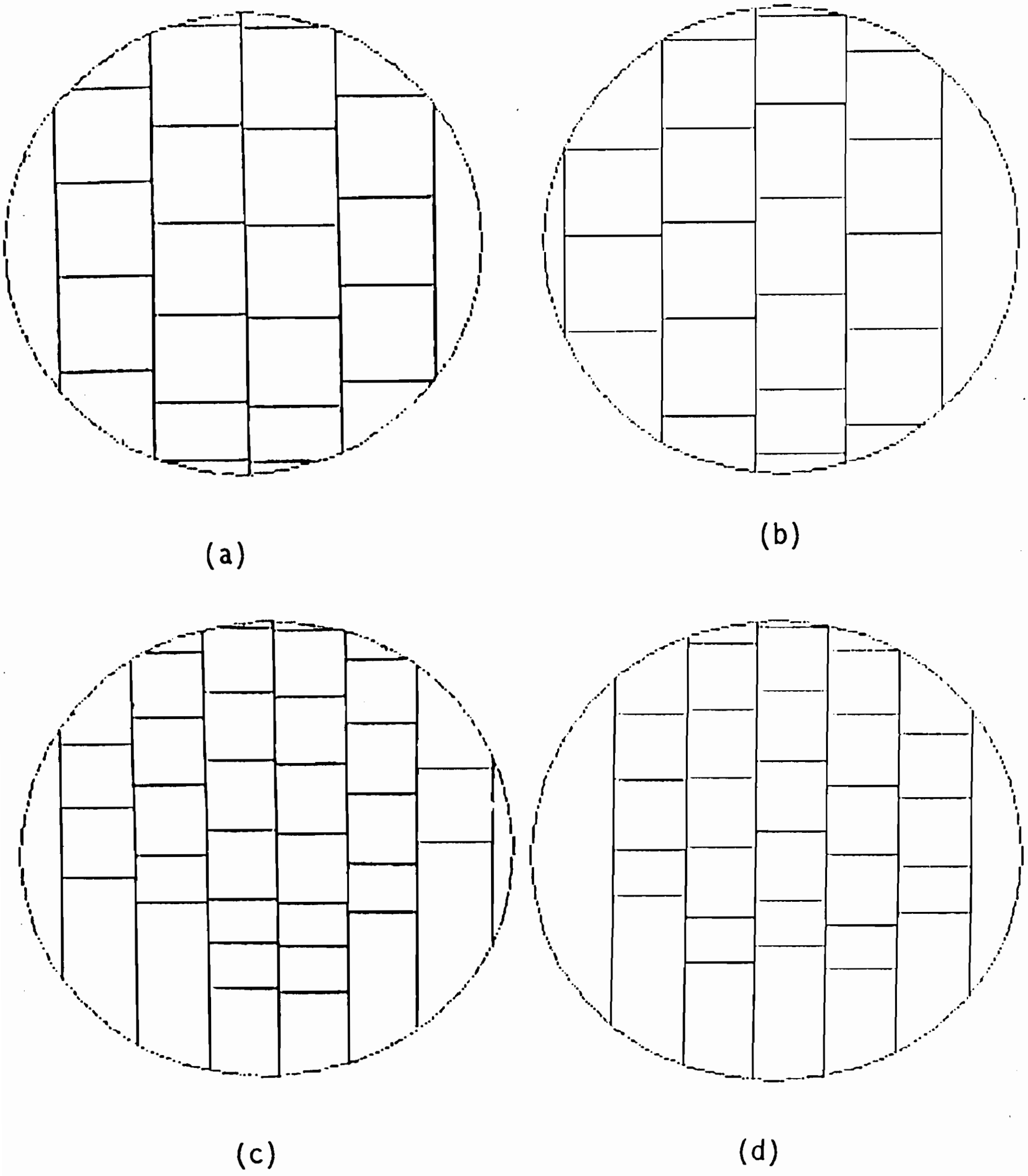


Figure 40. Sawing patterns of a 16 feet long log with a small-end diameter of 16 inches.
(a) Small-end using BOF.
(b) Small-end using BOFRING.
(c) Large-end using BOF.
(d) Large-end using BOFRING.

relative to ring angle and ring density. The total volume of the log as well as volumes of full-tally boards, 2/3-tally boards, and 1/2-tally boards were calculated. The total value, the value according to the pencil stock manufacturer's viewpoint, and the value according to the slat manufacturer's viewpoint were also computed this way.

Seven runs were made with characteristics as shown in Table 4. All runs included ring angle and ring density classification unless stated otherwise in Table 4. Also, all runs had a limited number of offset positions unless stated otherwise in Table 4. For all seven runs, all hand calculations correctly corresponded to data given in BOFRING's output (see Appendix A for details on output and calculations).

Table 4. Characteristics of logs and boards used to assess the computations. Rect means that rectangles were sawn while sq means that squares were sawn.

run	length (feet)	diameter (inches)	taper (in.)	commercial boards (in.)	sizes	others
1	10	16	4	6	rect	
2	10	22	4	6	sq	no angle
3	10	22	4	8	rect	
4	16	16	4	8	sq	no density
5	6	16	8	6	rect	no limit on offset position
6	6	14	8	6	sq	no density
7	16	16	6	0	rect	

3. Checking ring angle and ring density classifications.

The classification of boards according to ring angle and ring density was checked by comparing the output data with graphs produced by the model. Two subroutines, DRAWA and DRAWD, were added to the program. These subroutines give point coordinates that were then used with the computer program ACROSPIN[1] to draw the logs. To print graphs shown on a screen, the screen capture feature GRAB of Word Perfect[2] was used. Three dimensional logs could also be drawn with their complete sawing patterns. Angle limits were added in DRAWA and the density limit added in DRAWD (Figure 41). These two subroutines were not discussed in detail in this paper since they were not an intrinsic part of the program but rather a visual aid mainly used for validation purposes. In addition, there are many other commercial programs with similar graphics capabilities.

The logs analyzed were the ones used in Section VII-A-2. Figure 41 is an illustration of how ring angles and ring density are given in the output and how they can be found by graphical means. In Figure 41a, which represents the angle zones, each diagonal line corresponds to an angle limit. The zones delimited by these limits represent angle classes 1, 2 and 3. In a similar way, the inner circle in Figure 41b represents the limit between the two density zones. Zone 2 is inside the inner circle and zone 1 outside it. All the other runs were examined the same way. It was found that for all of them the outputs matched the graphs.

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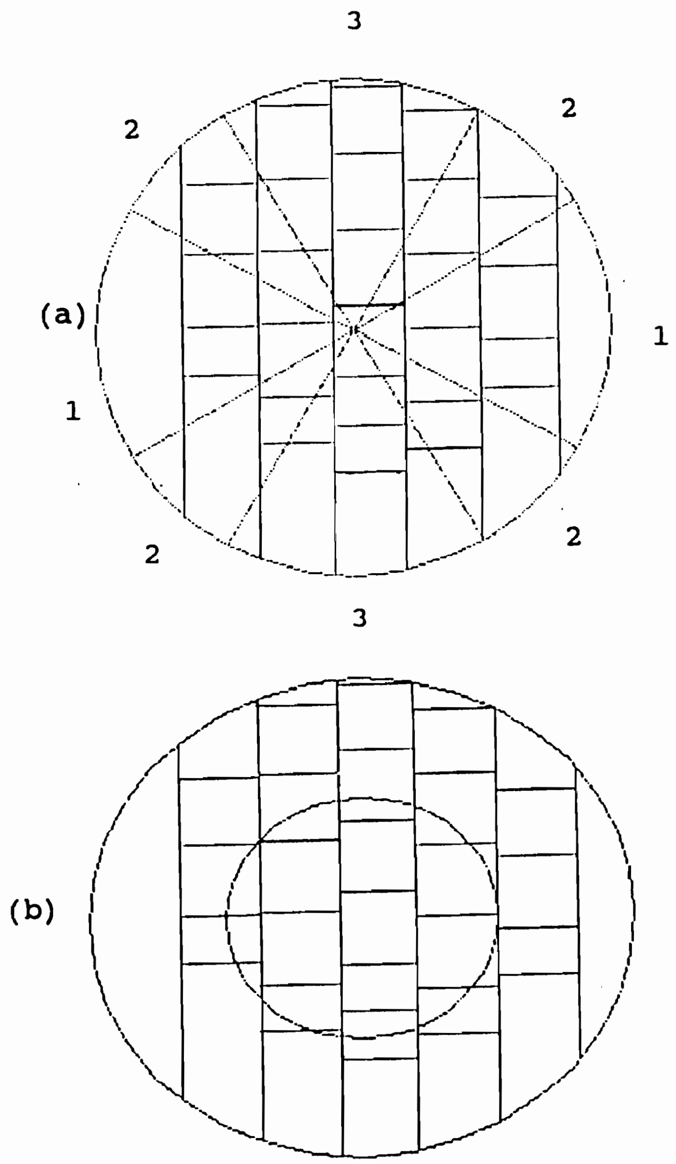
[1] Acrospin is a product of Acrobits, P.O. Box 5563, Redwood City, CA, 94063-0563. Use of this tradename does not constitute endorsement by Oregon State University.

[2] Word Perfect is a product of Wordperfect Corporation, 1555 N. Technology way, Orem, Utah, 84057. Use of this tradename does not constitute endorsement by Oregon State University.



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2 1 1
3 3 2 2 3
3 3 3 3 3 3
3 3 3 3 3
2 2 1
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1 1 1
1 2 2 2 2
1 2 2 2 2 2
1 2 2 2 2
2 2 2
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Figure 41. Graphical output of run 7 of Table 4.
(a) Graph and output for ring angle. The diagonal lines delimit the different ring angle class zones. The first column of the data output corresponds to the first flitch starting from the right. The first board considered is on the upper part of the log.
(b) Graph and output for ring density. The smaller circle delimits the two ring density zones. The data are in the same format as part a.

4. Checking the optimum solution.

Since the calculations had been checked and confirmed to be correct, the next step was then to look to see if the solution given in output was indeed the best of all opening faces tried in a run. For this, the same runs as in Section VII-A-2 were used. By monitoring the running process, all values computed for each opening face were recorded. Once the run was over, the final value given in the output was compared to the highest of the values previously recorded. For all seven runs the two values matched, indicating that the value saved and given in the output was the best of all the opening faces tried during the run (Appendix A).

B. PRODUCTION OF RECTANGLES COMPARED TO SQUARES.

The effects of sawing rectangular versus square full-tally pencil stock were analyzed. The main purpose was to assess from a price stand-point if the increase in volume recovery balances the decrease in pencil stock quality regarding ring angle. Thinner flitches allow more boards to be recovered from a log, but full-tally boards can no longer be oriented in order to optimize slat quality. Only growth ring angles were considered in this section. Growth ring density was not included, and will be discussed in Section VII-C.

1. Input data.

All the runs were made with input data as recorded hereafter by card order (as discussed in Section VI-C-3-a and shown in Figure 37).

