A SIMULATION MODEL FOR LOG YIELD STUDY

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This is to certify that the

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ABSTRACT

A SIMULATION MODEL
FOR LOG YIELD STUDY

by Jordan Alexander Tsolakides

A digital computer analytical technique has been developed as a means of studying the effect of alternative sawing methods on the grade and volume yield of the same log. Real activities are simulated through the use of the computer.

The work is methodological in nature. Its primary purpose is the development of a model which can be used to increase production efficiency. In addition, the study has the objectives of developing a circumference and defect reading method and of demonstrating the feasibility of the use of the model in a pilot project. This model, developed in order to accumulate data for analysis purposes, should prove to be superior to methods available in the past. Step by step procedures are provided for experimental applications.

The input data for the simulated processes are derived from a sample of six logs sliced into disks. A measuring method, developed along with the main model, is used to record circumference points and the location of defects on the disks. The six logs are used to illustrate the simulated operations and are sawn, via simulation, 164 times.

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The model consists of the main program and three supplementary subprograms; one for sawing lumber, one for rotating the log into a new position, and one for cant production. Allowance has been made for one-eighth and one-fourth of an inch kerf sizes, which can simulate band sawing, gang sawing, and circular sawing. The size, board feet, and defects are given for each board produced.

The model, written in FORTRAN language, has been executed on a CDC 3600 computer. It takes approximately three minutes to "saw" a log 16 times, in four different positions, and to measure the resulting boards.

Several sawing methods have been utilized to test the workability of the model. This model, a simulation analysis of log yield (SALY), shows the feasibility of a new approach to solving the vital question of how best to saw a log.

A SIMULATION MODEL

FOR LOG YIELD STUDY

By

Jordan Alexander Tsolakides

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Jordan Alexander Tsolakides

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In the past several years, the sawmill industry has made significant improvements in mechanization. From headsaws to lumber sorting, the flow of materials is being automated to greater degrees. Push-button operations with memory-control systems are becoming increasingly a part of the sawmill operation. Improved equipment and new types of handling and controls are reducing production cost and improving the quality of the products. Still, there remain unanswered questions relating to log characteristics and the appropriate sawing method for maximum return.

The nature of the logs presents the greatest problem since no two logs are alike. Studies conducted by various investigators applying a variety of sawing methods, have improved considerably the knowledge about the problem of optimum log yield. Statistically designed experiments as well as linear programming and computer (mathematical) models, are some of the techniques which have been employed in order to find the most profitable way of sawing the log.

However, the subject of more efficient conversion of logs into lumber needs further investigation as to the effect of log characteristics on yields of factory grades of lumber. More adequate information is needed as a basis for selection of the sawing procedures best suited to maximize the value of lumber produced from given qualities of log.

The effect of visible external defect orientation to the sawing faces of the log has been and is still being studied. Nevertheless, the effect of the same defects, when several available sawing methods are tested on the same log, needs further study in order to evaluate the log quality and variations in the grade of lumber as influenced by the sawing methods. What is needed is an analytical technique which will allow several sawing methods to be tried on the same log. The two main sources of variation in the yield, namely log characteristics and sawing methods, should be examined for their impact upon the yields obtainable. It is within this framework that this study will attempt to develop a methodology for the investigation of this problem.

Objectives of the Study

The general objective of this study is to develop and test a model of log breakdown operation wherein sawing activities can be simulated to the maximum extent possible. Such a technique will allow several sawing methods to be tested on the same log. Variations in the total yield from a particular hardwood log can be explored as a function of log characteristics and sawing methods. Such an investigation can produce information to be used for the development of more efficient sawing practices.

The specific objectives of the study are:

1. To develop a method of analysis for the investigation of the effect of sawing method on yield. With the use of a computer simulation, comparisons of the effect of the changing

relationship between log characteristics and sawing methods on the final output can be studied, avoiding laborious physical experiments.

2. To demonstrate the feasibility of the use of such a model with a pilot project.

II. LITERATURE REVIEW AND PROBLEM ANALYSIS

The Hardwood Grade Lumber Yield Problem

The End Use Consideration

Hardwood lumber is used mainly in manufacturing industries. Of the total hardwood lumber used for all purposes (6) in 1960, about 92 percent was consumed in manufacturing industries, with oak comprising one-third of the volume. Of the approximately 5.6 billion board feet consumed by the manufacturing industries, about 3.1 billion or 55 percent was used by industries classified (SIC) as Lumber and Wood Products. The largest item in this group, about 1.1 billion board feet, was consumed by the Dimension and Flooring Industries.

The other large industrial group was the Furniture and Fixture Industry with a consumption of 1.6 billion board feet or about 28 percent of the total. The largest amount in this group, about 1.3 billion board feet, was consumed by the Household Furniture Industry.

Hardwood lumber, when used in manufacturing is converted and utilized in random lengths and widths of relatively clear dimensions according to the special requirements of each industry's operations. The furniture industry, which is the biggest hardwood lumber user, requires clear or practically clear dimensions for its products. Since most hardwood lumber eventually is cut up into various sizes of clear dimensions, the value of rough boards depends simply on the amount of usable material they contain.

What the end user (manufacturing industry) is interested in, is the percent of clear area each grade of lumber will finally yield when converted into specific size dimensions. This end use calls for a variety of sizes according to the particular needs and types of end products. For example, different sizes are needed for solid parts of case goods, or core materials for plywood and still other sizes for chairs and tables.

Unlike other commodities, the rough lumber used by the manufacturer varies in quality and is seldom free of defects, resulting in waste when manufactured. The utility, therefore, of rough lumber varies and is a function of the grade of lumber used for the conversion of rough boards into blank dimension sizes. Utility is defined as the ratio of the volume of finished blank sizes of wood parts to the volume of rough lumber from which it was sawn (4). The percent utility, or yield, from the lumber of a given grade can be used as an estimating factor of the obtainable clear material. This percentage yield can be measured either as final machine size or final rough mill sizes. It varies with the species and the thickness of the board, decreasing as the board thickness increases (8).

The degree to which the hardwood lumber can be worked into relatively clear cuttings becomes the key factor in satisfying the manufacturing needs for rough lumber. This end use criterion establishes a pattern of demand for the production of lumber which when remanufactured will produce larger percentages of clear cuttings.

A price scale is the natural outcome of this demand, where lumber of higher quality commands higher prices. It becomes obvious then that lumber yielding higher percentages of clear cuttings and securing higher prices creates an incentive for the sawmill operators to seek and produce this type of lumber.

A lumber grading system is applied as a yardstick to help the purchaser to buy the grade which best suits his manufacturing purposes, while allowing the vendor to secure higher prices for his better products. This system based on the ultimate use of lumber can also be used as a criterion to measure the effectiveness of mill operation reflected by the total output of the lumber both in value per unit and volume.

Grades of Hardwood Lumber

Hardwood factory lumber is graded on a yield basis, measured on the amount of clear or sound material that can be obtained from boards, in specified number of cuttings of minimum width and length (13). In each grade a minimum percent of yield in clear cuttings must be obtained in the number of clear-face or sound cuttings permitted.

Almost all hardwood lumber in the United States is graded and sold under the rules of the National Hardwood Lumber Association. There are outlined procedures and steps to be followed in grading lumber (13).

A reference to these rules shows that these rules, allowing for minimum lengths and width for each lumber grade such as 6" x 8' for F.A.S. 4" x 6' for Selects and 3" x 4' for all Common grades, provide the basis for determining the yield that may be expected from each grade. This yield is determined by specifying the lengths and widths of cuttings required, and the number of cuttings permitted in relation to the total area contained in the board. However, lumber grades generally reflect the yield which can be expected within the minimum sizes permitted.

Some users recognize that there are variations in the types of boards within each grade not indicated by the grading rules (4). These various board types, although they do not affect the ultimate utility of the board, due to the location of defects, do influence the yield of the board when converted into the requirements of a specific industry. Dosker (4) classifies the boards into three types: (a) Rip type, (b) Cross-cut, and (c) Neutral type, depending on the distribution of the defects along the board. The type of board will determine whether it will be ripped or cross-cut or both in order to obtain maximum yield.

The factors which determine the proper grade of lumber from which wood parts will be produced are the sizes which can be obtained, their quality, and the percent of total yield. Another factor is the processing cost which varies with the grade of the lumber input.

Log characteristics can greatly influence the grade of the produced lumber and considerable variation may be expected in the type of board within the species and the log from which they were produced.

The demand of the end-user for clear cuttings can better be satisfied if the raw material from which they are produced is examined for its conditions and variations. Sawlog characteristics such as size and location of defects are the factors which determine the sawing practices for the production of grade lumber. The variations in log characteristics suggest variations in the sawing practices. Therefore, an examination of the effect of log characteristics on the grade lumber yield is considered necessary.

Distribution of Defects in Logs

Logs, unlike most other raw materials, due to their nature cannot be appraised adequately for their interior conditions in terms of defects. Thus it is very difficult to make precise predictions as to the value of the lumber to be produced from them. It is principally the existence of defects that determines the utility of logs for grade lumber production.

Sawlogs are seldom clear of defects. Some defects appear on the outside surface of the log and are easy to detect. Knots, scars, frost cracks, end checks, grub holes and bark distortions that clearly indicate an overgrown knot are some of the defects that appear on the outside of the log. Other defects such as mineral streaks, insect holes, overgrown knots and rot are usually hidden inside the log. In many cases, the ends of the log reveal some of these interior defects, like shakes, core rots, and splits, thus giving an indication of their presence. In general, although some of the defects can be noticed on the surface of the log or detected from existing surface indicators, their extent inside the log cylinder is very difficult to predict. An estimate only of the pattern of the defect distribution and especially the existence and size of knots inside the log can be obtained by examining the size of the tree from which a log has been produced. Larger trees usually have a thicker layer of knot-free wood than small trees. On the other hand, extremely large over-mature trees are usually more defective than young trees. As a rule, the defect frequency in a typical hardwood log increases from the outside toward the center of the log cylinder.

From the above discussion it becomes apparent that the value of logs for grade lumber production varies widely for different logs due to size, location and distribution of the defects. In fact these considerations are the ones that will determine in the subsequent work the choice of the best sawing method.

A log grading system is used to segregate the logs into value classes according to their individual characteristics. A grading system provides a measure of log value that enables both the buyer and the seller to arrive at a reasonable price for logs. It also provides a basis for the processing method to be used in order to maximize the grade and volume of the produced lumber.

Hardwood Log Grades

Logs vary according to their diameter, their defects, location in the tree and their length. Therefore, any grading system must first of all relate those log characteristics to the product that is to be cut from them.

The Forest Products Laboratory (21) has developed a grading system which provides a relationship between surface characteristics of logs and the grade of lumber sawed from them. This grading system has been devised primarily to (a) separate from wood-run logs those that are suited for sawing into standard factory lumber, and (b) segregate such logs into high, medium and low value categories as determined by the lumber-grade yield pattern they will produce when sawed into lumber by a skilled sawyer.

According to the Forest Service Standard Specifications, hardwood factory lumber logs are separated into three grades: F1, F2 and F3. For all three grades, there are limitations as to the log diameter, length, number of clear cuttings on the grading face, sweep and crook allowance and scaling deductions. Detailed specifications can be obtained from A Guide to Hardwood Log Grading published by the Forest Service (15).

The advantages of this system (1) are that the value of a group of sawlogs can be estimated and the lumber volumes and grades can be predicted correctly. The use of log grades allows for the assumption that the average log in any grade, cut at one time, will be very nearly the same as a corresponding log cut at any other time. Despite their advantages, these log grading rules are too complex and include too many variations and exceptions to be handy and easy to apply. They are too elaborate to be used with convenience and without any variances. In addition, log grades include the element of uncertainty, because the assignment of grade depends upon judgment.

Log Grades and Yield

A study by the Forest Products Laboratory of approximately 11,000 logs sawed at 28 mills, presents lumber yield tables by log grade and diameter of the logs separate for several species (21). As it is shown in these tables, the percent of the grade yield of lumber within a species varies greatly according to the log grade, and less within the diameter range. There are overlappings of course, but those must be expected since there are variations in log qualities even within the same grade.

In general, these tables confirm the fact that the average lumber grade yield of the three log qualities comes very close to the anticipated when the output is grouped into No. 1 Common and better, and all other grades below this grade into a separate group. In that case and for red oak (upland), which is also the species used in this study, the tables show an average yield of 70 percent of No. 1 Common and better for log grade F1 with the biggest portion of F.A.S., a 54 percent yield for log grade F2 with the biggest portion on No. 1 Common, and a 32 percent for log grade F3 with the biggest portion on No. 1 Common. In the latter case and considering the overall output, the No. 2 Common and 3B Common seemed to be the predominant grades.

The lumber grade mix produced from log groups separated by size varies within the same log grade when each log size is examined separately. These variations may occur due to variations in the individual log, but also due to variations in the sawing method or the human judgment exercised in sawing. The influence of these sawing practices and the involvement of human judgment will be discussed in the following sections.

Industry Practice

Sawing Practices*

The end use demand of the industry for clear lumber and the variations in the quality of the input logs are the two principle factors which generate the need for and forces the sawmill operators to apply a variety of sawing practices when grade sawing.