CARD 1

option	set	
1	0	gives output
3	1	green lumber sizes

9	0	no table (analysis format is used)
11	1	must enter shortest piece
12	1	must enter minimum and maximum log length
13	1	must enter log diameter increment
14	0	log face increment is fixed at .05
15	0	no shrinkage
17	1	selected number of offset positions

The minimum diameter was set to 14 and the maximum to 25. Sawkerfs were set to 0.125 inches, which is standard in the industry.

CARD 2

Sawing variations were 0.034 inches for the thickness and 0.018 inches for the width (manufacturer's data).

CARD 3

Wane was set to 0.66 for thickness and width.

The output option was set to 2, giving the analysis format. Angle limits were 60 for alpha and 30 for beta.

CARD 4

Shortest pieces were 4 feet long.

Log increments were 1 inch.

Number of offsets was 20. This amount allows an off-center position of 0.95 inches which allows the commercial boards to be off-centered in order to increase recovery.

CARD 5

Lumber sizes (inches):

width	1/2-tally		1.5
	2/3-tally		2.0
	full-tally		3.09
	commercial boards	6 inches	5.943
	commercial boards	8 inches	7.772

<u>thickness</u>	rectangular sawing	2.93
	square sawing	3.09

These data were supplied by the manufacturer. Runs were then made with only one of the following parameters changing in each new combination:

- Rectangular or square sawing.
- Log length (feet): 6, 8, 10, 12, 14, 16.
- Log taper (inches per 16 feet long): 2, 4, 6, 8.
- Lumber prices. These prices are relative prices chosen according to data provided by the manufacturer. Two sets were run:

dimension	price 1	price 2
1/2-tally	100	100
1/3-tally	110	105
full-tally	120	110
commercial board	43	43

- Ring angle class factors.

angle class	factor set 1	factor set 2	factor set 3
1	1.3	1.23	1.1
2	1.15	1.11	1.05
3	1.00	1.00	1.00

All runs were made with commercial boards of 6 inches. Runs with 8" commercial boards were made for all length and taper combinations but only for lumber price set 1 and ring angle factor set 2.

2. Best possible sawing pattern.

Only the manufacturing of pencil stock was considered in this whole study. Blocks and slats were not simulated. The best possible sawing patterns were found from a price standpoint by combining buyer's (the pencil slat producer) and seller's (the pencil stock producer) viewpoints. Pencil stock was given prices that were functions of stock dimensions. These prices correspond to a pencil stock producer's viewpoint. Each pencil stock was also given a price factor as a function of the growth ring orientation. This price factor corresponds to a pencil slat producer's viewpoint. The overall process, combining the results of these two values, gives a relative value per log. It is this value that was optimized in the program, resulting in the different sawing patterns. In Sections VII-B-3, 4, and 5, only runs with lumber price set 1 and angle factor set 2 as defined above were considered because the other price sets and angle factor sets produced results showing the same trends, although different magnitudes.

3. Effects from a pencil stock producer's viewpoint.

a. Volume. There was an expected increase in volume for all diameters when rectangles were sawn instead of squares as can be seen in Figure 42. More flitches and/or more boards in a flitch and/or longer boards were recovered when sawing rectangles. The two curves representing rectangular and square sawing increase as a function of log diameter. For larger diameters, the difference in volume recovery between rectangular and square sawing also increased in absolute value. To compare the effects of sawing rectangular versus square pencil stock, percentage differences were used where:

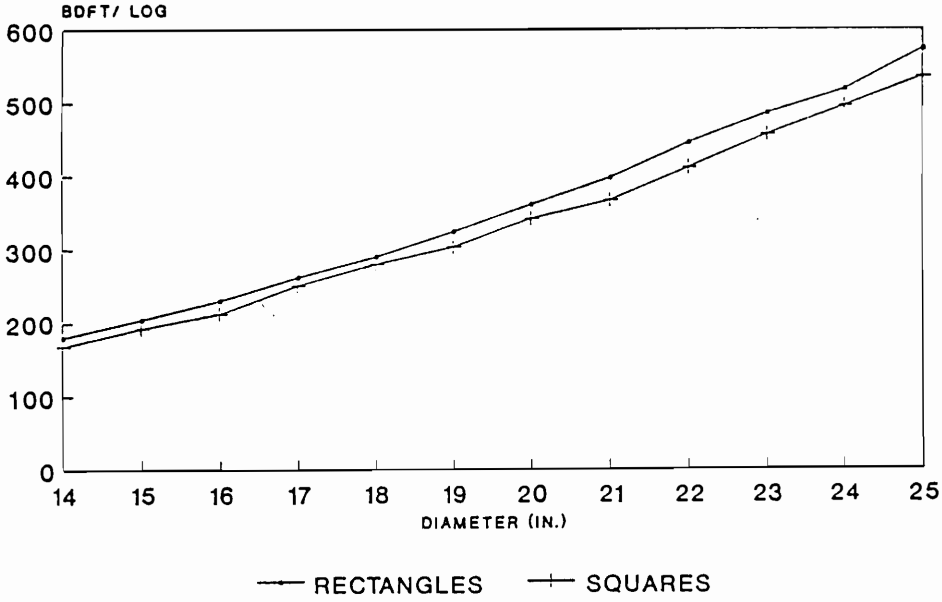

Figure 42. Example of volume recoveries for rectangular and square sawing. The example is for a log 16 feet long, with 6 inches taper per 16 feet, and when 6 inch commercial boards are sawn.

$$\text{difference \%} = \frac{(\text{volume rectangle} - \text{volume square}) * 100}{\text{volume square}}$$

Figure 43 shows these differences in volume recovery per log. No increasing or decreasing trend appears as a function of diameter. However, a cyclic pattern appears to be repeating itself with every three inches increase in diameter. In Figure 43, a peak is found for logs with diameters of 16, 19, 22, and 25 inches. This is not a perfectly regular pattern as the 21 inches diameter, which has a slightly larger value than a 22 inches diameter, illustrates. The three inch pattern can be explained by the thickness of a flitch, which is 3.09 inches for squares and 2.93 inches for rectangles. This means that all logs that have diameters that are three inches apart will have somewhat of a similar difference in sawing pattern between rectangle and square sawing. If a smaller log increment is used, the curve is more jagged. Important jumps in volume recovery may appear between two logs with diameters only 0.25 inch apart (Figure 44). For instance, there is nearly a 5 percentage point difference in volume between a log of 15.75 inches and a log of 16 inches. Because of this disparity in volume over a small diameter increment, it is impossible to make any conclusions on which log diameters will have the highest relative volume increase. Since no optimum log diameter can be selected, averages of all diameters were used for further analysis.

Table 5 records averages for all log lengths and all tapers when 6 inch commercial boards are sawn. For both length and taper, an increasing trend appears. For all tapers, average volumes of lengths were then computed.

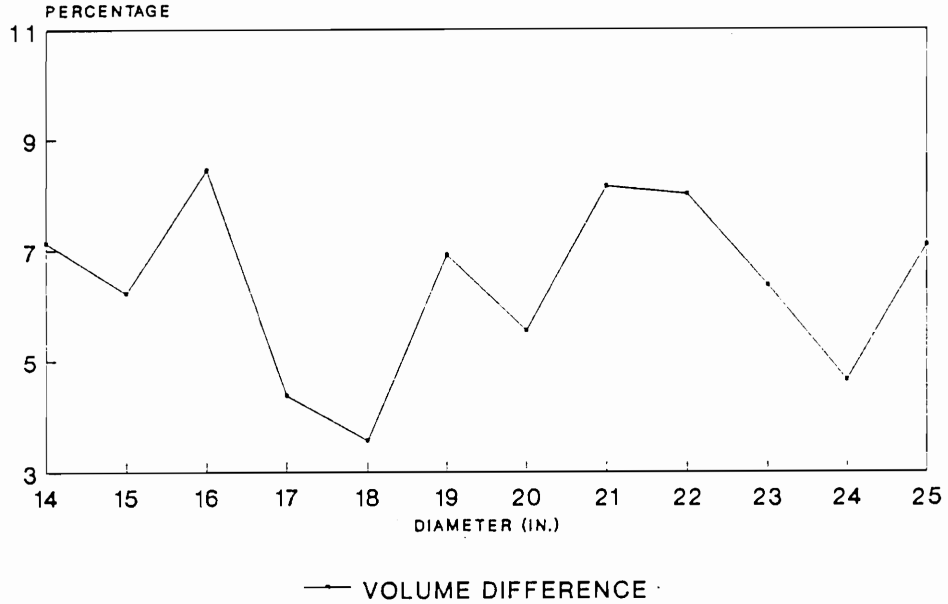

Figure 43. Percentage difference in volume recovery between rectangular and square sawing. The example is for a log 16 feet long, with 6 inches taper over 16 feet, and when 6 inches commercial boards are sawn. The increment between log diameters is 1.0 inch.

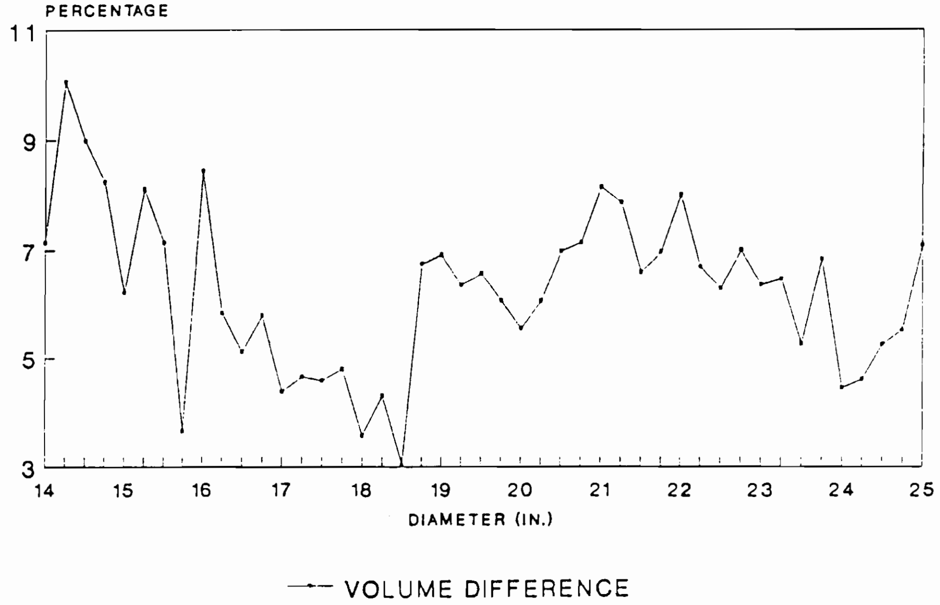

Figure 44. Percentage difference in volume recovery between rectangular and square sawing when the increment between log diameters is 0.25 inch. The example is for a log 16 feet long, with 6 inches taper over 16 feet, and when 6 inch commercial boards are sawn.

Table 5. Average percentage differences in volume between rectangular and square sawing for log diameters from 14 inches to 25 inches.

taper (inches)	length (feet)	average 6" commercial (percent)	average 8" commercial (percent)
2	6	5.51	5.99
	8	5.24	5.74
	10	5.17	5.28
	12	5.13	5.27
	14	5.38	5.46
	16	5.60	5.60
4	6	5.30	5.80
	8	5.52	5.71
	10	5.87	5.97
	12	5.59	6.06
	14	5.95	6.58
	16	6.28	6.38
6	6	4.88	5.49
	8	5.77	5.78
	10	6.29	7.30
	12	6.65	6.60
	14	6.11	6.14
	16	6.37	6.03
8	6	6.16	5.88
	8	6.30	5.98
	10	6.37	6.50
	12	6.01	6.26
	14	6.36	5.92
	16	5.93	6.04

Table 6. Average percentage differences in volume between rectangular and square sawing for log diameters ranging from 14 inches to 25 inches. 6 and 8 inch commercial boards.
(a) Taper fixed, all lengths combined.
(b) Length fixed, all tapers combined.

(a)			(b)		
taper (inches)	average 6 inches (percent)	average 8 inches (percent)	length (feet)	average 6 inches (percent)	average 8 inches (percent)
2	5.34	5.56	6	5.46	5.79
4	5.75	6.09	8	5.71	5.80
6	6.01	6.22	10	5.93	6.26
8	6.19	6.10	12	5.85	6.05
			14	5.95	6.03
			16	6.05	6.02

Similarly, for all lengths, the average volumes of tapers were also computed. The two sets of results are recorded in Table 6. Table 5 and 6 are given as examples. All other data used in the whole analysis are given in Appendix B.

These are just averages, and as Table 6 shows, fluctuations may occur. For instance, a 12 feet long log yields on average less than a 10 feet long log. An explanation for this is that values not volumes have been optimized in the model. An unexpected surge in volume recovery can be countered by an increase in lower grade material. In fact, the results concerning values are more consistent as shown in the following section. When 8 inch commercial boards are sawn, the improvements in volume recovery are slightly larger as shown in Figure 45. Figure 45 represents the average percentage difference as a function of log length. For this analysis, only graphs that show results as a function of length will be displayed. Results as a function of taper show similar trends and thus were not plotted. However, all data related to taper can be found in Appendix B.

It needs to be emphasized again that percentages and not real values were used. A higher volume from a percentage standpoint may not mean a higher total volume recovery. This is even more perceptible when dealing with values as will be discussed later (Figures 46 and 47 in section VII-B-3-b). Thus, with both types of commercial boards, the volume recovery always increases when rectangular full-tally boards are sawn. The overall average when sawing 6 inches commercial boards was 5.82% while it was 5.99% when sawing 8 inches commercial boards. This in turn will significantly influence a log's value. Standard deviations of 1.57% and 1.55% respectively show the large variations of the

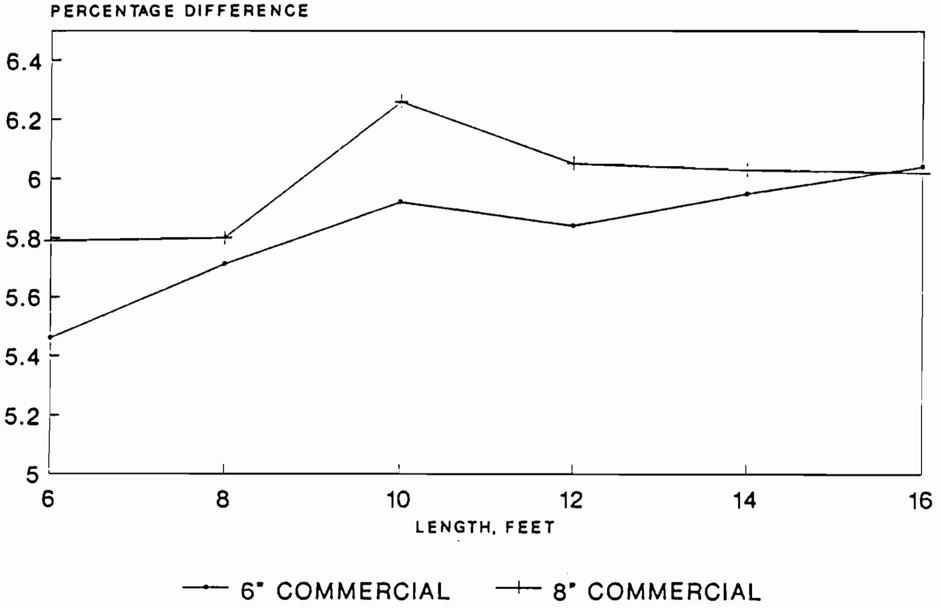

Figure 45. Average percentage differences in volume between rectangular and square sawing as a function of log length.

results from log to log.

b. Value. Only boards' prices as a function of their dimensions were considered from a pencil stock producer's viewpoint. As for volume, percentage differences were considered to study the effect of rectangular versus square sawing on value. The same general trends as a function of log diameter appear (Figures 46 and 47). Value increases and percentage differences as a function of diameter show similar curves to those found for volume (Figures 42 and 43). Sawing 6 inch or 8 inch commercial boards yields different results as illustrated by two distinct curves in Figure 46. Sawing 6 inch commercial boards resulted in an average gain of 6.56% while sawing 8 inch commercial boards resulted in a 7.14% gain. If real values are considered, it can be seen that sawing 8 inch commercial boards in fact yields a lower value than sawing 6 inch commercial boards (Figure 47). Again, it is important to keep in mind that percentage differences are used. The standard deviations are of the same magnitude as for volume. They are 1.78% for 6 inch commercial boards and of 1.92% for 8 inch commercial boards on the overall averages.

Six inch and eight inch commercial boards' data were then combined for both values and volumes. A comparison of the two curves shows a close relationship between the increase in volume recovery and the value gain (Figure 48). The relationship is not perfect because of the product mix changes discussed in the next section. A log fairly constantly yields 0.94% more in value than it does in volume. On average, a 6.85% increase in value is recovered per log by sawing rectangular versus square pencil stock. This large gain in value is closely related to the gain in volume.

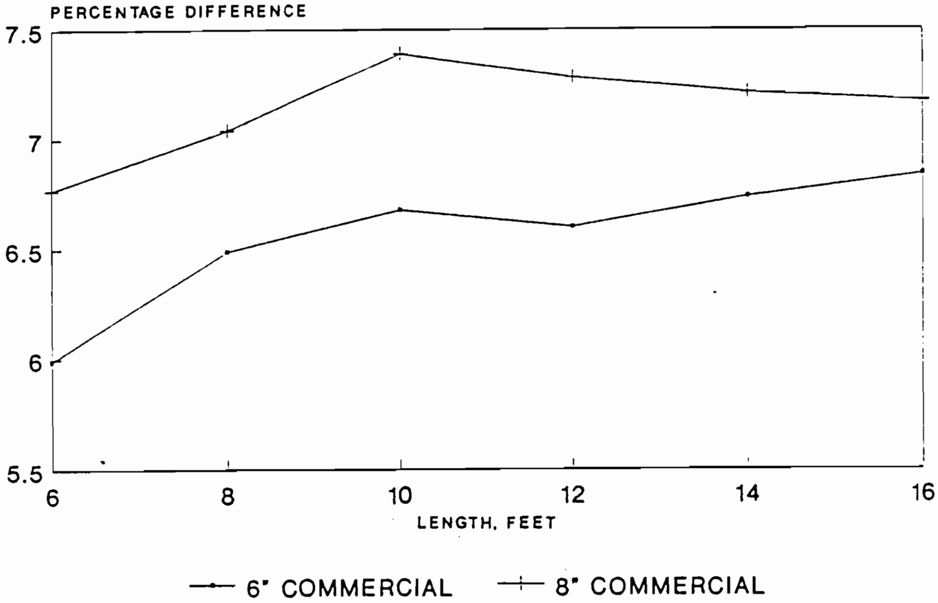

Figure 46. Average percentage differences in value between rectangular and square sawing as a function of log length from a pencil stock producer's viewpoint.

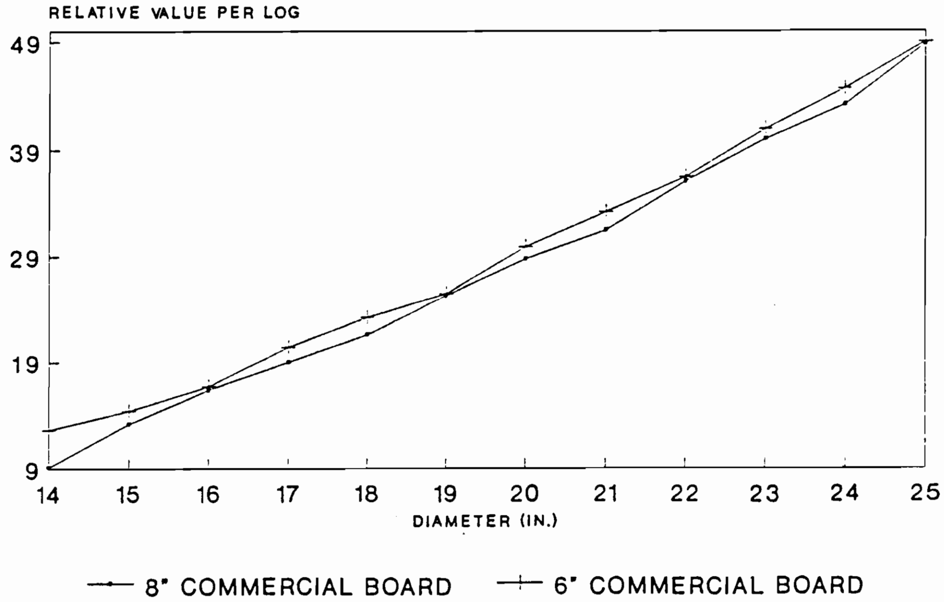

Figure 47. Relative value recovery when sawing 6 inch or 8 inch commercial boards. Squares were sawn in a log 12 feet long, with 6 inches taper over 16 feet.