The basic principle that governs these practices is that each board, before it is cut, is evaluated on its own merit for its potential yield. The potential grade of the four faces of the log are examined and the log is sawed on the face with the highest grade until the grade of this face drops below that of the other faces.

During the processing, the logs are manipulated on the carriage in such a way that as many boards as possible of the higher grades can be extracted. However, the success of this processing method depends on the general quality of the log and its size. Creighton (3) reports that profit cannot be realized in sawing every log, as is the case with small defective logs. In that case the grade yield advantages of the above processing method may be offset when smaller and lower grade logs are sawed, by the increase in the machine and labor cost associated with log turning and handling and cutting individual boards as compared with a gang saw process. Malcolm (11), gives a detailed description of how

*In small sawmills where all cuts except edging and trimming are made with the headsaw.

logs of different qualities should be sawed for best results. He also outlines several procedures in selecting a sawing face, based on the surface defects of the log and their distribution.

The application of these procedures requires a number of log turnings and handlings. The conformity of these procedures to the requirements of grade sawing makes such an operation a very complex one. Not only skill, but knowledge as well as sound judgment is required by the sawyer who decides how to proceed, when a specific pattern of defects appears. Grade sawing know-how is of paramount importance in this operation.

There are two main variable inputs which determine the final output of the mill: (a) logs of various grades, and (b) the sawyer's decision as to the way the log should be sawed for better grade yields. While the grade of a particular log cannot be altered as such, the sawyer's decisions when he manipulates the log on the carriage can cause variations in the grade output of this log. The effect of the sawyer's judgment will be examined in the following section.

The Role of the Sawyer

Several decisions are required in "grade sawing" in order to effectively convert the logs into grade lumber. The sawing method used is determined by a set of rules which the sawyer applies during the breakdown process of the log. The implementation of these rules is not automatic, but depends on the sawyer's evaluation of the characteristics of each particular log.

The existence of the defects, the variation in their size, and especially their distribution occuring on a board's face, requires the sawyer's judgment in order to evaluate it for its potential grade. Following this evaluation, a choice must be made between cutting this board or turning the log and cutting another face of higher potential grade. This kind of selective sawing procedure must pay off, if the quality of the log processed contains great percentages of high grade lumber which can be produced by this method, thus compensating for the time and effort required. In this case, the board-by-board decision made by the sawyer is a big advantage. On the other hand, logs of low quality will require too much attention and time which possibly will not be warranted by the small gain in grade that will result. These low quality logs may be processed in a simpler way determined by a single decision upon one view of the log.

The problem of grade yield of each of the log grades has to be investigated for the effect of the sawyer's board-by-board judgment. Such an investigation may reveal to what extent this judgment helps to increase the overall grade lumber. It may also reveal that with certain logs there is no need for such a judgment since the character of the log itself excludes larger amounts of grade lumber or the time required to extract higher grades of lumber is very high, making this operation too costly.

The lack of precise knowledge as to what constitutes a maximum yield or the percent lumber grade mix of the individual log does not allow for a standardized sawing method to be used in order to compare the results of such a method. An investigation which will produce results of alternative sawing methods on the same log might indicate the possibility of the application of such a method and also to what extent and with what grade of logs this application will be more desirable. A procedure which will relate the characteristics of a log with various sawing methods can help the investigator to differentiate between the effect of log characteristics and sawing method on the total lumber grade yield. If the same log can be sawed several times with different sawing methods and the outcome of this practice is evaluated in terms of grade of the produced lumber, then this may point out the way to better understanding of the log value and the yield variations as they are influenced by the sawing method.

Production data that are now available give yield and lumber grade distributions in averages from a certain number of logs. Variations in yield that may occur among the individual logs, or the causing factors of these variations are hard to detect. Factors which can cause variations can be the machine, the log, or the judgment of the sawyer. Excluding variations due to machine, the other two factors are hard to determine. As a result of this it is very difficult to determine exactly the impact of log grade on the yield without having the log variations associated with variations in the operator's decision. Yield records thus established in most cases may not be considered as the best measures of the obtainable yields from logs if these logs were processed in the most efficient manner.

It is therefore desirable to eliminate other factors in the comparisons of various sawing methods, using a standardized process, and to evaluate the resulting lumber grade of each method produced from the same log. Ultimately, what is required is a suitable basis for choosing among the alternatives and their results. A better understanding of the interaction between log characteristics and sawing method will aid greatly in achieving correct decisions.

Research on Yield Improvement

Past Treatment of the Problem

Literature dealing with subjects similar to this study is rather rare. The following literature, however, can be cited as using techniques from the area of "Operations Research" and also related to the subject matter of this study.

The effect of defect placement and taper set out on lumber grade yields when sawing hardwood logs was studied by Malcolm (10). A statistically designed experiment was used to study the grade yields of red oak species sawed by six sawing methods. The sawing methods tested utilized two different positions of sawing faces relative to location of major defects, and two degrees of taper setout. One of the six methods was used as a control method in which defect placement and adjustment for taper as such were ignored.

Average lumber grade yields and monetary values from all log grades combined were compared with each sawing method. Yields and monetary values of each log grade were also compared for each sawing method.

Results as reported by Malcolm, show that ignoring taper and the relative position of defects on sawing faces results in a loss of potential grade. The placement of defects at the corner of sawing faces results in higher quality lumber than when defects are placed in the center of the faces. Full taper setout had a greater potential for producing higher lumber grades than one-half taper setout. When taper was ignored, lumber grades comparable to that obtained from full taper could be obtained from similar logs having opposite low and high quality faces if the low quality faces were sawed first. Sawing the low quality face first automatically puts the high quality face parallel to the saw line, resulting in production of full length boards from the high quality face.

Malcolm's study was based on present day sawing practices of log turning, testing sawing instructions as they are given by the FPL, against some of the variation, employed by the sawyers at the field, when grade sawing.

Jackson and Smith (9) studied the problem of sawing the log in the most profitable way consistent with the market requirements of various lumber sizes. A linear programming technique was used to determine the optimum combination of lumber sizes to be produced from each log size. Sawing procedures were selected for each size that yielded the highest net profit on the basis of the total amount of lumber of each size that can be sold. Under this program all logs had been utilized by one process or another. However, the most profitable ways of converting the log were not utilized, because some sales restrictions would have been exceeded, resulting in excessive amounts of product for which there would be no market. The above study was restricted to certain product sizes to demonstrate the use of linear programming as a technique to determine the optimum production combination which will maximize profits.

Linear programming technique was also used by Row, Fasick and Guttenberg (19), in order to study sawing problems of a high speed southern pine mill. The area of their study included four basic factors: (a) amount, quality and cost of timber; (b) possible sawing patterns and their yield; (c) machine time available on the mill equipment; and (d) sales requirements.

Data on yield of logs sawn by several patterns, the time requirements of each pattern and log class, on each machine including restrictions on machine time, were analyzed by linear programming technique. Although the log and lumber grades of southern pine are different from those of hardwood and specifically red oak, it is interesting to note their findings.

The grade of C and better and No. 1 lumber yield declined as the log grade decreased, while No. 2 grade increased as log quality fell. The log grade No. 2 seemed to be the break-even point of this study.

The influence of sawing pattern was significant only in conjunction with log grade and machine time. Their lumber yield findings by sawing patterns were associated with bandsaws, linebar resaws, horizontal resaws and a sash gang saw. The mix of boards and dimensions cut was reported in relation to the particular patterns of these machines.

The authors arrived at best sawing patterns on the basis of the most profitable ones, according to sales policies, and the cost of raw material. As they point out, at any given price set the total recovery values will vary with the sawing pattern and also, patterns that give the greatest lumber yield return may not be the most profitable. In effect, the alternative machine time cost may exceed the gain from operations that increase the product value.

An experimental approach to theoretical sawing of logs was reported by Peter and Bamping (16). The authors analyzed the application of a new technique for evaluating sawing methods. A log was actually sawed and the defects were measured on the produced boards and plotted on an end section diagram of the log. By applying then a transparent overlay indicating theoretical sawlines, grade and value figures of the (theoretically) produced lumber were obtained.

Lumber yields were based on a "right cylinder," i.e., in a cylinder determined by the diameter of the small end of the log, and "clear diagram" faces were used as quarter sections of the log circumference in which no knot penetrated the "right cylinder."

Data based on this technique were reported separately by effect of width, grade, and a combination of them, based on the number of clear diagram faces and lumber value per thousand board feet.

A breakdown by sawing method on lumber values indicated that board width values between log quality groups did not indicate any trends despite variations in the average diameter of the groups. The effect of grade indicated increasing average grade values as the log quality improved. When grade and width were combined, a value spread within groups and a value increase between groups was observed.

Riikonen and Ryhänen (18) used a computer (mathematical) model in order to find the best sawing method among different sawing alternatives, which gives the most profitable economic results. Their basic approach was a mathematical expression of produced board sizes along cone shaped softwood logs, as the radius of the log changes at a distance X from the large end. The effect of price and cost factors was used in order to improve the reliability of the results obtained. The quality variations of the raw material and product were considered by calculating parallelly the results given by a good quality and a poor quality log, and placing the results of individual logs between these extreme values.

Other Possible Solutions

Considering the nature of the raw material as well as its limitations, the investigation of optimal grade yield can be approached in different ways. One way would be a statistical approach, using a large size sample of each log grade used today. Thus, the difficulty of testing identical logs for this type of analysis may be overcome. The sample logs can be processed in subgroups for various sawing methods, using one method per subgroup. The results can be evaluated in terms of grade and volume, averaging them for all logs of the same subgroup. The statistical approach can help in such investigations, provided that machine and human judgment variations are considered.

The disadvantages of this approach are the cost and time required, and the fact that alternative sawing methods have to be used in different logs.

Another testing approach can be the use of a theoretical log. Experimenting with such a log, while it will fill the need for the use of the same log for the testing of several sawing methods, is weak from the point of view that it is not realistic. Any data derived from the experiment will correspond to the constructed theoretical log and not to the actual one. Also, defects have to be generated which then increases the complexity and the disadvantages of this approach.

A third approach, which combines the advantages of the two previously mentioned testing methods, can be the simulation approach, with the use of real logs. It is this approach which has been developed in this study as a possible solution to the optimum grade yield problem.

Computer Simulation

Simulation—defined as systematic abstraction and partial duplication of real world phenomena, activities, or operations—is used for the design of a system in terms of certain conditions, and the analysis of specific rules, policies and procedures (20). Further, simulation as a method for systematic abstraction suggests the construction of a model used as a key for the solution of the simulated activity. McMillan and Gonzalez (12) refer to simulation as the process of conducting experiments on the model instead of with the real system.

Although a simulation model is fallible, there are a number of applications where it is preferred. In our case no other feasible experimental means exist which can utilize the same log for various sawing methods. Application of other techniques described above are not considered feasible due to magnitude of computations involved and the disadvantages mentioned.

For more information about simulation, one can review the existing literature on this subject (7,14). At this point it is more desirable to discuss how this technique can be applied to logs and, consequently, to sawing methods.

The replication of the sawing activities is proposed to be done in two stages. In the first stage an assessment of the log exterior and interior characteristics will be made so that input data on the size, shape, and defect location can be gathered. For this purpose the real log will be cut into disks (elements) sufficiently small to reveal most of the interior defects of the log. The disks are of discrete thickness, the same for all of them. The circumferences as well as the defects on the face of the disks, are measured and recorded. These measurements provide one set of input data. Thus the location of the defects appearing on a board cut from that log in any orientation relative to source reference plane of the defect along the log axis can be determined.

In the second stage the sawing methods, which become the parameters of this study, are selected. One of the sawing methods will be that which allows for the turning of the log. Other methods will be those that allow the use of the gang saw in one or two passes. In all these methods the position of the log in relation to the outside main characteristics will be considered. These sawing methods provide another set of input data. The computer program which was written for this study, utilizing the two sets of input data plus appropriate instructions, is used to simulate the sawing activity. A detailed description of both stages is presented in the next section.

This technique allows the same log to be sawed several times and also the test of any alternative hypotheses desired on real logs, taken in small sample size. The approach becomes feasible in the event of computer use, which permits enormous saving in time and cost.

The simulated log breakdown operation can be used to synthesize a basic sawing method, based on present day sawing practices, against which the results of alternative methods can be compared. The principles of other sawing machines, such as gang saws, can also be introduced by assigning their operating characteristics as program parameters. The results of the same log can be compared with those obtained from machines used at present.

Major advantages and disadvantages of a simulation model are cited below (17).

Advantages: 1. Provides better understanding of the system by those who operate it.

2. Results in quicker acceptance of proposed changes because, once the operators of the system understand and accept the description of the system given by the model, they can proceed with the evaluation of the assumptions contained in the input data and the implications of the output in future decisions.

3. Can stimulate and produce ideas. When the model is completed and tested for reliability, new operating concepts can be advanced.

4. Promotes complete analysis. Analysis of the operational factors can be expanded to great depths.

5. The model does not depend on a mean or median value in order to describe a variable. The complete range of variables, as well as their relationships, can be introduced.

Disadvantages: 1. The modelling process may invite excessively unrealistic assumptions. The quality of these assumptions determines the value of the model.

2. Obtaining accurate input data is a difficult problem, often underestimated or neglected.

3. Model developers can easily become technique oriented rather than problem oriented.

4. Simulation models permit evaluation of ideas created by the human mind and therefore they are only as good as the ideas are.

In the present study, due to the destructive nature of the technique used for the production of the input data, the log cannot be processed for lumber production. Therefore, there are no real standard results for comparison. Also, certain necessary simplifications are introduced in order to carry out the simulation. For example, the output of the simulated sawing is presented as printed pictures of boards. Due to printer limitations various errors in the size and shape of the appearing defects, to be discussed later, will be unavoidable. The output shows one face of the board only. (Note, however, that in this case both faces are alike and either choice would represent "poor face.")

III. METHODS AND PROCEDURES

The Source of Data

The Raw Material

The simulation of the log breakdown operation was accomplished with the use of information obtained from red oak logs. There are several species included under this name, all belonging to the Erythrobalanus group. Because the wood of the species included in this group cannot be identified with certainty, any reference hereafter to the species will refer to this group.

Red oak was selected because of its importance to the hardwood-using industries. The wood of this species, as in the white oak, is generally straight-grained, heavy, strong in bending and endwise compression, and high in shock resistance. Further, it machines well and finishes smooth. Due to these characteristics red oak lumber is widely used in flooring, where its hardness, high resistance to abrasion, and ability to finish smoothly makes it most desirable. It is also greatly used in the furniture and cabinet industry and in general millwork.

A total of six logs were used for this experiment, with two logs assigned for each log grade. The selected logs were graded according to the U. S. Forest Service standard grading rules (15). After the grading each log was numbered with a grade, and a serial within the grade. Thus the logs were numbered 1.1 and 1.2 for the top grade, 2.1 and 2.2 for the medium grade, and 3.1 and 3.2 for the low grade. The diameter of the logs at their small end were: 13 inches for both 1.1 and 1.2 logs, 11 inches for both 2.1 and 2.2 logs, and 15 and 13 inches for logs 3.1 and 3.2 respectively. The length of the logs varied from 10 to 12 feet. In this experiment they were arbitrarily set to an eight-foot length, with the sole purpose of reducing the time and effort required for the execution of the work.

It is realized that most of these logs were not average logs for their respective grades. For example, the diameter of log 1.1 and 1.2 was the minimum diameter required for logs of this grade. The diameter of logs 2.1 and 2.2 was also the minimum diameter for that grade. In addition, the reduction of their lengths into eight feet, further contributed to the deviation of the aforementioned logs from an average log of their respective grade. The logs were chosen at random from a limited supply, and therefore the choice was made between a few logs of each grade. All logs were purchased at a local sawmill, where they were also marked and disked in order to expose and measure their internal defects.* An end section diagram of the logs with projections of all outside defects, is given in Figure 1. (Scaled illustrations of all logs are given in Appendix B.)

Log Preparation

Before the logs were cut into disks for the measurement of the internal

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*A cut-off, De Walt, radial arm saw was used. The saw utilizes a 40-inch blade and is driven with a manual crank.

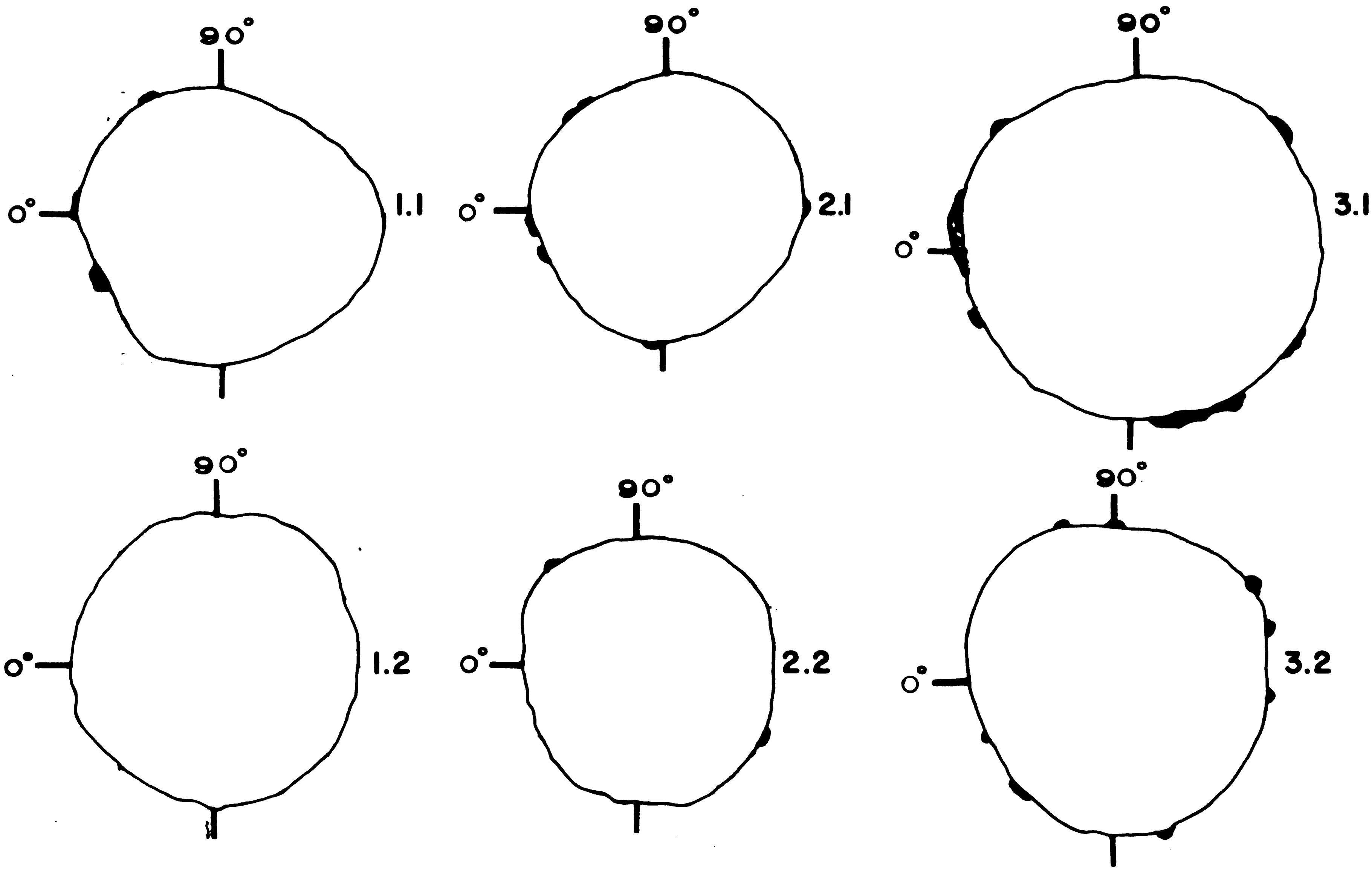


Fig. 1. Projections of the small end log circumferences

defects, and in order to be able to reconstruct their shape, they were marked along their long axis. Each log was balanced on one face, and a vertical line was drawn passing through the pith at each end. Then another line was drawn, perpendicular to the first and again passing through the pith. These axes, designated as X and Y on both ends of the log, were used as the ends of three marking lines cut with a portable electric circular saw, along the log's long axis (Figure 2). After each log was marked, it was sliced into disks of one-inch nominal thickness. The actual thickness of the disks was one inch minus the kerf, or a net thickness of three-quarters of an inch. In the present study, the disks are taken at their nominal one-inch thickness. All disks were numbered in a sequence as they were cut, starting from the small end of the logs. A total of 96 disks was produced from each log.

Slicing the log into disks, rather than boards, greatly facilitates the precision and convenience of data recording. Disks are closer to a realistic situation, where the shape of the circumference—not likely to be circular, or otherwise uniform—can better be traced as it varies along the long axis of the log. Disking also fits better with the developed technique for circumference and defect recording. This technique, as it will be explained further below, enables one to handle the whole log relatively easily.

If the logs instead were to have been sawn into boards, the inside defects similarly would have been revealed. Transformation of all defect

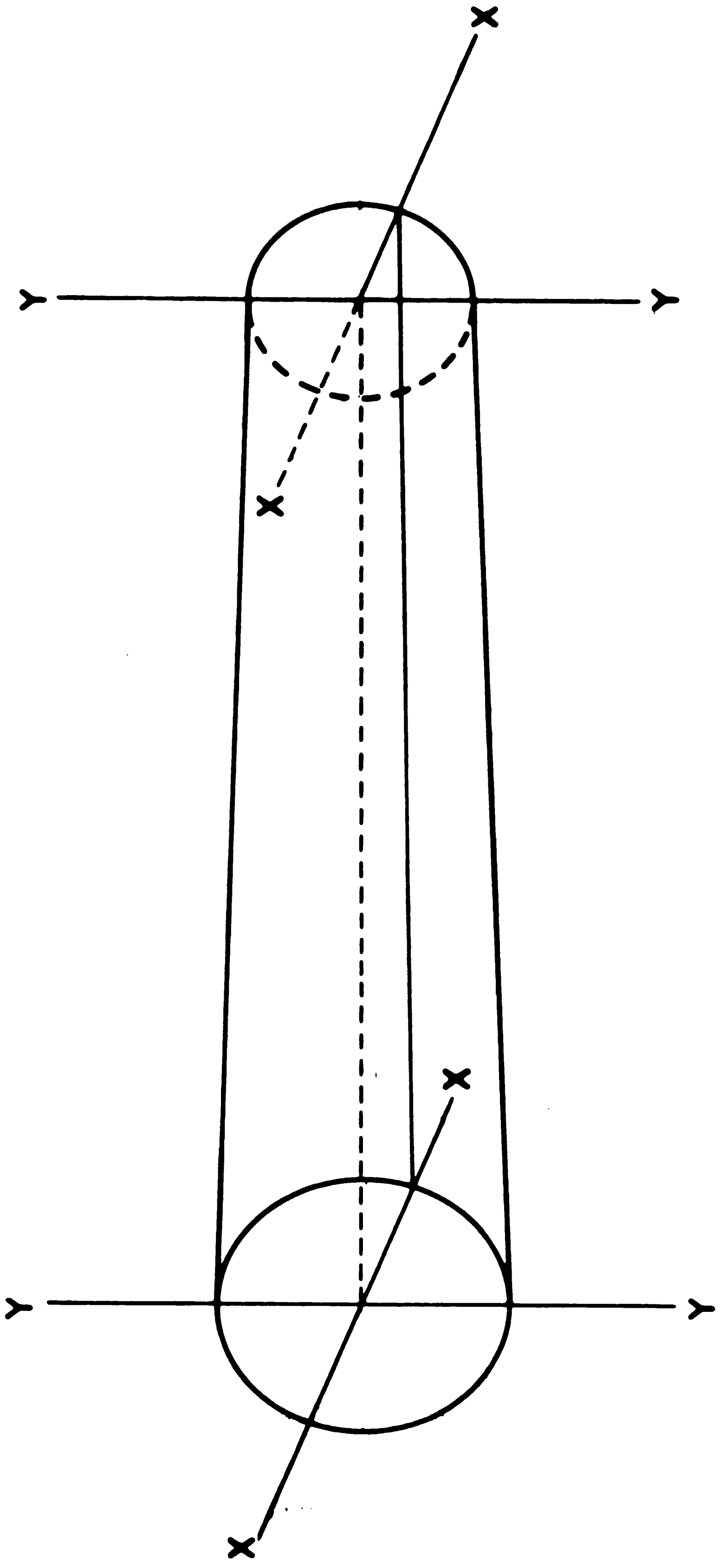


Fig.2. Log Marking Before Breakdown Into Disks

locations from board to disk format could be made. This method, however, cannot conveniently give the shape of the logs as is the case with disks. Crooked logs, for example, would be difficult to trace—particularly for slabs falling short of the full length of a log. Also, especially for long logs, the actual process of measuring defect locations on boards as against disks would be tremendously more cumbersome.

The disks were made one inch thick so measurements of the defects could be taken according to their actual size and location inside the log in discrete, uniform data intervals. The transposition of these defects to the resulting boards was thus performed by projecting one-inch units of defects on the boards' faces. This established a control procedure that permitted cross-checking the location of defects in the board and log by measuring the distance of the defect along the boards and matching it to the disk cut from the log at the distance in inches indicated by the disk number.

After the logs were cut into disks, the three lines marked along the logs appeared on the circumference of each disk. These three marks were used as the reference points for the placement of the disk on the measuring device.

Circumference and Defect Recording Method

An important aspect of this study was to develop a method of recording directly the circumference, as well as the size and location of the internal defects of the logs. A coordinate system of X and Y axes was used for

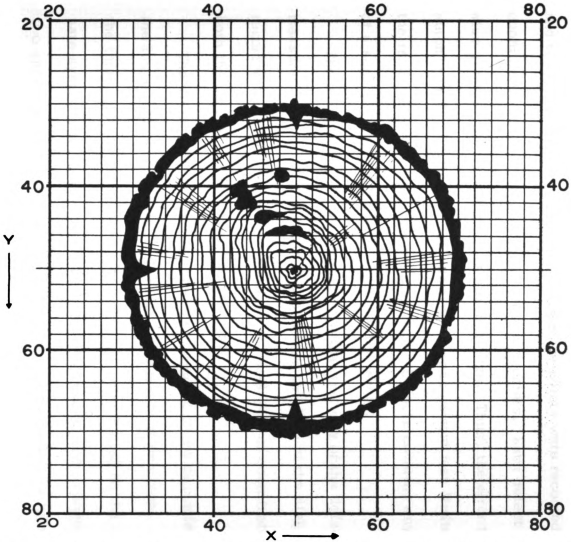


Fig. 3. X-Y Coordinate Grid System for Defect and Circumference Measurements
Unit: 1/4 inch square

that purpose (Figure 3). A grid was drawn, on a transparent polyethylene sheet, consisting of 100 by 100 squares. These squares, a quarter of an inch each, were used as the measuring units for both the circumference and the defects of the disks. Circumference points were recorded by the coordinates of the unit which included these points. Each defect was also given in units instead of its absolute size. Thus, the error that automatically was involved in this type of measurement was limited to the range of zero to one-quarter of an inch. Defects covering any part of a square were considered as covering the whole.