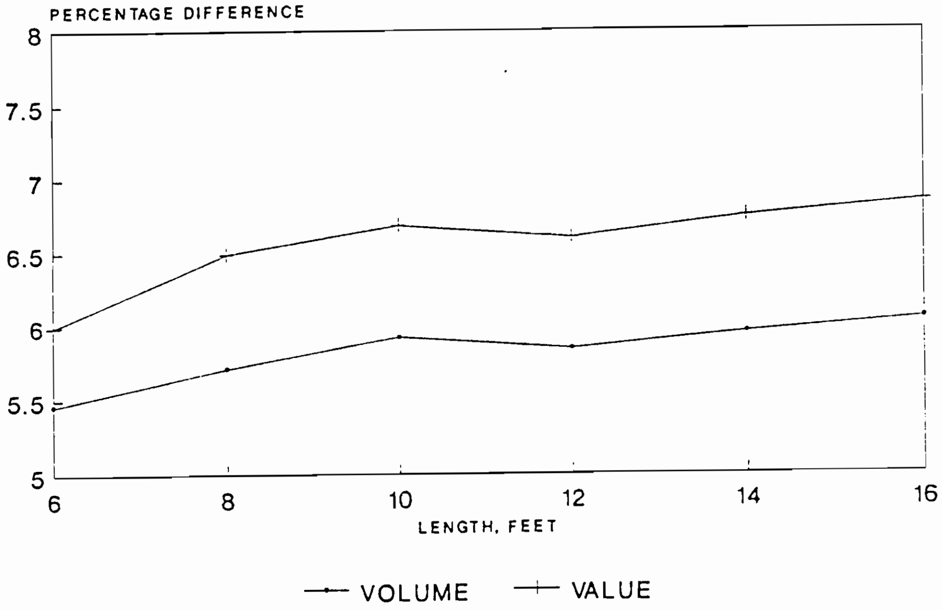

Figure 48. Percentage changes in volume and value from a pencil stock producer's viewpoint when sawing rectangular full-tally boards versus square full-tally boards.

c. Product mix. The difference in product mix between the two sawing methods was calculated by subtracting the percentage of full-tally boards found when sawing rectangles from the percentage found when sawing squares. The same procedure was repeated for 2/3-tally and 1/2-tally boards. These changes in product mix are shown in Figure 49. Proportionally more full-tally boards were recovered, with a 1.45% average increase. The relative production of 2/3-tally boards decreased 1.74%, and the relative production of 1/2-boards slightly increased 0.29%. However, the average standard deviations linked to those values were large; they were 5.44% for full-tally, 5.42% for 2/3-tally, and 1.26% for 1/2-tally boards. These overall changes in product mix result from the increase in volume that occurs when rectangles are sawn. The increase in volume is proportionally larger in full-tally than 2/3-tally boards.

It is also of interest to note that for a given flitch thickness and sawing pattern, for instance rectangular sawing, the product mix changes as a function of length (Figure 50) and taper. This characteristic is due to the assumptions which limit the number of short, 2/3-tally boards in a flitch to one and which do not allow short, full-tally boards in a flitch to be recovered. Long logs or logs with large taper will thus reach their maximum capacity of 2/3-tally boards without being able to recover short, full-tally boards. This indicates that the proportion of full-tally boards will decrease as a function of length or taper. For a 6 feet long log, full-tally boards represent 78.23% of the total volume and 2/3-tally boards 20.36%. When a 16 feet long log is sawn, then full-tally boards represent only 72.63% of the volume, and 2/3-tally boards 26.05% (Figure 50).

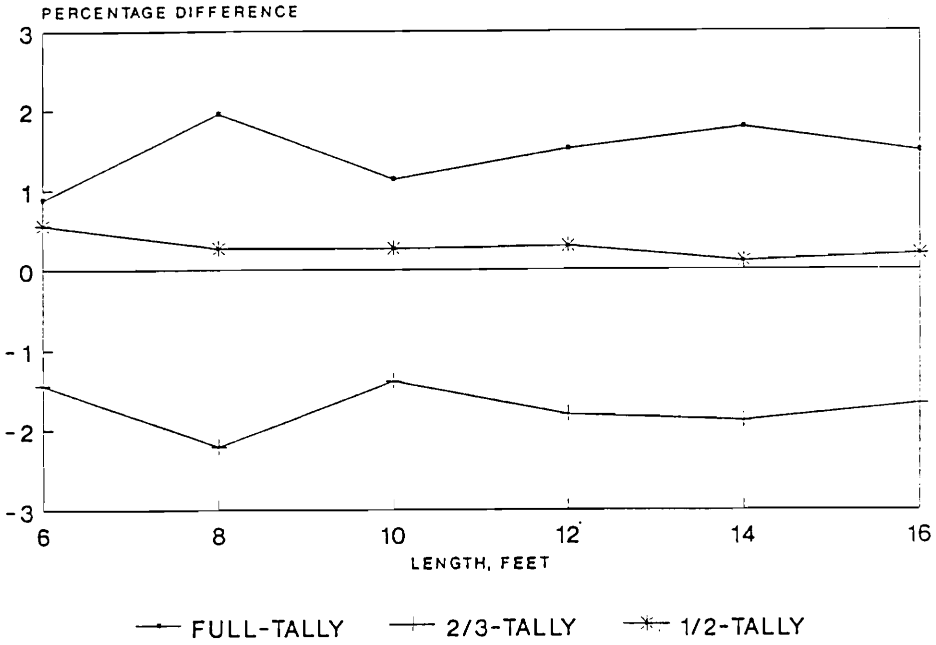

Figure 49. Changes in product mix as a function of length for rectangular sawing (6 and 8 inch commercial boards average).

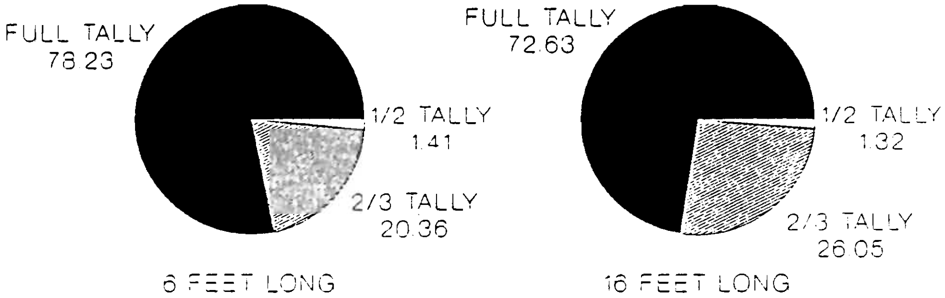

Figure 50. Product mix changes as a function of log length when sawing rectangular, full-tally boards. These are average values for all diameters for logs with 4 inches taper over 16 feet and when sawing 6 inch commercial boards.

4. Effect from a pencil slat producer's viewpoint.

The same sawing patterns that were used previously were used here. From a slat producer's viewpoint, the price given to each board was solely the one related to growth ring angle. Half-tally boards and commercial boards were not taken into account since they were assumed not to be sawn into slats.

a. Value. It was assumed that there were no price changes by the pencil stock producer to compensate for the changes in pencil stock quality regarding ring angle. The purchasing price of full-tally and 2/3-tally boards remained the same for both the rectangular and square sawing methods. Also, the higher volume recovery was not considered from a slat producer's viewpoint because they buy a fixed volume. These conditions meant that it was best to consider values on a per board foot basis for this part of the analysis. Values given in the output correspond to log values, and were divided by the combined volume of full-tally and 2/3-tally boards produced from the log. Even though it was noted above that commercial boards were not considered, their presence in a log still indeed affected the sawing pattern. Therefore, the two distinct cases were treated independently.

Figure 51, which represents the percentage difference when rectangular versus square full-tally boards were sawn, shows little value variation as a function of log length. Likewise, little variation as a function of taper can be seen (Appendix B). A large drop in the per board foot value occurs. Sawing 6 inch commercial boards will yield a loss of 6.56% and sawing 8 inch commercial boards a loss of 6.46%. The standard deviations associated to these values are 0.97% and 0.96% respectively. It is dangerous to compare these losses

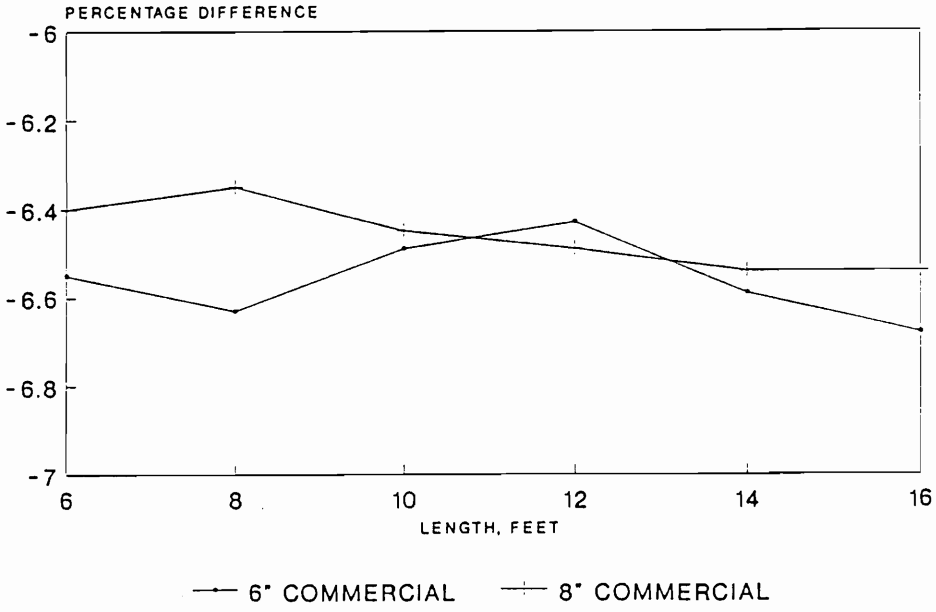

Figure 51. Average percentage differences in value between rectangular and square sawing as a function of log length from a pencil slat producer's viewpoint.

directly with gains obtained by the pencil stock producer since the relative values and basis scales used are different from both viewpoints. A per log approach was taken in one case and a per board foot in the other one. These important changes in value are due to major shifts in angle class mix.

b. Angle class mix. The changes in angle class mix were calculated the same way as for product mix. Relative percentages of classes one, two, and three were computed for both rectangular and square sawing. The differences between these two sawing methods were then found by subtracting the values corresponding to rectangular sawing from those corresponding to square sawing. Figure 52 is a good illustration of why these changes occurred. The diagonals on these two logs delimit the three angle class zones. Class 1 is the highest class yielding the best grade. Class 2 is the medium class, and class 3 the lowest class yielding the poorest grade. When square full-tally boards are sawn, the upper and lower triangles contain class 1 material since these boards can be oriented. When rectangular full-tally boards are sawn they can no longer be oriented. Those two zones then contain only class 3 material. This lowest grade material, which represented only 6.6% of the boards when squares were sawn, represented 53.18% of the boards when rectangles were sawn (Figure 53). This dramatic surge in production of the lowest grade material also implies a decrease in medium class material from 69.19% to 34.22% and of higher class material from 24.21% to 12.59%. Not only did an important value loss appear, but also the change in angle class mix might not be compatible with customers' demands.

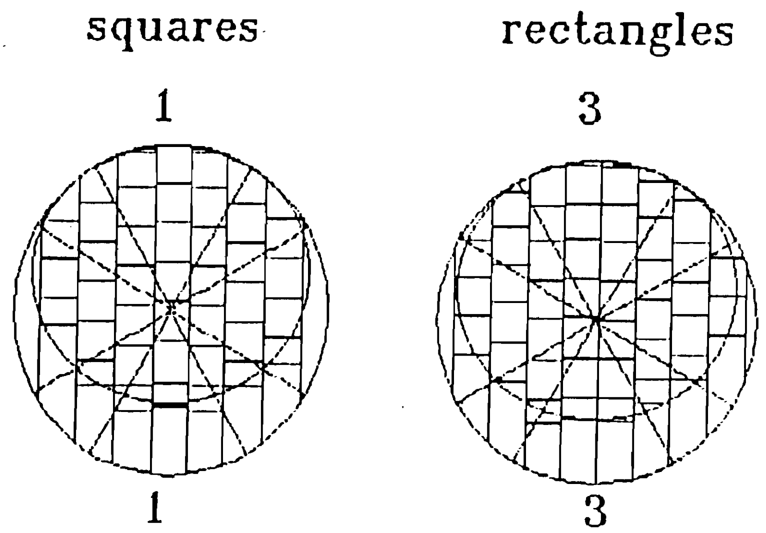

Figure 52. Example of sawing patterns when sawing rectangular and square full-tally boards.