The advantages of this approach are that the size of the defect can be measured in discrete units whose position on the face of the disk can be recorded by standard X and Y coordinates. Each pair of coordinates gives both the size of the defect and its location.

The disking procedure permitted measurement of the circumference of the log and the log defects to be taken in intervals of one inch. When the three circumferential marks on each disk were placed on the coordinate system grid, any variance from the hypothetical line connecting the two end-centers of the log or any change in its diameter was immediately indicated and recorded—to the nearest inch for the former, and quarter of an inch for the latter.

Since each disk in a given location represents the whole log in that particular distance, cutting the logs into one-inch thick disks satisfied the need for a three-dimensional reading. Also, defect readings were facilitated under the assumption that any defect appearing on one face of the disk extends for one inch inward. Readings of the defects were taken on the front face of each disk, in the two dimensions, X and Y. The depth dimension, being one inch, was introduced automatically.

In cases where face defects do not extend to the depth of one inch —i.e., back clear—then there is an error in the reading of approximately a quarter of an inch to one inch. This error, however, is balanced by the assumption that face defects of consecutive disks are continuations of the previous disk's back defects. For example, a defect appearing on the face of disk No. 73 is considered to be also the back of the preceding disk, No. 72, even if disk No. 72 has a clear front face. Under this assumption, measurements were taken only on the front face of each disk. This had the effect of cutting the working time by 50 percent. For practical applications of this experiment, this is a considerable reduction.

Recording Procedures

In order to obtain the coordinates of the circumference of the disks and the location of the defects, each disk was placed underneath the transparent grid. The two opposite marking points were placed on the Y axis at X=50, and the third on the X axis at Y=50 (Figure 3).

All four points of the circumference at X50 and Y50 were recorded, to the nearest quarter of an inch. Any other salient point was also recorded so that the actual shape of the log easily could be reproduced during the processing of data by the computer. Next, the defects on the face of the disk were measured to the size of quarter of an inch square units. Defects larger than one squate inch were recorded in units of one square inch and were especially coded with the number one so that the final reading will appear again in quarter-inch units. Distinctions between defect and circumference recordings were shown by assigning the code number two to the latter type of data.

Measurements of each unit defect were recorded, first for the X axis and then for the Y axis. Since the diameters of the logs used were greater than 10 inches, the grid was divided from one to 100 units in both the X and Y directions. Thus, each measurement was represented by a pair of numbers, each containing from one to three digits. In the case of this experiment, all data occurred as two-digit numbers, except when units of one square inch were measured. In those special cases, the additional code number preceded the others. As an example, the reading of a defect indicated with the number 3964 means that this defect is located at X39 and Y64. A 13964 means that this same unit should be expanded to the right and down for four units (one square inch), thus including a total of 16 units. A number 23050 should be read as a point at the circumference, as indicated by the initial number 2, and that this point is located at X30 and Y50.

Making it a practice to read first the X's and then the Y's, it becomes a routine process to measure and record any desired point on the surface of the disk. The time required for this work varies with the quality of the log and the number of defects appearing in its particular disk. In any event, it takes between two and 15 minutes per disk, or 192 to 480 minutes for all 96 disks of a log. Later in this study a new technique will be described, involving a digitizer device, which cuts the time requirement to a very small portion of the above mentioned.

Computer Simulation

Preparation of the Input Data

All the data derived from the measurements of the disks were punched on data processing cards. A very simple coding was used for this transformation. It was mentioned previously that the number one in front of any pair of coordinate numbers indicated a square of 16 units, and that the number two was used for circumference points. Therefore, the maximum number to be recorded for each measurement was a five-digit number, requiring five columns on the data processing card. (Where no special code designation was required, the first column was left blank.)

On each card, out of the 80 columns available, the first five were reserved for log and disk identification. Columns 6 to 55 were used for circumference readings, and the remaining columns for defect readings. When one card was not enough, the remaining data were punched on a new card, starting in column six. Some disks required as many as ten cards.

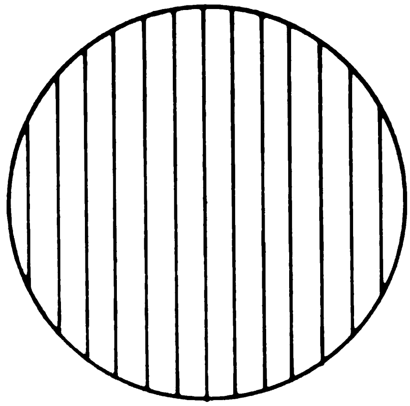
A computer program was written for the execution of all calculations required in this study. The final program, written in FORTRAN language, was executed on the CDC 3600. This program is given in Appendix B.

Sawing Methods

Sawing methods can be divided basically into two categories: sawing through, or live sawing, and sawing around the log. Through sawing consists of parallel saw cuts through the log. It may require one turning of the log, or no turning at all if a gang saw is used. This kind of sawing can be used with both circular and gang saws. Sawing around the log requires turning of the log two, three or more times. Various sawline combinations can be used in this type of sawing. This kind of sawing can be used in circular or band saw operations.

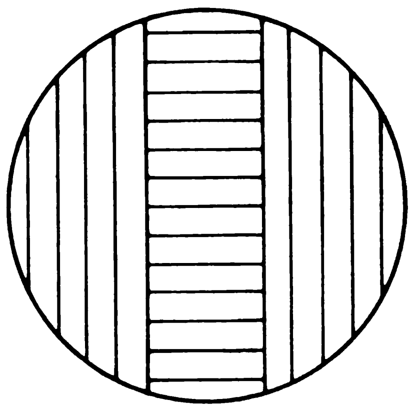
To make the applicability of the present study as broad as possible, a variety of presently used, basic sawing methods was chosen. The only requirement was that some of the methods be usable on both circular and gang saws. Since the effect of outside characteristics of the log on the grade yield would be, in studies of this kind, the main criterion in evaluating the results of each method, four different positionings of the sawing faces of the log—relative to the main outside defects—were used (Figure 5).

Altogether, three sawing methods were employed in the simulated log breakdown operation (Figure 4). They represent basic sawing methods from which other combinations can be derived. All the methods used one-half taper and were applied twice to each log: first, with a one-fourth of an inch kerf to simulate circular saw cutting, and second, with a one-eighth of an inch kerf to simulate gang or band saw cutting.



METHOD No. 1

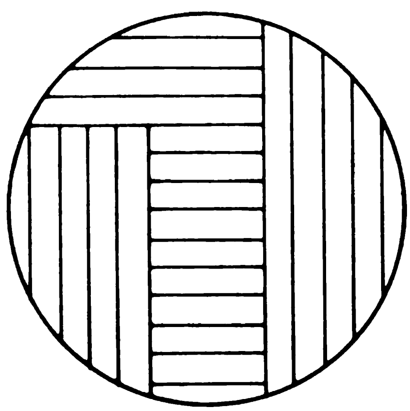
1. Circular Saw
2. Sash Gang Saw



METHOD No. 2

1. Sash Gang Saw
2. Circular Saw and Sash Gang Saw

Cants: 4" and 6"



METHOD No. 3

1. Circular Saw (SYNTHESIZED)

Fig. 4. The Three Sawing Methods Used on The Same Log

From the three methods used, one—the grade sawing method—was designated as a control against which to compare the grade yields of the other methods. This method, described below as Method No. 3, is a synthesized method. That is, after the log was cut into boards by sawing through, the produced boards were used to develop manually a sawing pattern based on present-day sawing practices. The procedures followed in this method are described in the following section. At this point it must be stated that although Method 3 is a simulated method, the complete simulation involves the results of the computer sawing, and the manual manipulation of the resulting boards, to achieve the pattern corresponding to Method 3. Therefore any reference hereafter to Method 3, will imply both computer and manual simulation.

The methods used in this study are the following:

1. All logs were sawn by through sawing, in four different positions each 45 degrees apart. This method allowed for positioning the sawing faces between defects, at the center of the defects, and parallel to them.

2. All logs were sawn in four different positions, as in Method 1. Cants of four and six inches were left to be sawn by a gang saw.

3. All logs were sawn by through sawing, in two positions: first, placing the sawing face between the major outside defects and sawing through; second, by sawing perpendicular to the first cut. The boards produced by these two sawings were graded manually, and were used for the "synthesized" sawing pattern referred to above.

In the simulation, each log was sawed 14 times: four for Method 1, eight for Method 2, and two times for Method 3. The use of two kerf sizes increased the number of simulated sawings to 28. Multiplying the number of sawings per log by the total number of logs results in 164 sawings. This can be compared to the 164 logs, which would be needed to apply these sawing methods on a one-to-one (non-simulated) ratio.

Sawing Program

The first requirement of the sawing process was to select the initial sawing face. In the previous section, in describing the sawing methods, it was stated that each log was sawn in four different positions, using Methods 1 and 2, and in two positions using Method 3. The best sawing face of each log was one of the four sawing faces, but not necessarily the first one sawn. The following is an explanation of how the logs were cut in this study. The same procedure can be used as a general guideline for any given log.

The starting point for the sawing of all logs was the mark corresponding to Y=50 and X=30 in Figure 3. (Figure 3 in this case is considered as representing the end section diagrams of the logs shown in Figure 1.) This point is assigned to a line forming a zero degree angle with respect to the X axis. For the sake of simplicity, and in order to illustrate the procedures followed, let us consider a circle representing the end section diagram of a log. The three marks previously explained are placed on the same circumference locations as in the real logs (Figure 5). A rectangle (efgh) is inscribed in the circle, dividing the circumference of the circle into four equal parts. The inscribed rectangle is oriented in such a way that its

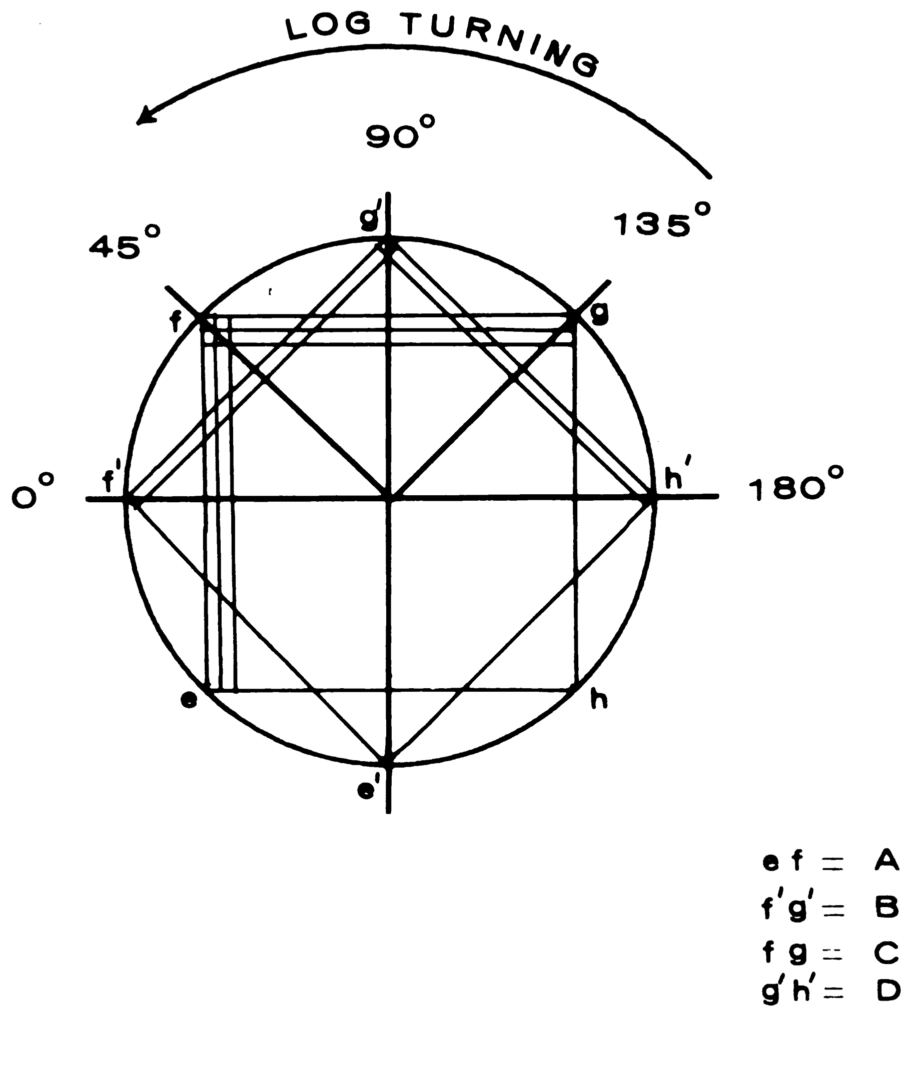


Fig. 5. The Four Sawing Faces of the Logs Used in this Study, and the Starting Point for Each Face

top and bottom sides are parallel to the X axis and the left and right sides are parallel to the Y axis. Thus the projections of the three marks are located at the centers of the three respective sides of this rectangle. The face (ef) denoted by the left side of the rectangle is the first face to be sawn. Starting from the zero degree point, the log is sawn completely.