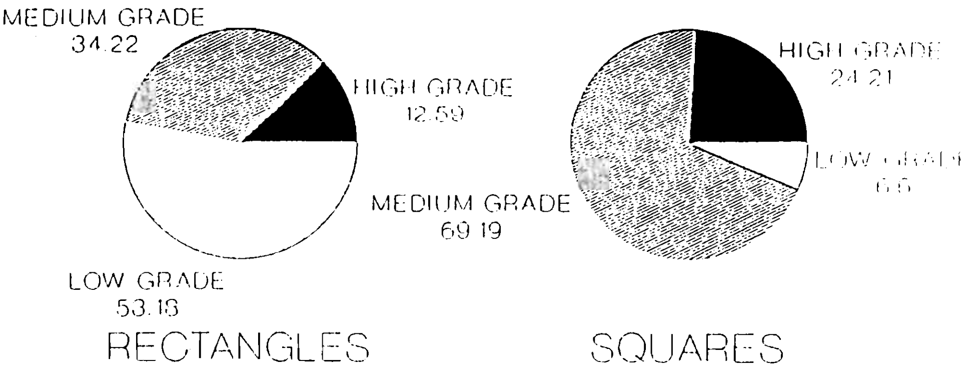

Figure 53. Changes in angle class mix between rectangular and square sawing.

5. Effect on the whole process.

In this case, both pencil stock prices as a function of board dimensions and angle class factors were considered simultaneously. The values given here were the ones being optimized by the program. On a per log basis, all average values are close to zero, with an increasing trend as a function of taper and length followed by a flattening of the curve and even a slight decrease for long logs when 8 inch commercial boards are sawn (Figure 54). The only loss that occurs on the average is for 6 feet long logs when 6 inch commercial boards are sawn. On average, a 0.15% increase in value can be recovered from a log when 6 inch commercial boards are sawn and 1.12% when 8 inch commercial boards are sawn. Relatively large standard deviations, of 1.73% and 2.08% respectively, show that the values will oscillate between positive and negative as a function of the log's characteristics. As explained in Section VII-B-3-b, the higher percentage difference for 8 inch commercial boards does not mean a higher absolute value. The specific shape of the curve is due to the assumption made on the sawing pattern. Two-thirds-tally boards, which proportionally increase as a function of length or taper (Figure 50) can not be oriented. Moreover, they will in general be of low ring angle quality since they are located on one edge of the flitch (Figure 52).

There is thus a slight overall gain when rectangular, full-tally boards are sawn instead of squares. Short logs, or logs with little taper will on average yield a loss. Large standard deviations make the results sensitive to the exact characteristics of the log. Also, other changes in manufacturing costs, such as drying or handling, were not considered and would affect the results.

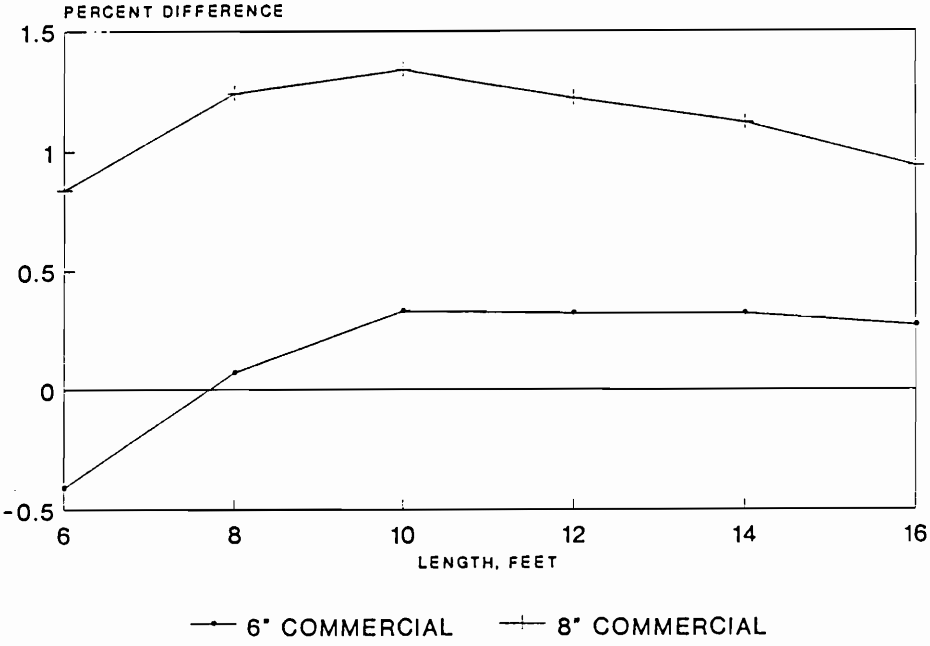

Figure 54. Average percentage differences in value recovery between rectangular and square sawing as a function of log length for the overall process.

6. Sensitivity to price variation.

Until this point, the data analyzed were the result of specific sets of prices given to pencil stock according to their dimensions and angle class factors. This section deals with what happens when those prices vary.

a. Variation of pencil stock prices. Runs were made with the two sets of prices as defined in Section VII-B-1. The angle class factors were the same for both runs and correspond to the ones previously used. Only 6 inch commercial boards were considered. Averages for all diameters were computed for both price sets. The volume, overall value, value from a pencil stock producer's viewpoint and value from a pencil slat producer's viewpoint were compared for the two runs. It appears that for volume and value, the data from the two price sets are very close to each other. There is on average a small 0.04 % decrease in the volume recovery and a 0.01 % increase in overall value recovery between price set 1 and price set 2. The values from a pencil stock and a pencil slat producer's viewpoints show respectively a decrease of 0.09 % and an increase of 0.02% between price set 1 and price set 2.

Data in Table 7 show these percentage variations as a function of log length and taper for both price sets. These data show a percentage difference between sawing rectangular versus square full-tally boards. Real values obviously show greater changes in value since higher prices are given to boards. However, the aim of this study was not to look at the real recovery but rather at the effect of sawing rectangular versus square full-tally boards. Therefore, these real increments in values were of no interest here and were not considered. Most logs have exactly the same sawing pattern for both price sets.

Table 7. Average percentage differences between rectangular and square sawing for the two price sets given to pencil stock.

	volume		overall value		value to a stock producer		value to a slat producer	
	set 1	set 2	set 1	set 2	set 1	set 2	set 1	set 2
taper								
2	5.34	5.26	-0.51	-0.51	5.95	5.86	-6.57	-6.56
4	5.75	5.71	0.29	0.25	6.52	6.40	-6.31	-6.30
6	6.01	6.00	0.40	0.42	6.75	6.70	-6.38	-6.39
7	6.19	6.14	0.42	0.46	7.01	6.90	-6.59	-6.54
length								
6	5.46	5.44	-0.41	-0.38	5.99	5.92	-6.50	-6.47
8	5.71	5.61	0.07	0.04	6.49	6.36	-6.51	-6.48
10	5.92	5.83	0.33	0.32	6.68	6.58	-6.42	-6.41
12	5.84	5.85	0.32	0.33	6.59	6.54	-6.33	-6.34
14	5.94	5.92	0.32	0.33	6.74	6.63	-6.46	-6.43
16	6.04	6.02	0.27	0.30	6.84	6.77	-6.57	-6.56

Changes occured only in a very few logs where a different opening face was selected yielding different volumes and values. The lower prices used in set 2 mean that angle class factors will have a more important weight in the overall price and in selecting the correct opening face. This explains the changes between the two price sets, and the decrease in volume and in value from a pencil stock producer's viewpoint in favor of an increase in overall value and in value from a pencil slat producer's viewpoint. Pencil stock prices have thus little effect on the changes that occur when rectangular instead of square pencil stock are sawn.

b. Variation of angle class factors. Runs were made with the three sets of angle class factors defined in Section VII-B-1. The prices of boards according to dimensions were left the same for the three runs and correspond to price set 1 used in Sections VII-B-3, 4 and 5. Again, only 6 inch commercial boards were considered. Averages for all diameters were computed for the three factor sets. There was very little change in the sawing pattern for the three factor sets as the almost similar percentage difference in volume suggests (Table 8). On the average, there was 0.02% difference in volume recovery between the results obtained with factor set 1 and factor sets 2 and 3. In addition, there was also little change in the product mix and angle class mix. There was also little change from a pencil stock producer's viewpoint since no angle class factor was considered there. The only changes from a pencil stock producer's viewpoint were linked to the changes in volume. On average, a 0.03% difference in value appeared between the results obtained with factor set 1 and factor set 3 and only 0.01% between the results from factor set 1 and factor set 2. From a pencil slat producer's

Table 8. Average percentage differences between rectangular and square sawing for the three angle class factors.

	volume			overall value		
	set 1	set 2	set 3	set 1	set 2	set 3
taper						
2	5.31	5.34	5.27	-2.40	-0.51	2.88
4	5.67	5.75	5.84	-1.53	0.29	3.57
6	6.06	6.01	6.23	-1.46	0.40	3.75
8	6.17	6.19	6.16	-1.46	0.42	3.88
length						
6	5.44	5.46	5.42	-2.27	-0.41	2.95
8	5.67	5.71	5.65	-1.81	0.07	3.43
10	5.96	5.92	5.95	-1.54	0.33	3.68
12	5.82	5.84	5.87	-1.51	0.32	3.63
14	5.89	5.95	5.98	-1.53	0.32	3.69
16	6.03	6.04	6.07	-1.61	0.27	3.73

	value stock producer			value slat producer		
	set 1	set 2	set 3	set 1	set 2	set 3
taper						
2	5.94	5.95	5.94	-8.48	-6.57	-3.15
4	6.45	6.52	6.57	-8.08	-6.31	-3.05
6	6.80	6.75	6.79	-8.27	-6.38	-3.07
8	6.99	7.01	7.00	-8.45	-6.59	-3.15
length						
6	6.00	5.99	6.01	-8.40	-6.50	-3.14
8	6.45	6.49	6.48	-8.35	-6.51	-3.12
10	6.72	6.68	6.75	-8.33	-6.42	-3.12
12	6.60	6.60	6.62	-8.17	-6.33	-3.03
14	6.69	6.74	6.75	-8.26	-6.47	-3.10
16	6.82	6.84	6.85	-8.42	-6.57	-3.14

viewpoint, the changes in angle class factors have a great impact on the percentage difference in value between rectangular and square sawing. On average, the three angle class factor sets yielded a loss of 8.32%, 6.46% and 3.11% respectively (Figure 55). In factor set 1 there was a 30% difference in the value given to class 1 and 3. This difference was 23% for factor set 2, and 10% for factor set 3 (see Section VII-B-1). Thus the larger the difference in the factors given to the highest and lowest angle grades, the larger the loss from a pencil slat producer's viewpoint. This sensitivity to angle class factors is due to the important changes in angle class mix between rectangular and square sawing (Section VII-B-4-b). The large increase in class 3 material that occurs when sawing rectangular pencil stock means that the smaller the difference given to the three factors, the less loss that will occur. When the overall process is considered, the changes are of the same magnitude. Angle class factor set 1 yields an average loss in value of 1.71%, whereas factor set 2 yields an average gain of 0.15%, and factor set 3 an average gain of 3.52%. The difference among the three factor sets remains close to constant as a function of length or taper as shown in Figure 56. Angle class factors thus have an important impact on the overall value and from a pencil slat producer's viewpoint. The value given to each angle class may change a loss into a gain. Because of the important changes in angle class mix, the economical feasibility of sawing rectangular versus square pencil stock will partially depend on the relative value given to each angle class.

7. <u>Area</u>.

The area option (see Section VI-C-1-e) was added to simulate grading inaccuracies resulting from the

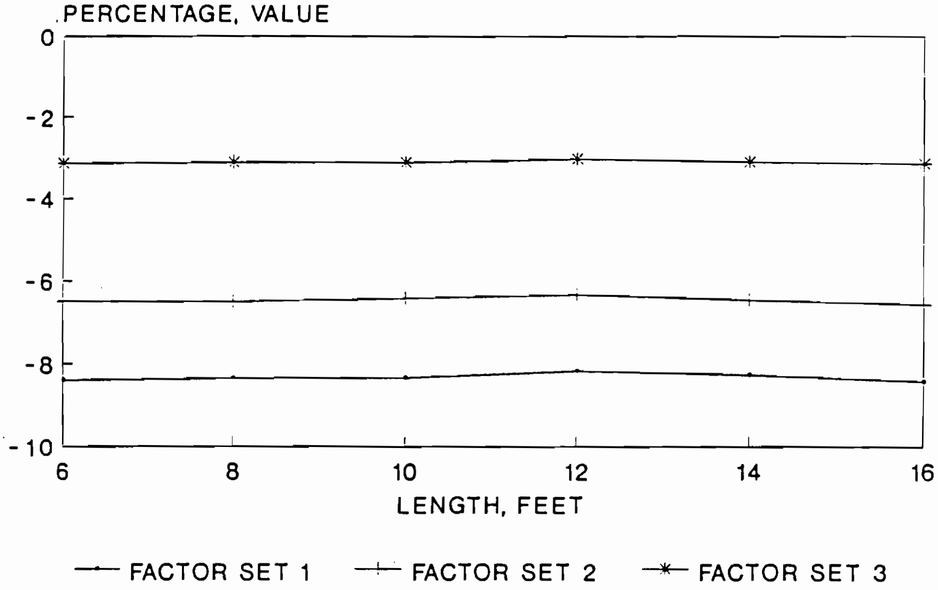

Figure 55. Effects of angle class price factors on value from a pencil slat producer's viewpoint.

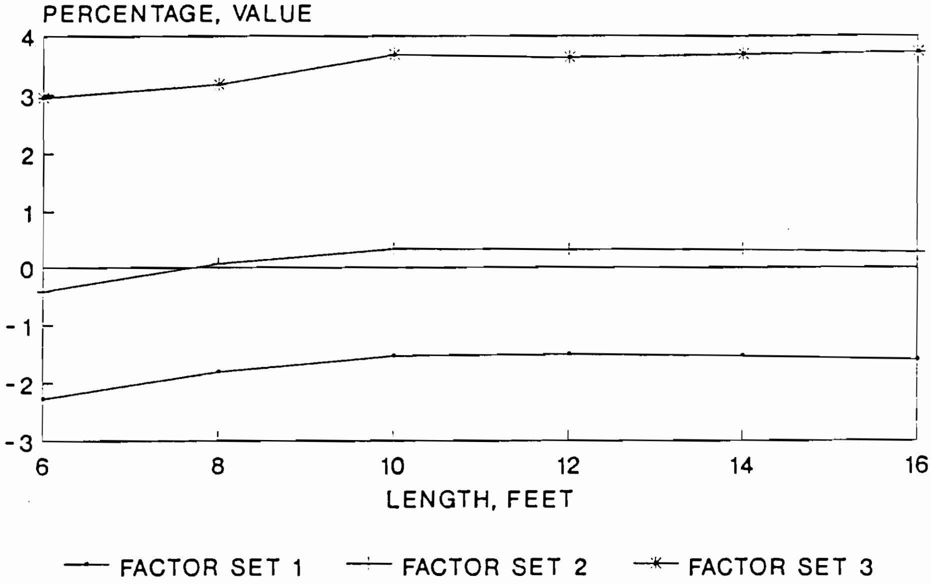

Figure 56. Effects of angle class price factors on the overall value.

difficulties involved in a grader being able to detect small areas with different ring angles. The aim was to assess how allowing a certain amount of lower grade material in pencil stock affects the results regarding rectangular versus square sawing. Runs were made with two different areas, 10% and 20%, plus one run with no area allowed which corresponds to the data used in previous sections. Runs were made only for 6 inch commercial boards. The six logs considered had the characteristics shown in Table 9.

Table 9. Characteristics of logs used to analyze the effects caused by varying the amount of lower grade material allowed.

log	1	2	3	4	5	6
taper (in/16ft)	2	6	2	6	2	6
length (ft)	6	6	12	12	16	16

The same approach of using average percentage differences to analyze the results was taken. No major changes in volume or value recovery appeared when allowing different areas of lower grade material. The maximum difference in the average volume was 0.24%, 0.44% for the overall value, 0.23% for value from a pencil stock producer's viewpoint, and 0.55% for value from a pencil slat producer's viewpoint (Table 10). No trend seems to appear as a function of the area allowed. In order to have more points to detect a trend, two additional runs were made for log 5 with areas of 5% and 15% (Table 11). For this specific log, results show no trend as a function of the area allowed. The reason for so little change is that both squares and rectangles are affected by these areas of lower grade allowed.

Table 10. Average percentage differences between rectangular and square sawing for different areas of lower grade material allowed in pencil stock.

log	area %	volume change	overall value change	change in value to a stock producer	change in value to a slat producer
1	0	5.46	-0.68	5.79	-6.56
	10	5.46	-0.78	5.76	-6.66
	20	5.47	-0.99	5.68	-6.76
2	0	4.88	-0.84	5.44	-6.41
	10	5.16	-1.28	5.51	-6.96
	20	4.98	-1.20	5.42	-6.77
3	0	5.13	-0.59	5.85	-6.57
	10	5.12	-0.81	5.89	-6.81
	20	5.26	-0.52	5.93	-6.57
4	0	6.62	0.85	7.22	-6.35
	10	6.53	0.64	7.24	-6.60
	20	6.77	0.54	7.43	-6.83
5	0	5.60	-0.01	6.49	-6.57
	10	5.78	-0.45	6.55	-7.07
	20	5.67	-0.24	6.57	-6.85
6	0	6.35	0.58	7.16	-6.55
	10	6.34	0.50	7.39	-6.86
	20	6.24	0.35	7.21	-6.86

Table 11. Average percentage differences between rectangular and square sawing for different areas of lower grade material allowed in pencil stock. Five different areas were allowed for a log 16 feet long with 2 inches taper over the length.

log	area %	volume change	overall value change	change in value to a stock producer	change in value to a slat producer
5	0	5.60	-0.01	6.49	-6.57
	5	5.59	-0.23	6.46	-6.77
	10	5.78	-0.45	6.55	-7.07
	15	6.65	-0.20	6.40	-6.67
	20	5.67	-0.24	6.57	-6.85

Changes in angle class mix for this log sample are shown in Figure 57. Little change occurred between areas of 10% and 20%. However, between areas of 0% and 10%, an increase in class 1 appeared. When sawing rectangular pencil stock, the increase was from 13% to 20%, and when sawing square pencil stock it was from 24% to 41%. A decrease from 69% when no area was allowed to 52% when 10%area was allowed also appeared in the production of class 2 material when sawing square pencil stock. Similarly, a decrease from 55% to 48% in the production of class 3 material appeared when sawing rectangular pencil stock. There were thus changes in angle class mix, which in real values resulted for both sawing methods in higher value recoveries. However, percentage differences showed little variations in volumes and values. This indicated that the analysis made in the previous sections, where no area of lower grade material was allowed in pencil stock, was truly indicative of the effects associated with rectangular versus square sawing.

C. RING DENSITY.

Ring density in a pencil slat is not as much of a critical feature as is ring angle; however, it is taken into account for grading slats. It should also be noted that having rectangular instead of square full-tally boards will not change a board's ring count unless it is on the density zone boundary. Ring density will thus have only a minor impact in the decision whether to saw rectangular or square pencil stock. Therefore, the part of the analysis regarding ring density was not as extensive as the part regarding ring angle.

The data used were the same as that defined in Section VII-B-1 for the ring angle analysis. However, the