By rotating the log counterclockwise 90 degrees, the top side of the rectangle (fg) is brought into a vertical position, thereby putting the second mark at zero degrees. This point now becomes the reference for sawing the log in the second position.

If instead, the log is rotated counterclockwise 45 degrees, the top side of the initial rectangle is brought into a position (f'g') where the second mark is placed at 45 degrees on the circumference of the circle. This side describes a new rectangle (e'f'g'h' in Figure 5) which designates the new sawing position of the log. In this manner any other selected sawing face is represented as the side of a rectangle. The center point of this selected face, projected on the circumference of the log, gives a point to which an angle is assigned, measured from the point designated as zero degrees.

In this study, for programming convenience, the logs were sawn at 0, 45, 90, and 135 degrees, which represented four sawing faces given by the two rectangles of Figure 5. The 0 and 90 degree positions are given by the rectangle efgh, and the 45 and 135 degree positions by the rectangle e'g'g'h'. For simplicity of notation, positions ef, f'g', fg, and g'h' will be referred to as A, B, C, and D respectively. In the simulated sawing, any rotation angle can be assigned, and any face can be sawn. Assigning the rotation angle in increments of one degree, for example, will give 360 sawing faces.

The above described sawing faces were used for all logs when using Methods 1 and 2. The logs were sawn live in both methods. In Method 2, however, a cant was left after each sawing. The size of this cant was measured from the center of the log as given by the coordinates X=50 and Y=50 (Figure 3). One-half of the cant size was measured to the left of that point and the other half to the right of it. Since the sawing starts from the left side, the left half of the cant may fall within the board limits of the last board before the cant. In such cases, the position of the cant was shifted to the right at a distance equal to the overlapping, plus the kerf size, and the board was cut to full size. The computer then, is instructed to jump the assigned cant size and continue the sawing process to the right by leaving a kerf. The remaining cant is sawn by rotating the log 90 degrees.

Method 3, the simulation of present sawing practices, was carried out by "sawing" the log live twice. First, the best sawing face was chosen among the four faces described earlier. Starting from the selected face, cuts were made parallel to the Y axis.* Then, turning the log 90

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*Starting points for the sawing of these faces were: log 1.1, 135°; log 1.2, 0°; log 2.1, 135°; log 2.2, 0°; log 3.1, 90°; and log 3.2, 45° (Figures 1 and 5).

degrees, it was sawn again. Thus the quality of each set of boards was revealed, as sawn with respect to the X and Y directions.

After the produced boards were graded manually, they were used to synthesize a basic sawing pattern equivalent to the actual practice followed by sawyers as they work their way into a log. That is, the initial choice was made among the four boards—the first and last one from each live sawing. In each case, the board of the highest grade was identified and selected. Next a comparison was made between the grades of the remaining three boards and the board immediately alongside the one selected. This process was continued to the last board, always by "turning" the log and selecting the best remaining complete board or—where previous sawing had removed some of the width—the best remaining partial board. In cases of equal grade boards, the wider was chosen. If there was equal grade and width, the choice was made arbitrarily. Thus a sawing pattern was developed which came close to the one that would have been followed if this log actually had been sawn.

The simulated sawing process can be described briefly as follows. The computer program first locates the starting point or zero degree angle. Then, perpendicular from the zero degree center of the assigned sawing face, it proceeds in opposite directions with one-quarter of an inch increments until it reaches the limits of the log cylinder. The two opposite limiting points specify the width of the board. Next, the scanning proceeds inward in increments of one-quarter of an inch until it reaches the assigned board thickness of one and one-eighth inch, and allowing for the specific kerf size, recycles the entire process further into the log. When the log is rotated, by any assigned rotation angle, the same process is repeated, just as if we were dealing with a new log.

The model also scans the log for defects and counts the number of all defect units, by quarter-inch squares, in a sequential order. It starts from the first disk and one defect unit, and penetrates through the cylinder of the log until all disks are explored for defects in a position given by the coordinates of the first unit defect. The process is repeated until all unit defects appearing in any disk's face are checked and counted. The output of this searching is printed under the printout of the board produced from the log. Each board includes the defects encountered in the area occupied by this board inside the log.

For all three sawing methods, to handle the problem of taper, the circumference of each log was rounded in the shape of a cylinder. This rounding was accomplished by using the four opposite circumference points of the small-end disk. Thus taper adjustment during the operation was avoided.

Another factor considered was the size of the kerf. The two kerf sizes used for each method and log were introduced into the model so that comparisons of the influence of kerf on the grade of the resulting boards could be made.

The effect of cant production was investigated by introducing two cant sizes on all logs sawed. Although maximum lumber grade is the controlling factor in grade sawing, producing cants from the heart portion of lower grade logs may increase their overall dollar return.

Finally, to bring the simulation still closer to industry practice, the boards produced by all methods and from all logs were edged to the width of the small end and trimmed one inch at both ends.

Operating Characteristics of the Model

In order to simplify the problem certain limits were introduced in the simulated break-down operation. These limits—in the form of model elements, and policies for the execution of the work, and sawing rules—were:

1. Elements: (a) cut the log into lumber; (b) rotate the log, or coordinate system, by 45 degrees; and (c) rotate four times.
2. Policies: (a) use one particular method at a time; (b) repeat it with all methods assigned; (c) leave two cant sizes when sawing with Method 2; (d) saw first on circular saw and next on sash gang saw; and (e) shift cants sawed with Method 2 to sash gang saw by turning them 90 degrees, and saw in one pass.
3. Rules: (a) saw one and one-eighth of an inch thick lumber only, and accept boards three inches wide or more; (b) change sawing method after the log is completely sawn; (c) cut log completely with all methods before shifting into another log; (d) cut only in X or Y directions; and (e) change design (machine) when each cut is completed.

The simulated rotation of the log was accomplished by rotating the X-Y coordinate system, using the general mathematical formula:

$$X1 = X \cos\theta + Y \sin\theta$$

$$Y1 = - X \sin\theta + Y \cos\theta$$

where X1 and Y1 are the coordinates of the new system having the same origin as X and Y. A given defect unit will have two pairs of coordinates, and the relationship between these coordinates involves the angle θ. The new X1,Y1 system is obtained from the X,Y system by rotation through the angle θ. In this program θ was equal to 45 degrees (Figure 6). With the use of this formula, the defect location on the plane of each disk was rotated to new positions as the requirements of the log's positioning demanded.

Finally, a test is built into the program for checking the accuracy of the output. This check is accomplished by printing out the following three characteristics for comparison with the measurements obtained from the actual cutting of the logs:

1. Coordinates of the end section of the log circumference
2. Coordinates of each board produced from the log
3. Coordinates of a unit defect on the face of the board.

Lumber Grading

The lumber produced by the simulated sawing was graded manually. A modified version of the National Hardwood Lumber Association grading system was used. Under the modified system, the grades of "select" and "sound wormy" were not considered. All boards were graded on the basis of defects with no allowances made for pith, wane, or split. Any kind of defect appearing on the face of a board—including mineral streaks and spots—was considered the same as any other non-acceptable defect. The minimum sizes of the boards under this modified system were the same

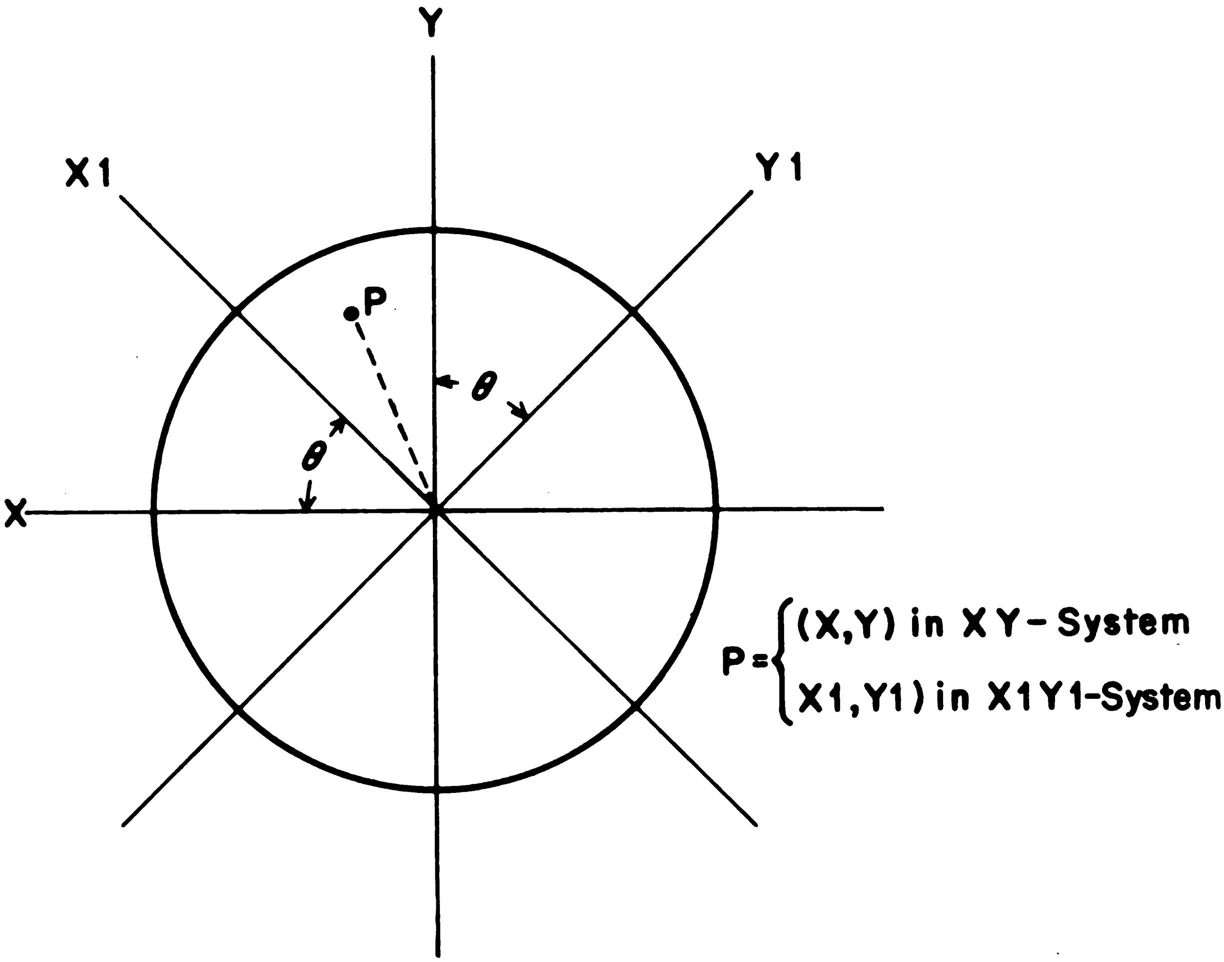


Fig.6. Simulation of Log Turning by Turning the X-Y Coordinates

as in the N.H.L.A. rules. All the boards were measured for their width to the nearest one-quarter of an inch.

The simplified grading system used in this study was chosen purely as a matter of convenience, to achieve the kind of analysis attempted here. It would be recalled that during the investigation of the interior defects of the log all defects were recorded in the same manner, with no distinction made for defect types. Thus not only was defect recording simplified, but it was possible—in projecting the defects from the disks onto a board face—to use the same technique for all defects. All defects therefore appeared as being of the same quality.

The grading system of this study is not associated with the model and is not an inherent limitation of it. In cases where the N.H.L.A. rules should be used, defect types could be coded individually using a larger set of data columns to record the observations, so that they may appear on the face of the board. Therefore, any yield figures derived from the produced boards and graded with the presented system should be considered for their value as related to this study only. They may not be applicable elsewhere.

Yield Evaluation

The evaluation of sawing methods was done by computing the grade volume recovery by each method, separately for each log. A price-grade ratio was used in order to put the results of all alternative sawing methods on the same basis. The monetary values used were based on the July 22, 1967

Hardwood Market Report for plain sawed 4/4" red oak (F.O.B. Mills-Wausau, Wisconsin area). They were as follows, in thousand board feet: FAS, \$230; No. 1C, \$140; No. 2C, \$80; No. 3A, \$60; and No. 3B, \$54. The total sum, estimated by adding the value of all grades recovered by each method, was standardized to an equivalent value in thousands of board feet based on log scale. (The tabulated results of these evaluations are presented in Appendix A.)

Analysis of Variance

The yield value results of the sawing methods for each log grade, and for all grades, were tested with an analysis of variance which compared methods and grades and their interaction. The purpose of this test was to find if the mean yields for the sawing methods tested differed significantly. In this way, it may be determined whether the interaction of log grades used and sawing methods is important affecting the results.