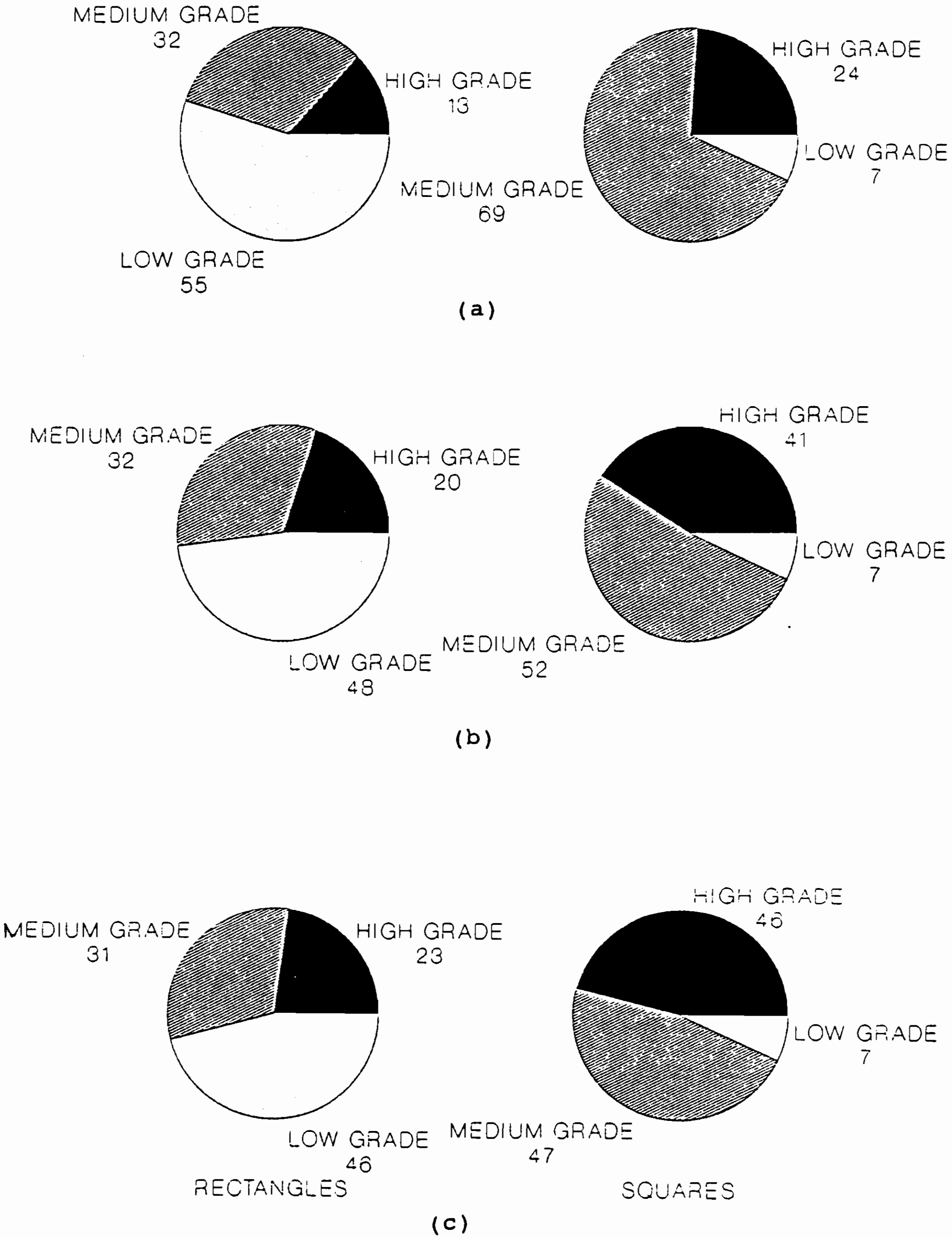

Figure 57. Changes in angle class mix between rectangular and square sawing. Three different areas defining the amount of lower grade allowed in pencil stock were (a) 0%, (b) 10%, and (c) 20%.

runs were limited to a sample containing only logs of lengths 6, 12 and 16 feet, and of tapers of 2 and 4 inches over a length of 16 feet. Ring angles were not considered here. Only 6 inch commercial boards were assumed to be sawn. Three sets of runs were made with three different radii defining the limit between the two density classes. The three radii, referred later to simply as density limits, were:

Run 1, 0% of total log radius.
Run 2, 50% of total log radius.
Run 3, 70% of total log radius.

Factors given to the density classes were value of 1 for class 1 (high grade), and 0.7 for class 2 (low grade). Also for the density limit of 50%, two other runs were made with different factors given:

	class 1	class 2
Run 4	1	0.8
Run 5	1	0.6

The same percentage difference approach as in Section VII-B was taken for this analysis. The limited number of runs made did not provide sufficient data to define any trend as a function of length or taper. The average increase in volume was of the same magnitude as the one found when ring angles were considered. This was expected since the size reduction on each board remained the same in both cases and since prices had little effect on volume (Section VII-B-6). The average percentage differences in volume for all five runs varied from 5.54% to 5.73% (Table 12). Thus, little change occurred due to the characteristics given to ring density. From a pencil stock producer's viewpoint, the percentage increase in value recovery was directly linked to the increase in volume as was found when considering ring angle. On average for the five runs, the value increase was between

Table 12. Average percentage differences between rectangular and square sawing as a function of ring density.

	volume change	overall value change	change in value to a stock producer	change in value to a slat producer
run 1	5.62	6.68	6.25	0.44
run 2	5.54	6.80	6.21	0.62
run 3	5.71	6.34	6.34	0.00
run 4	5.66	7.00	6.34	0.70
run 5	5.73	6.66	6.40	0.28

Table 13. Changes in ring density class mix.

	squares		rectangles	
	class 1 %	class 2 %	class 1 %	class 2 %
run 1	100	0	100	0
run 2	50	50	51	49
run 3	12	88	14	86

0.63% to 0.68% higher than the volume increase. This range of values matches what was found when considering ring angle in Section VII-B, where for the same log sample the difference was 0.64%. Contrary to ring angle, the effect on the value from a pencil slat producer's viewpoint and on the overall value was a positive gain. The same per board foot approach was taken as in Section VII-B-4.

Changes in density class mix were small when changing from rectangular to square sawing. However, rectangular sawing yielded a slightly higher proportion of class 1 material than did square sawing. Table 13 shows that for a density limit of 50% (run 2), the increase was 1%, while it was of 2% for a density limit of 70% (run 3). These slight changes in density class mix make the value from a pencil slat producer's viewpoint increase slightly. This increase is 0.44% for a density limit of 70% (run 3) and 0.62% for a density limit of 50% (run 2). A variation of the factor values will also affect the results slightly. The larger the difference in values given to both density classes, the higher the percentage differences in value will be when rectangles versus squares are sawn. The increase in value was 0.70% when the class 2 factor was given the value of 0.60 (run 5), and it was 0.28% when the class 2 factor was given the value 0.80 (run 4). The overall value increased due to the increase in volume and the changes in density class mix. The average ranged from a 6.34% gain to a 6.60% gain with no trend showing for the log sample used. As from a pencil slat producer's viewpoint, the increase in overall value varied as a function of the values given to the density class factors. The larger the difference was between class 1 and 2, the higher the recovery (Table 12).

Thus, for the specific case of manufacturing rectangular versus square pencil stock, ring density had little effect on the decisions made. This was especially true in comparison to the important effects caused by changes in the ring angle.

VIII. CONCLUSIONS

The Best Opening Face log breakdown model was successfully modified to keep track of growth ring angle and growth ring density in boards. The application to pencil stock manufacturing, which considered rectangular versus square sawing, showed a number of significant results.

1) There was a substantial increase in volume recovery when sawing rectangles due to a reduction in flitch thickness. The change in volume recovery varied as a function of log length, taper and diameter. The average volume increase was 5.90%.
2) There was a substantial increase in value recovery from a pencil stock producer's viewpoint when sawing rectangles mainly due to the improvement in volume recovery. The average percentage increase in value was 6.85%.
3) There was a substantial decrease in value recovery from a pencil slat producer's viewpoint when sawing rectangles due to important changes in the angle class mix. The average loss in value was 6.51% per board foot. The low quality pencil stock regarding ring orientation, which represented 6.60% of the production when sawing square full-tally boards, represented 53.18% of the production when sawing rectangular full-tally boards.
4) When combining both pencil stock and pencil slat producers' viewpoints, there was a slight increase in overall value. The average increase in overall value was 0.64% per log.
5) The results were sensitive to relative prices given to pencil slats regarding their ring orientation.

6) Sawing rectangular or square pencil stock was affected very little by growth ring density.

The results given considered only changes in the volume and value recovery of pencil stock. They did not take into account other changes that could occur when rectangular pencil stock is processed and that could affect the values (labor, drying, machines, etc.).

This model has some limitations and could be improved further. Pencil blocks could be considered instead of full length pencil stock. Other sawing patterns could be simulated, for instance cant sawing and full-taper sawing for the log. From a more general standpoint, the algorithm used to compute ring angle and ring density could be implemented in other programs dealing with other aspects of a board's quality.

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APPENDICES

APPENDIX A

VERIFICATION, INPUT, OUTPUT

Input data used to generate curves comparing BOF to BOFRING.

```
run 1:  BOF
 11   1123111  1 1 213.0 21.0    6.0   .001    .125   .125      .078125
.0625      .0625     .078125   .078125 .078125 .078125 .078125 .078125
-1.0         61616  1.                                          5
2.0       3.0        2.0       3.0       5.943     7.772
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
```

```
       BOFRING

 11   1123111  1 1 213.0 21.0    6.0    .001    .125  .125      .078125
.0625      .078125   .078125    .078125   .078125   .078125
.25 .25   2  60. 30.   1.  1.   1.
-1.0         61616  1.
3.0       2.0        2.0       3.0       5.943     7.772
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
```

```
run 2:  BOF

 11   1123111  1 1 213.0 21.0   4.0  .001   .125    .125       .078125
.0625      .0625     .078125  .078125 .078125 .078125 .078125 .078125
-1.0         61212  1.                                 5
2.0       3.0        2.0       3.0       5.943     7.772
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
```

```
       BOFRING

 11   1123111  1 1 213.0 21.0   4.0  .001   .125    .125       .078125
.0625      .078125   .078125    .078125   .078125   .078125
.25 .25   2  60. 30.   1.  1.   1.
-1.0         61212  1.
3.0       2.0        2.0       3.0       5.943     7.772
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
```

run 3:   BOF

```
 11   1123111  1 1 213.0 21.0   2.0  .001   .125     .125      .078125
.0625      .0625     .078125   .078125 .078125 .078125 .078125 .078125
-1.0         61010  1.                                            5
2.0       3.0        2.0       3.0       5.943     7.772
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
```

BOFRING

```
 11   1123111  1 1 213.0 21.0   2.0  .001   .125      .125      .078125
.0625      .078125   .078125   .078125  .078125  .078125
.25 .25   2  60. 30.   1.  1.   1.
-1.0         61010  1.
3.0       2.0        2.0       3.0       5.943     7.772
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
530. 530. 530. 530. 530. 530. 530. 530.
```

Record of all values from all opening faces tried in a run in order to find the best solution (Chapter VII-A-4). Values are expressed in dollars per log.

run 1	run 2	run 3	run 4	run 5	run 6
14.10	27.52	31.08	22.64	8.06	5.35
13.87	27.65	30.30	22.75	8.38	5.52
13.77	27.34	30.26	22.72	8.38	5.48
12.95	27.50	30.08	22.93	8.32	5.51
13.05	27.76	30.62	22.12	8.27	5.76
13.58	27.68	30.72	22.57	8.31	5.34
12.58	27.86	30.39	23.13	8.61	5.31
12.68	27.57	29.80	22.60	8.51	5.54
12.79	27.22	30.00	22.23	8.73	5.58
	26.38	29.70	22.63	8.59	5.77
		29.80	22.49	8.84	6.14
		30.58	22.33	8.59	5.77
		31.42	22.44	8.23	5.58
			22.61	8.75	
				8.34	
				8.23	
				8.60	
				8.84	
				8.59	
				8.73	
				8.60	
				8.31	
				8.28	
				8.32	
				8.37	
				8.38	
				7.76	
				7.77	
				7.54	
				7.48	
				7.54	
				7.48	
				7.54	
				7.77	
				7.55	
				7.76	

Example (with run 5) of how hand calculations were made, and of how output tables are presented.

Input data.

```
 11    123111    1 216.0 16.0    8.0    .001      .125      .125
.034       .018      .018       .018      .018      .018
.66 .66 111  60. 30.  1.23  1.11  1.0      .5  1.2  1.
-1.0         4 6 6  1.                             20
2.93      1.5        2.0       3.09      5.943     7.772
100. 100. 100. 100. 100. 100. 100. 100.
110. 110. 110. 110. 110. 110. 110. 110.
120. 120. 120. 120. 120. 120. 120. 120.
 60.  60.  60.  60.  60.  60.  60.  60.
 60.  60.  60.  60.  60.  60.  60.  60.
```

Output data.

- alpha is the angle limit in degrees between class 1 and 2.
- beta is the angle limit in degrees between class 2 and 3.
- the density limit is given as entered in card 3.
- the amount of lower grade allowed in a board is also given as entered in card 3.
- the next part of the output gives the ring angle and density class of each lumber. Each row represents a flitch starting on the right hand when facing the log's large-end. Within a line, the first number represents the first board starting at the top of the flitch. Each number represents the ring angle or density class. A 0 represents a commercial board.

Output tables

```
                        BEST OPENING FACE          LUMBER
         LOG          DISTANCE FROM CENTER           RECOVERY  LUMBER   LUMBER
       DIAMETER  LENGTH      LEFT      RIGHT    RANGE      FACTOR   TALLY    VALUE
         (IN.)    (FEET)      (IN.)     (IN.)                       (BD.FT.)
0                    6        7.457     7.863     1 ST       7.68      78      8.84
+        16.0

                   VOL(FULL)   VOL(2/3)   VOL(1/2)     VAL(PM)   VAL(CALCED)
                     40.50       19.00         .00         8.03          66.64
0
           SAWING SEQUENCE:  1  1  1  1  1                                OFFSET: 1.421 IN.
0
                                         NUMBER OF PIECES
                                              4 FT    6 FT
0                                  3X1.5       0       0
0                                  3X2         2       5
0                                  3X3         0       9
0                                  3X6         0       2
0                                  3X8         0       0



             ALPHA      BETA       DENSITY LIMIT     AREA LOWER GRADE(%)
             60.00      30.00          0.50               .00

             FACTOR     ANGLE 1       ANGLE 2         ANGLE 3
                         1.23          1.11            1.00

             FACTOR      DENSITY 1        DENSITY 2
                           1.20             1.00


angle classification                      density classification


  2  2  2                                  1  2  2

  3  3  0  3                               1  2  0  2

  3  3  0  3                               1  2  0  2

  3  3  2  3  3                            1  2  2  2  2

  2  1                                     1  1
```

Example of hand calculation. The positions of the lumber in the log were found with the help of graphics.

volume of full tally (number of pieces * length * nominal volume):

9 * 6 * .75 = 40.5 = VOL(FULL)

volume of 2/3 tally (number of pieces * length * nominal volume):

((2 * 4) + (5 * 6)) * .5 = 19 = VOL(2/3)

volume of 1/2 tally (number of pieces * length * nominal volume):

0 = VOL(1/2)

lumber tally (sum of volumes computed above + volume of commercial boards):

40.5 + 19 + 0 + (2 * 6 * 1.5) = 77.5 = LUMBER TALLY

value for P&M (sum of each category's volume * their respective price):

(40.5 * .12) + (19 * .11) + (18 * .06) = 8.03 = VAL(PM)

value for California Cedar (board size * angle factor * density factor * length):

flitch 1 (.5 * (1.11 * (1 + 1.2)) + .75 * (1.11)) *6 = 12.32

flitch 2 (.75 * (1.2 + 1)) * 6 + (.5 * 4) = 11.9

flitch 3 .75 * (1.2 + 2) * 6 = 14.4

flitch 4 (.5 * 1.2) + .75 * (2 + 1.11)) * 6 + (.5 * 4) = 19.59

flitch 5 .5 * (1.2 * (1.11 + 1.23)) * 6 = 8.42

VAL(CALCED) = 66.63

combined lumber value (board size * price * angle factor * density factor * length):

flitch 1 (.5*.11*(1.11*(1+1.2))+.75*.12*(1.11))*6 = 1.405

flitch 2 (.75*.12*(1.2+1))*6+(.5*.11*4) = 1.408

flitch 3 .75*.12*(1.2+2)*6 = 1.728

flitch 4 ((.5*.11*1.2)+.75*.12*(2+1.11))*6+(.5*.11*4) = 2.295

flitch 5 .5*.11*(1.2*(1.11+1.23))*6 = 0.926

commercial board 2*6*1.5*.06 = 1.08

LUMBER VALUE = 8.842

Example of output as given in the analyses format. The data from left to right are:

- diameter
- length
- taper
- commercial board
- total volume recovery
- total value recovery
- number of full-tally pieces free of wane
- number of full-tally pieces with wane
- number of 2/3-tally pieces
- number of 1/2-tally pieces
- volume of full-tally produced
- volume of 2/3-tally produced
- volume of 1/2-tally produced
- value for pencil stocks' manufacturer
- value for slats' manufacturer
- number of pieces with ring angle in class 1
- number of pieces with ring angle in class 2
- number of pieces with ring angle in class 3
- number of pieces with ring density in class 1
- number of pieces with ring density in class 2

```
14.00  6  2  1   57   33.71  6  4  0  0   26   12   0   5.33  380.50  0.  4.  6.  0.  0.
15.00  6  2  1   63   37.80  8  3  0  0   36    9   0   6.08  316.80  0.  4.  7.  0.  0.
16.00  6  2  1   68   47.00  8  4  0  1   35   12   2   6.64  394.35  0.  3. 10.  0.  0.
17.00  6  2  1   83   56.45 10  6  0  1   44   18   2   8.38  471.23  2.  4. 11.  0.  0.
18.00  6  2  1   87   64.38 13  4  0  0   57   10   0   8.89  535.96  1.  5. 11.  0.  0.
19.00  6  2  1  104   68.89 12 10  0  1   52   30   2  10.78  583.43  2.  7. 14.  0.  0.
20.00  6  2  1  122   85.11 19  6  0  0   85   18   0  13.01  709.41  3.  8. 14.  0.  0.
21.00  6  2  1  132   92.92 20  8  0  0   90   24   0  14.21  779.97  2. 10. 16.  0.  0.
22.00  6  2  1  144   99.84 23  6  0  2  103   18   4  15.62  833.36  3.  9. 19.  0.  0.
23.00  6  2  1  158  115.60 29  3  0  0  129    9   0  17.42  957.69  4. 10. 18.  0.  0.
24.00  6  2  1  171  119.67 28  9  0  0  123   27   0  18.86 1003.22  6. 11. 20.  0.  0.
25.00  6  2  1  192  129.75 33  7  0  2  146   21   4  21.35 1080.38  5. 14. 23.  0.  0.
```

APPENDIX B

ANALYSIS DATA

Average percentage differences in overall value between rectangular and square sawing for log diameters ranging from 14 inches to 25 inches.

taper inches	length feet	average value 6" commercial percent	average value 8" commercial percent
2	6	-0.67	1.10
	8	-0.72	1.16
	10	-0.81	0.33
	12	-0.59	0.48
	14	-0.23	0.55
	16	-0.01	0.00
4	6	-0.92	0.81
	8	-0.24	0.95
	10	0.59	1.24
	12	0.85	1.55
	14	0.67	1.74
	16	0.79	1.74
6	6	-0.84	0.36
	8	0.52	1.20
	10	1.15	2.31
	12	0.88	1.70
	14	0.12	1.13
	16	0.59	1.31
8	6	0.81	1.11
	8	0.73	1.64
	10	0.40	1.47
	12	0.15	1.15
	14	0.71	1.07
	16	-0.28	0.74

Average percentage differences in overall value between rectangular and square sawing for all diameters from 14 inches to 25 inches.

(a) Taper fixed, all lengths combined.

(b) Length fixed, all tapers combined.

taper inches	average 6" percent	average 8" percent
2	-0.51	0.60
4	0.29	1.34
6	0.40	1.34
8	0.42	1.20

length feet	average 6" percent	average 8" percent
6	-0.41	0.84
8	0.07	1.24
10	0.33	1.34
12	0.32	1.22
14	0.32	1.12
16	0.27	0.94

Average percentage differences in value from a pencil stock producer's viewpoint between rectangular and square sawing for log diameters ranging from 14 inches to 25 inches.

taper inches	length feet	average value 6" commercial percent	average value 8" commercial percent
2	6	5.80	6.89
	8	5.67	6.76
	10	5.66	6.23
	12	5.85	6.37
	14	6.24	6.65
	16	6.49	6.49
4	6	5.64	6.78
	8	6.36	6.91
	10	6.81	7.21
	12	6.56	7.50
	14	6.72	7.87
	16	7.02	7.68
6	6	5.44	6.40
	8	6.81	7.06
	10	7.13	8.44
	12	7.23	7.68
	14	6.70	7.21
	16	7.18	7.28
8	6	7.07	7.01
	8	7.13	7.44
	10	7.13	7.69
	12	6.75	7.57
	14	7.28	7.11
	16	6.67	7.21

Average percentage differences in value from a pencil stock producer's viewpoint between rectangular and square sawing for all diameters from 14 inches to 25 inches.

(a) Taper fixed, all lengths combined.

(b) Length fixed, all tapers combined.

taper inches	average 6" percent	average 8" percent
2	5.95	6.57
4	6.52	7.33
6	6.75	7.35
8	7.01	7.34

length feet	average 6" percent	average 8" percent
6	5.99	6.77
8	6.49	7.04
10	6.68	7.39
12	6.60	7.28
14	6.74	7.21
16	6.84	7.17

Average percentage differences in value from a pencil slat producer's viewpoint between rectangular and square sawing for log diameters ranging from 14 inches to 25 inches.

taper inches	length feet	average value 6" commercial percent	average value 8" commercial percent
2	6	-6.56	-6.08
	8	-6.52	-5.88
	10	-6.60	-6.15
	12	-6.57	-6.16
	14	-6.59	-6.37
	16	-6.57	-6.57
4	6	-6.69	-6.24
	8	-6.71	-6.24
	10	-6.31	-6.23
	12	-5.82	-6.23
	14	-6.12	-6.39
	16	-6.25	-6.17
6	6	-6.41	-6.32
	8	-6.37	-6.17
	10	-6.00	-6.37
	12	-6.33	-6.15
	14	-6.59	-6.29
	16	-6.56	-6.16
8	6	-6.34	-6.26
	8	-6.42	-6.09
	10	-6.75	-6.42
	12	-6.58	-6.65
	14	-6.55	-6.29
	16	-6.90	-6.59

Average percentage differences in value from a pencil slat producer's viewpoint between rectangular and square sawing for all diameters from 14 inches to 25 inches.

(a) Taper fixed, all lengths combined.

(b) Length fixed, all tapers combined.

taper inches	average 6" percent	average 8" percent
2	-6.66	-6.42
4	-6.46	-6.49
6	-6.44	-6.39
8	-6.69	-6.54

length feet	average 6" percent	average 8" percent
6	-6.55	-6.40
8	-6.63	-6.35
10	-6.49	-6.45
12	-6.43	-6.49
14	-6.59	-6.54
16	-6.68	-6.54