The results of this test, although severely limited by the very small number of observations, are discussed in the following section.

IV. RESULTS AND DISCUSSION

Evaluation of the Model

Model Characteristics

In a sawing operation, the most important consideration is the effect which various judgments, made in the form of sawing methods, will have on total profits. A simulation model offers the possibility of testing these decisions outside of the real system and of measuring the effects on total yield of various log grades. The various sawing methods chosen to be tested become parameters in the simulation model.

Two sets of data are introduced into the model. The first consists of data describing the raw material being processed. The second, consisting of data corresponding to decisions previously made, sets the parameters of the model. It is the second set of data which causes changes in the variables, reflected in the output which is used for analysis and evaluation. The output data are measurements of the effect of the interactions between the raw materials and the sawing methods. Therefore, essential characteristics of the model are the type of input data and the form of the output data. In order to run the model, instructions are needed for processing the input data and producing the output data. If the purposes of the simulated model are to be fulfilled, the greatest advantage will be an increased understanding of the complete operation cycle.

The Experimental Model

It will be recalled that the main objective of the study is to construct and test a model which would provide a means for the same log to be sawed with different methods. The model has been tested for its workability and has been proven to fulfill the purpose set for this study. The interaction of elements, policies and rules introduced into the model to accomplish the sawing program outlined under Methods and Procedures achieved the first objective of this study. A schematic representation of the model in the form of a flow diagram is given in Figure 7.

The output of the sawing program includes, for each sawing, a calculation of the resulting sizes and volumes of individual boards, and the total yield. Also presented are the number of clear cuttings and cutting units required for each grade of lumber, based on the surface measure of the individual boards (Figure 8). Thus, the first step in demonstrating the workability of the model was accomplished.

The model has been used to saw one-inch thick lumber. Yet the form is such that it allows for any other thickness, or combination of thicknesses, which may be desired. The same holds true for the cant sizes. Although four- and six-inch cant sizes have been assigned in the pilot runs, the model is written in a form such that any size can be assigned. Increments for both thickness of lumber and cant size can be used from one-quarter of an inch and up.

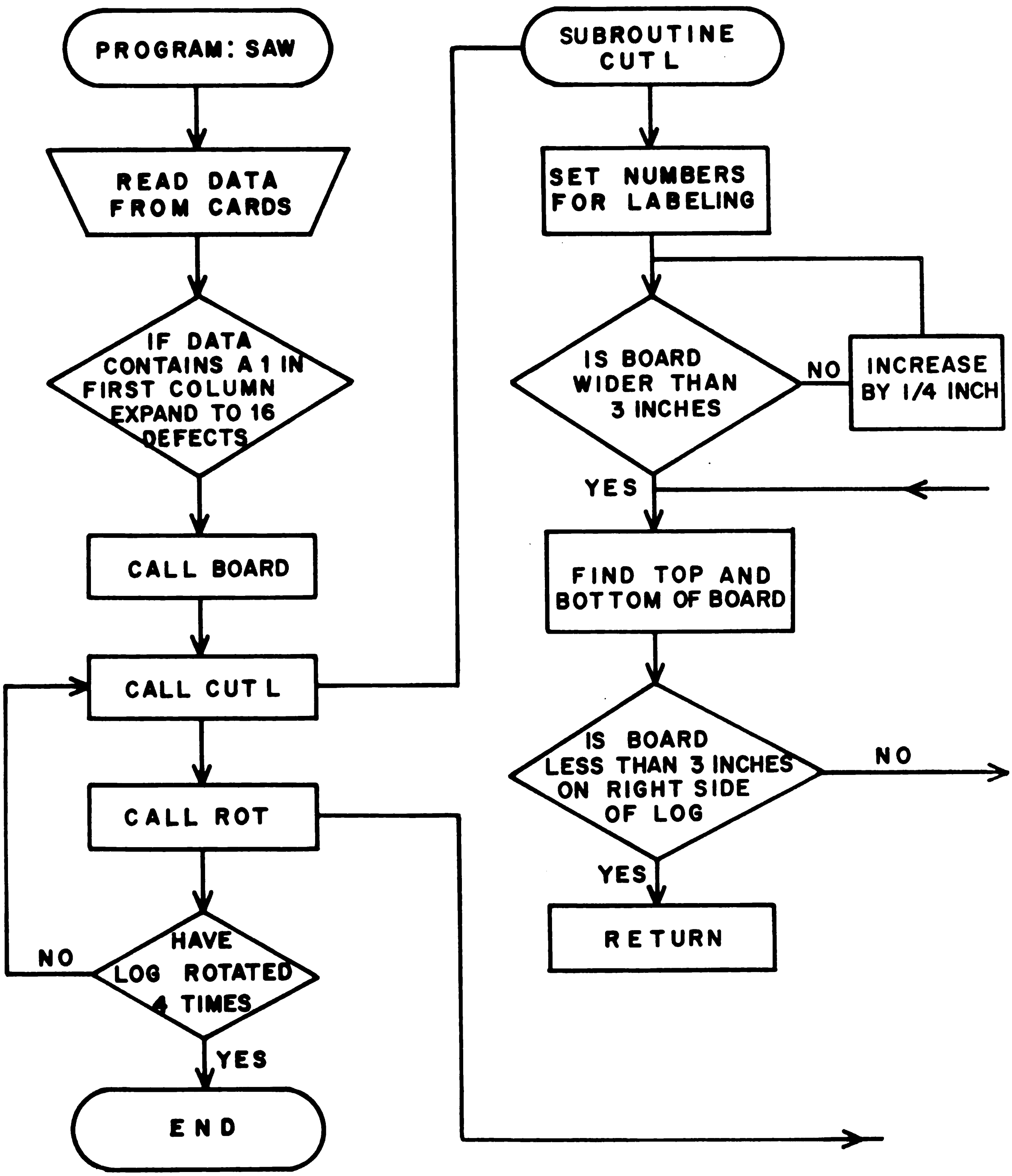
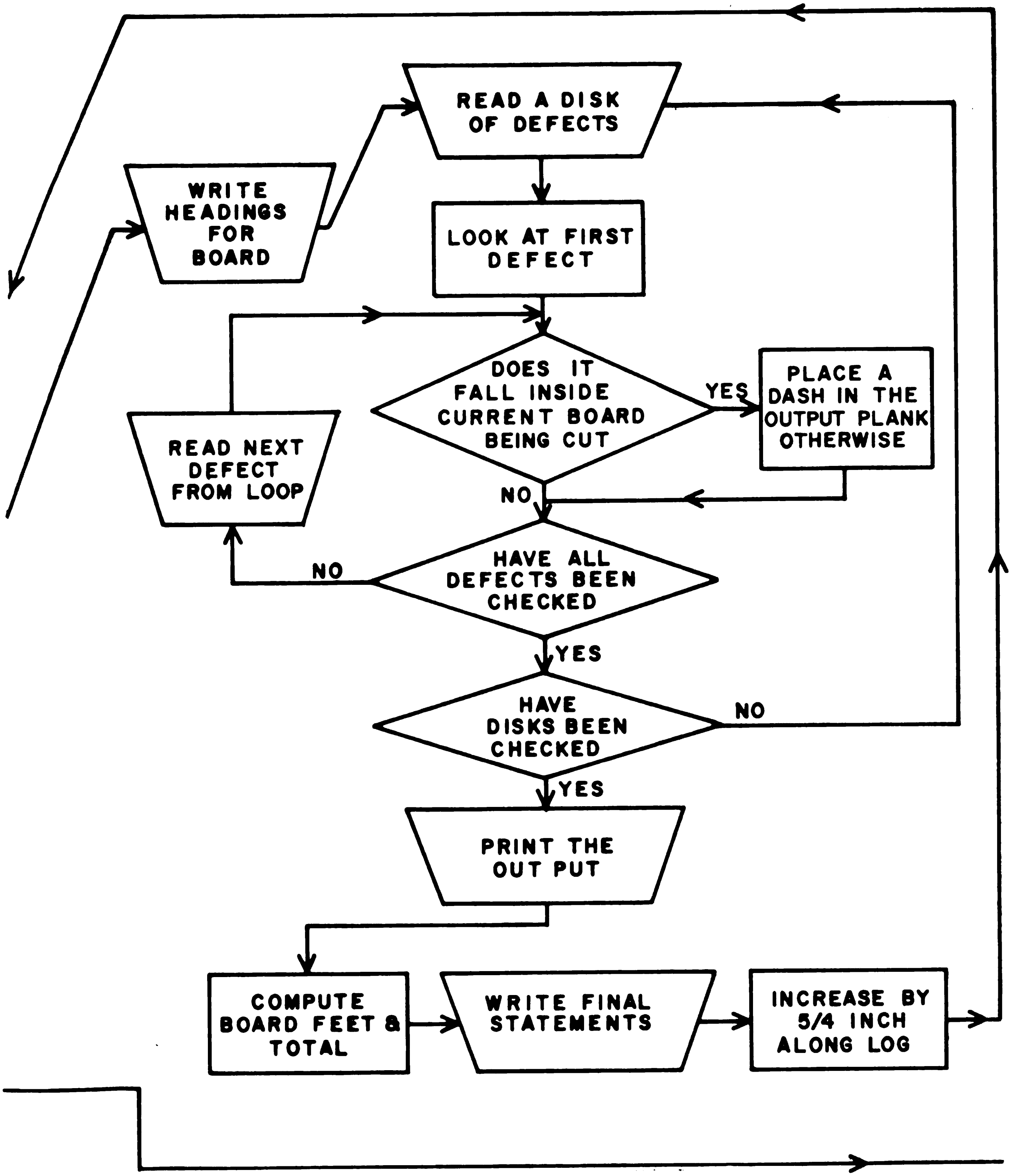
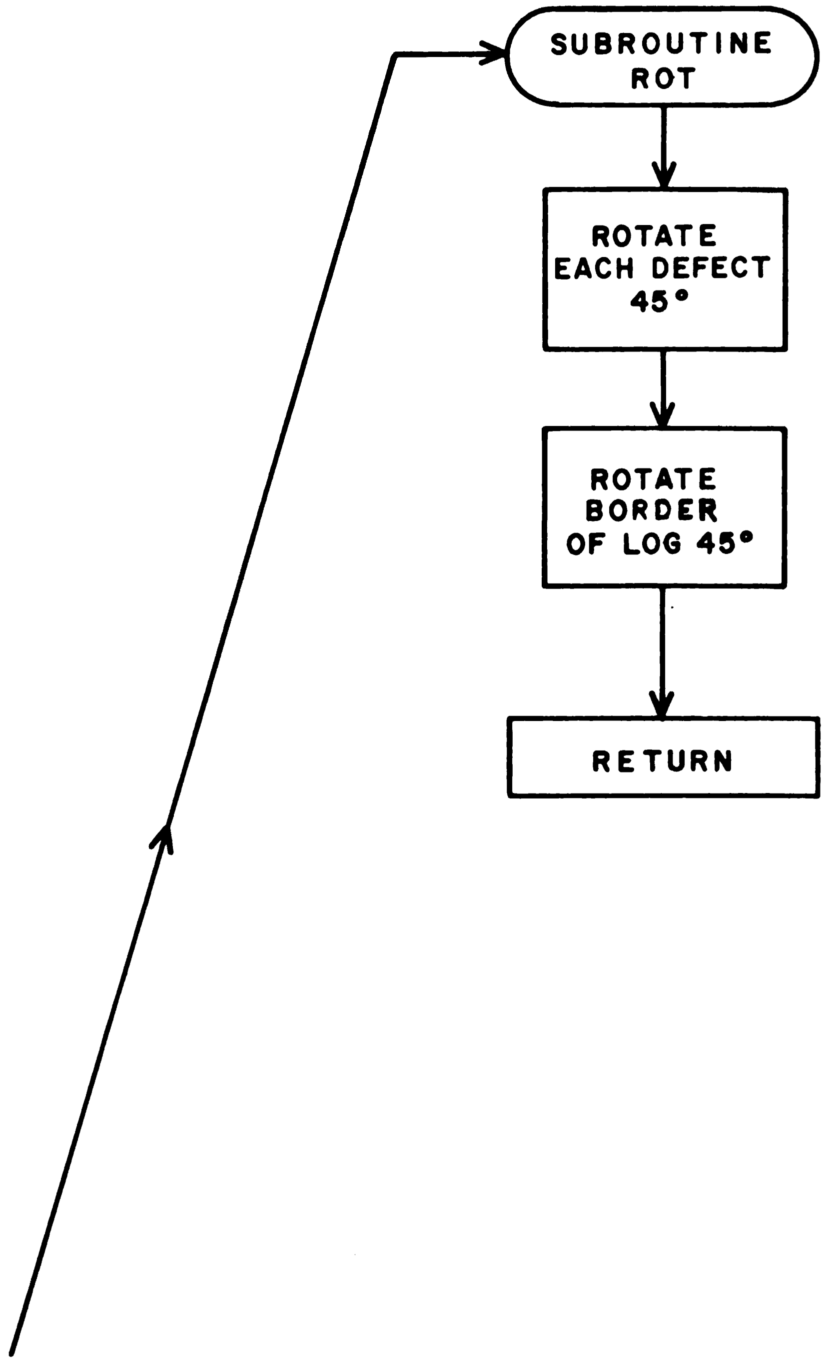
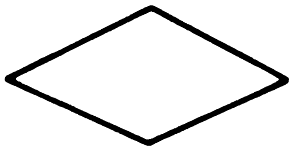


Fig. 7. Flow Chart of the Simulated Log Breakdown


READ A DISK OF DEFECTS
WRITE HEADINGS FOR BOARD
LOOK AT FIRST DEFECT
DOES IT FALL INSIDE CURRENT BOARD BEING CUT
YES
PLACE A DASH IN THE OUTPUT PLANK OTHERWISE
READ NEXT DEFECT FROM LOOP
NO
HAVE ALL DEFECTS BEEN CHECKED
NO
YES
HAVE DISKS BEEN CHECKED
NO
YES
PRINT THE OUT PUT
COMPUTE BOARD FEET & TOTAL
WRITE FINAL STATEMENTS
INCREASE BY 5/4 INCH ALONG LOG

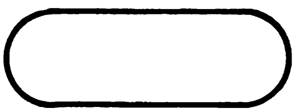

SUBROUTINE
ROT
ROTATE
EACH DEFECT
45°
ROTATE
BORDER
OF LOG 45°
RETURN

A rectangle indicates any processing operation except a decision.

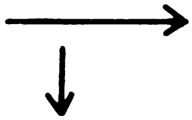


A diamond indicates a decision. The lines leaving the box are labeled with decision results that cause each path to be followed.

A trapezoid indicates an input or output operations.

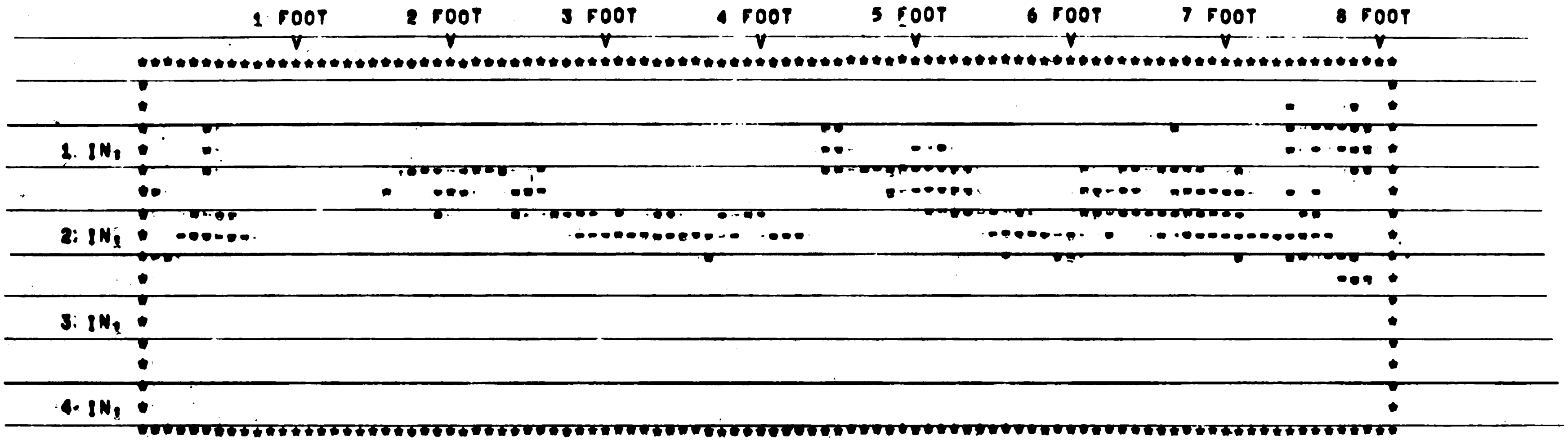


An oval indicates the beginning or ending point of the program.



Arrows indicate the direction of flow through the flowchart; every line should have an arrow unit.

THIS REPRESENTS AN EIGHT FOOT BOARD, CUT FROM LOG QUALITY 1, NUMBER 2



~~THIS IS BOARD 4 WITH 2,67 BOARD FEET, SO FAR 21,83 BOARD FEET HAVE BEEN CUT FROM THIS LOG,~~
THIS BOARD EXTENDS FROM 39 TO 55 ON THE X-AXIS, IT IS ONE-1/8 INCH THICK BETWEEN 45 AND 49 ON THE Y-AXIS,
~~THIS IS THE CANT AND IS CUT WITH A SASH-GANG SAW, IT HAS A 1/8 INCH KERF, AND HAS BEEN ROTATED 45 DEGREES,~~

FOR 1 COMMON WE NEED AT LEAST 21 UNITS IN 1 CUTS (LESS THAN 5), MINIMUMS ARE--4 IN, BY 2 FT, OR 3 IN, BY 3 FT,

~~FOR 2 COMMON WE NEED AT LEAST 15 UNITS IN 1 CUTS (LESS THAN 7), THE MINIMUM IS 3 IN, BY 2 FT,~~

FOR 3A COMMON WE NEED AT LEAST 10 UNITS, UNLIMITED CUTS, THE MINIMUM SIZE IS 3 IN, BY 2 FT,

~~FOR 3B COMMON WE NEED AT LEAST 7 UNITS, UNLIMITED CUTS, MINIMUM WIDTH IS 1-1/2 IN, MUST CONTAIN AT LEAST 36 SQ, IN,~~

Fig. 8. A Sample of the Simulation Output

The rotation angle of the log, which for this study was set to 45 degrees, can also be altered to fit any specific requirement. The decision to use a 45 degree rotation was based on the assumption that changing the position of the log by 45 degrees places the sawing faces between the knots, at the center of the knots, and parallel with the knots.

The major advantages of this model are:

1. It offers an analytical technique to investigate log yields, which otherwise may be very difficult to achieve in as complex a problem as the breakdown operation. In a production problem of this kind, trial and error procedures would be very expensive and time-consuming. It is here that the simulation model can offer a great contribution.

2. There is no human decision and participation during the computer simulation. The problem is entirely structured before the simulation is run.

3. Evaluation criteria are provided. In addition to an attempt at maximizing lumber grade yields, other specific measures such as kerf waste minimization, optimum log diameter-cant size relationship, and variable processing time might be used.

4. It appears possible that the interaction of the inputs can be simulated in a manner which will lead to a new understanding of the functional relationships involved.

Major disadvantages of the model are:

1. Taper removal. It will be recalled from the earlier discussion that taper is removed equally from both sides. Taper adjustment is avoided, since before the log is "sawed" it is treated as if it were in the form of a cylinder. The model at its present stage does not provide for full taper removal.

2. The number of defect units, appearing in the face of each printed out board as individual dashes, may not always coincide with the total number of existing unit defects. This is so because defect units up to three—in our case—may be covered by the first defect and they are not projected on the face of the board. Thus there is no way of knowing the depth

of board face defect. With one-inch thick lumber it is not far from reality to assume that the depth of each unit defect is one inch. However, with thicker boards it may present the investigator with a problem. The model can easily be modified to cover this limitation by assigning different characters, in addition to dashes as defect units. These could occur by quarter of an inch intervals.

The important characteristics of the technique are:

1. The input data can be empirically derived.

2. There is a wide flexibility in the choice of procedures.

3. The essential nature of the model—including the manual manipulation of the boards in Method 3—is a step-by-step, microanalytical portrayal of the physical system.

Pilot Project

Experimental Runs

The pilot experiments discussed below were undertaken for the purpose of testing procedures, evaluating the operational feasibility of the model, and developing hypotheses and ideas.

More specifically, the pilot experiments were undertaken to show: (1) if the model constructed for this experiment functions when actual data are introduced, and (2) if results can realistically be portrayed in terms of board grade variations. It should be stressed that the grades of the lumber used to evaluate each method were designed specifically for this study. Therefore, the evaluation of the results corresponds to these particular grades only. The grades themselves were used to focus attention upon the results of decisions that were made in the course of the simulated activity. The analysis of the results, then, is to be considered as offering an illustrative example of the methods.

All logs were processed several times, in different positions and with different kerf sizes. The simulation of the breakdown operation included the following methods and machines (Figure 4): (a) Method 1 - using a circular saw and a gang saw. (b) Method 2 - using a gang saw and leaving a cant of four inches on the first trial and six inches on the second trial. (Both cants were turned 90 degrees and were sawn again on the same saw.) (c) Method 3 - using a circular saw and sawing by "turning" the log.

For each run, the important consideration is the overall value of the product of each log grade. This value was calculated from the proportions of the various grades of lumber produced during each trial. The obtained values were then added, and the sum was standardized on a thousand board feet log scale basis. Values based on a log scale are desirable in order to determine value differences on the basis of the same denominator. Also, because logs are purchased on a log scale basis, lumber yield values can be referred to the same basis as log values.

Calculation of the yield values from the alternative sawing methods was based on the lumber yield obtained, with no regard to processing cost of the logs. Although the best analysis would result if such costs were included in calculating the value yield of each method and log grade, only the purchasing cost was available for use here. An evaluation of the sawing methods offered here, therefore, has the purpose of pointing out the differences among methods, and among various positions of the same log within a method. It does not give precise information as to the actual profit or loss achieved.

In order to find the purchasing cost, a log grade-price scale was used. The log prices were taken from those prevailing in the local market during the summer of 1967. They were adjusted to the log scale used to evaluate lumber production.* The adjusted log prices were as follows: $53 for log grade No. 1, $40 for log grade No. 2, and $33 for log grade No. 3. Net value yields of the produced lumber were estimated by subtracting the log purchasing cost of each grade of log from the yield value obtained when the same log—via simulation—is sawed with different methods. The results are presented in Table 12 of Appendix A.

The utility of the model as a method of investigation is demonstrated with the tables cited in Appendix A. Results of circular sawing and gang sawing of the same log, when sawing through or when a cant is left, can be compared among them or with the results obtained by using present day grade sawing practices. Thus the second objective of this study has been achieved.

When a comparison is made between the results of Method 3 and those reported in publications, one should be careful to consider the factors noted in earlier parts of this study. There are obvious differences between the yields obtained in this study and the published yield figures (20). In general, the results in the present study were lower for the higher grade logs, and higher for the lower grade logs, as would be expected from the analysis of the sample logs referred to in earlier pages of this study.

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*Original prices of Doyle scale were adjusted to International 1/4 inch scale prices.

Several explanations can be given for the observed differences in log yield. First, the logs used for the simulation were not average logs for their respective grades. Logs 1.1, 2.1 and 3.2 were most atypical of logs for their grade. On the basis of their appearance the logs were classified as grades No. 1, 2, and 3. When cut into disks, however, the logs which had been graded as No. 3 proved to be of a better than average quality for that grade. Those which had been appraised as No. 1 grade turned out to be poorer than average for that grade. This observation points out the need for the simulation technique for the investigation and possible re-evaluation of the existing log grading rules. (This subject will be discussed further in the next section.)

Other factors contributing to the different yields obtained in this experiment were the diameter and the length of these logs. It would be recalled that the diameter of four of the logs was the minimum diameter for their grade. The length of these logs was arbitrarily set to eight feet, which further reduced to a certain percent the volume of higher grade lumber. The lumber grading system used in this study was another factor in reducing the percentage of higher grade lumber. Boards which otherwise should have been graded as "select," for example, were classified as No. 1 Common.

Finally, an important observation brought out by the experimental runs for cant production is worth mentioning. Because of the restrictions imposed on lumber size, several potential boards were not produced. These were the boards which failed to meet the required minimum thickness of one and one-eighth inches. Test runs for three, four, five, and six inch cants clearly indicated a relationship between volume and cant size. When cant sizes are arbitrarily set without regard to log diameter, as was the case in this experiment, it is possible that certain parts of the log around the circumference are wasted. These are the parts which do not meet the lumber size requirements. Thus, a potential piece of perhaps high grade lumber is missed.

Despite these limitations, the indisputable fact is that the same log —when cut in different positions and with different machines—produces different results. In Table 1, for example, for log No. 1, the yield of No. 2 Common varies from 14 percent (position D) to 78 percent (position B).

Comparisons of Results

Comparisons of the results of Method 1 and 2 with those of Method 3 (the control method) can be made in two ways: first, by comparing the volume yield of each method, and second by comparing the value yield attained by grade variations within each method and log grade, which can be expressed in dollars per thousand board feet log scale basis. The comparison of volume differences for the average of the two logs of each grade shows the following results (Tables 1-10). For log grade 1, Method 1 gave about 6 percent more volume yield than Method 3, when a circular saw was used. With the use of a gang saw, the difference was increased to about 18 percent. For the same log grade, Method 2, when a four inch cant was produced, gave about 13 percent more volume than Method 3. With a six inch cant, this difference was reduced to about 3 percent. The higher volume yield of both Methods 1 and 2 can be attributed to the use of fewer sawlines, and consequently less kerf waste. Also, due to one extra board produced by Method 1 with the use of gang saw, and Method 2 with a four inch cant.

For log grade 2, Method 1 showed about 4 percent higher volume yield than Method 3, when a circular saw was used. The use of a gang saw increased the difference to about 14 percent. Method 2, when a four inch cant was produced, showed about 4 percent more volume than Method 3. With a six inch cant the volume dropped below that of Method 3 by 9 percent. The reasons for the higher percentages obtained are the same as in the previous case of log grade 1. The reduction in the volume when a six inch cant was produced, was due to the loss of the last board for each log, which failed to meet the required thickness limitation. The critical factor in this case was the relationship between cant size and log diameter.

For log grade 3, Method 1, when a circular saw was used, showed about 6 percent less volume yield than Method 3. With the use of a gang saw, the volume yield exceeded that of Method 3 by about 6 percent. Method 2 with a four inch cant showed a 15 percent less volume recovery than Method 3, while with a six inch cant the difference was reduced to 5 percent below that of Method 3. The reason for the relatively higher recovery with a six inch cant was that the logs of this grade were of larger diameter, which probably gave a better cant size-log diameter relationship. The greater volume yield of Method 3 in all cases of log grade 3, with the exception of gang sawing in Method 1, can be attributed to a more complete utilization of the log by the "log turning" procedures of Method 3. In through sawing, parts at the right side of the log were wasted due to lumber size restrictions. By turning the log by 90 degrees, these parts were included into boards cut in the new position of the log. Thus ten boards were produced by Method 3, while Method 1 produced seven boards with a circular saw and eight boards with a gang saw. In the case of gang sawing in Method 1, the kerf differences outweighed the volume recovery advantage of Method 3.

Table 11 shows the value yields obtained by all methods, on a thousand board feet log scale basis. For log grade 1, the value obtained by Method 1 and circular sawing was about 1 percent above that of Method 3. With the use of a gang saw, Method 1 showed a 16 percent greater value yield. Method 2 with a four inch cant showed about 10 percent more value yield. On the other hand, Method 2 with a six inch cant gave 17 percent less value yield than Method 3 on log grade 1.

The observed differences in value yield between Method 1 and 2 and those of Method 3, for log grade 1, could be attributed to the same factors cited when the limitations of the logs were discussed. Also, Method 3, which is more appropriate with logs containing larger proportions of higher grade lumber, did not produce enough high grade lumber to warrant the waste involved in the use of this method. The much higher value recovery of Method 1, shows the advantages of a simpler sawing method when not enough high grade lumber is present. The increased volume recovery obtained with use of a gang saw proved to be far more important, with regard to value yield, than the little amount of higher grade lumber recovered by Method 3 in excess of that of Method 1 (see Table 10, Grade 1).

The value yield pattern for log grades 2 and 3 is almost the same for all three methods as discussed above for the volume yield comparison. The only exception is in the results obtained by Method 3 from log grade 3. In this case the value yield from Method 3 was higher than that obtained from any other method and type of sawing except for the gang sawing Method 1. The reason for this generally higher yield is apparently the much larger percentage of higher grade lumber extracted by Method 3, as shown in Tables 3, 6, 9, and 10. These results support the already known and stated fact that Method 3 is more suitable for logs which turn out to have higher potential for grade lumber production.

Statistical tests are a possible way to appraise the importance of the observed differences among methods as discussed directly above. The observed differences, when tested by an analysis of variance, showed no significance or interaction effect. Since the limited number of observations in this study was inadequate for statistical testing purposes, it is obvious that more log sawing needs to be simulated. It would then be possible to make more reliable predictions as to the interaction between log grades and sawing methods, and the significance of yield differences among them.

Implications

The simulation technique, with its explicit methodology for the execution of the work, has particular value in the present era of computer availability. The evaluation of all variables entering into actual production can be done only through the use of a computer which can carry out long and complex sequences of operation. There are several implications of this technique. Each of those discussed below will require the use of a computer for its execution.

Library of Log Defects

One very practical application of this technique would be the establishment of a library of log defects. Samples of logs, stratified according to their surface characteristics, can be sliced into disks revealing their internal conditions. Using the recording method described in Section II, and equipment to be described at the end of this section, the size and distribution of the defects can be recorded on punched cards. The stored data can be investigated for the existence of any possible pattern of defect distribution and frequency, according to species, diameter and location of the logs in the tree. Through the use of a digital plotter computer device, the size and distribution of the defects may be reproduced on a scale so that a visual, schematic model of the log's cylinder will be obtained.

Such a library of log defect distribution can function as a permanent reference on a given population of logs and may be used for studies of yield predictions. Knowledge gained through this type of investigation can help to better evaluate existing log grading rules. These rules can perhaps be revised to better fit the desired production goals. With an increased accumulation of data, stored on a permanent basis and readily available, new prospects in the analysis of wood processing may be opened to researchers.

Laboratory Testing Technique

One of the major problems of the breakdown operation is the amount of human decision making and participation during the operation. It appears entirely possible that the two main inputs—log characteristics and sawing methods—can be simulated in laboratory testings. The results of their relationship can be evaluated better, so that new understanding of the interaction of these two factors can be obtained. A large number of variables can be handled. The only limitation is the ability of the computer to handle the data.

The simulation approach can be used to gain insight into the entire system, or to specific parts of it. In the present simulation, for example, such variables as quality and diameter of logs, board size, sawing faces and cant size are isolated and their effect on the operation is reproduced. Statistical tests must then be made to determine which variables are important and which are unimportant. Thus, simulation makes possible the study of a variety of variables within the alternative sawing methods. The selection of the best method may become obvious. More likely, the policies to be followed will continue to require a great deal of judgment. The simulation results, however, will aid in balancing one alternative against another. The ability to examine many alternative methods at frequent intervals makes it possible to do a better job of planning.

Logs separated by species, quality, and diameter within the quality, can be used to provide the input data for the simulation process. Several assumptions regarding the sawing method can be made and introduced as parameters. Outcomes of these decisions can be evaluated and compared. The use of a computer which can compress testing into a few minutes of processing time makes possible the study of a great many decisions.

By introducing their operational characteristics, the effect of using separate sawing machines or a combination of them also can be studied. The model, supplemented with the manual manipulation of boards described in Method 3, offers the possibility of assigning any sawing method and kerf size to fit a particular machine, whether it be a circular, band, or gang saw.

Overrun and underrun studies also can be carried out via laboratory testing. Similarly, the determination of optimum cant size in relation to specific diameters can be another application of this technique. Laboratory investigations can lead to the preparation of charts which, by interpolation and extrapolation, will be able to give the proper cant size for a desired diameter of a log.

In general, knowledge gained by experimenting with the model can help to incorporate changes into present-day operating systems, possibly in the direction of simplified decision rules.

Data Recording Equipment

A precise recording of log circumference and defects can be obtained by tracing through a digitizer. Such a machine also affords enormous savings in time, which otherwise can be the biggest handicap for practical application of this testing technique. Input data to be fed into the model can be produced routinely by tracing the disks, or films of disks, previously cut from logs.

A device like the PF 10 Pencil Follower,* operating on the basis of an X and Y coordinate system, can operate as simply as pointing a pencil at the coordinates. Circumference points or defect units can be digitized simply by tracing them. Data recording can be set for continuous or intermittent operation. In this process, the coordinates of any point or unit are immediately displayed and recorded, to an accuracy of ± 0.008 inch (1/128). With the use of this machine, shapes can be put into a digital computer. A big advantage of this machine is that an unskilled operator easily and rapidly can select the required information to be digitized.

The given accuracy is considered more than adequate for log tracing. For normal accurate line tracing, at about one inch per second, the reading errors may be ± 0.008 inch. For rough digitizing, while tracing at four inches per second, errors of ± 0.04 inch (3/64) may be observed.

The accuracy obtained at four inches per second appears suitable for log tracing. At this speed, a disk with a diameter of 15 inches can be

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*Manufactured by the Thomson Division, Edwin Industries Corporation, Syracuse, New York.

traced in approximately 15 seconds. An eight-foot log, containing 96 disks, would require 1,440 seconds, or 24 minutes, for circumference reading. Assuming that the same or a little more time will be consumed for defect readings, then one hour's time would be needed to test a log eight feet long. This time is considered very realistic and can be used for actual laboratory testing procedures. The output, in the form of punched cards, can be fed into the computer along with the sawing model. Even faster processing of the data can be achieved by simply having it channelled directly into the computer.

Future Refinements and On-Line Control

Expected future developments of devices which will scan the log and reveal the internal size and location of the defects could improve input-output control. The knowledge of the position and size of the internal defects, and the knowledge of the best sawing method for an aggregate of defect patterns, can greatly improve not only yield but processing techniques as well. X-rays, and perhaps laser beams could provide the basis for the development of scanning equipment to investigate the inside condition of a log. The first is already in the experimental stages of detecting log defects (2). The combination of simulation techniques and detecting devices is expected to bring not only better control but also the prospect of more automation. Besides, the use of such devices will alter the destructive nature of the recording method developed in this study to a non-destructive form, which then can use the same logs for real processing in order to verify the results.

Logs being processed can be made to pass in front of diameter measuring devices and scanning machines which can transmit the data to a connected computer. The computer in turn will select the proper sawing method on the basis of the input data. The output for each individual log will be the proper sawing program. A battery of sawing equipment can be arranged to handle this type of operation.

Application to Other Materials

Although wood is among nature's most complex materials, it is interesting to note that this technique does not necessarily restrict itself only to logs. The model can be used to test grade yields in other heterogeneous materials with hidden defects, such as plastic or rubber products. This model can be especially helpful for cases where a certain pattern of defect distribution exists, which can vary among different batches but not within the same batches. A continuing sampling program can provide information applicable to all other similar groups. Other types of defect distribution can also be investigated. Polymer materials such as rubber, for example, can be investigated through this methodology for testing quality variations due to bubbles.

V. SUMMARY AND CONCLUSIONS

A computer simulation model of the log breakdown operation has been developed, which will enable investigators to use it as an analytical tool for studying log yields. This technique can help to measure the influence of alternative sawing methods, applied to the same log, on the value and volume yield of various log grades.

A circumference and defect recording method also has been developed, by means of which measurements of the log characteristics can be transferred onto punched cards and fed into the computer for processing by the simulation program.

Two sets of data are introduced into the model. The first consist of data describing the raw material being processed. The second, consisting of data corresponding to the sawing methods, sets the parameters of the model. The raw material data for this study were gathered by cutting six red oak logs into one-inch thick disks, then measuring their circumference and the size and location of the defects. The computer program which was written for this study, utilizing the two sets of input data plus appropriate instructions, is used to simulate the sawing activity.

As an illustration of the simulated activity, a pilot experiment was carried out. The goal of the experimental runs was primarily one of testing the ability of the model to perform an explicitly designed operation. The six logs used in this study were sawed—via computer simulation—164 times, using live sawing, and cant production. Sawing by "turning the log" was simulated in part by the computer, supplemented with manual manipulation of the resulting boards. This last method, which is among those commonly used today, was intended as a control. In order to show the differences in the yield when simpler methods are used, the results of the other methods should be compared to this control method. Allowance has been made for one-eighth and one-fourth of an inch kerf sizes, which can simulate band sawing, gang sawing and circular sawing. The size, board feet, and defects are given for each board produced. Results from the experimental runs are discussed in Section IV and presented in tables in Appendix A.

The model written in FORTRAN language, has been executed on a CDC 3600 computer. It consists of the main program and three supplementary subprograms; one for sawing lumber, one for rotating the log into new position, and one for cant production. It takes approximately three minutes to "saw" a log 16 times, in four different positions, and measure the resulting boards.

The validity of the results of the simulation model is checked with a control mechanism within the model which allows validation of the produced results. This control mechanism consists of the coordinates of the end section of the log circumference, the coordinates of each board produced from the log, and the coordinates of the defect units on the face of the board. The results of the experimental runs were checked and verified for their accuracy.

The important characteristics of the technique are its essential simplicity, the wide flexibility that it affords in the choice of procedures, and the fact that its input data can be derived empirically. Considering the time saved by this approach the testing of a great number of logs can be achieved at a much reduced cost. Disadvantages of the model, at its present stage, are the lack of full taper removal and the inability to show the depth of board face defects.

In general, the model is flexible and can be used for any thickness of lumber and cant, and any degree of log rotation desired. Different sawing faces, board thicknesses, and cant sizes can be introduced as variables by assigning the specific angle and size required. Various kerf sizes, simulating various sawing machines, can also be introduced. Thus the effect of these machines on the grade and volume yield of the logs can be studied. Since our concern in this study was to find a way of investigating log yield problems and testing the model for its reliability, the indicated limitations can be handled by expanding the present model. Specific production constraints used here easily can be altered to fit a particular form of operation desired.

It is expected that this study will have opened the way for more investigation of the yield potentials of sawlogs. The model itself, although not yet fully refined to meet all the requirements of an actual log breakdown operation, nevertheless can contribute significantly to such investigations. The optimum relationship between cant size - log diameter for example, is one of the areas which can be fully investigated with this model.

Some implications for improving research and production procedures are the potential development of a library of log defects, the possibility of further laboratory testing, and the utilization of existing defect recording equipment. Eventually it may be adaptable to on-line control of actual sawmill operations.

Meanwhile, the model is so constructed that future refinements can be incorporated. Complete computer simulation of grade sawing could be a significant improvement to the present model. With the addition of a program which can express the lumber output of the present program in terms of clear cuttings, a full solution to the hardwood log yield problem will have been achieved.

This model shows the feasibility of a new approach to solving the vital question of how best to saw a log. It should prove to be superior to methods available in the past.

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APPENDIX A

Table 1. Lumber Grade Yields by Method 1 and Circular Saw, Log Grade No. 1

Log Grade and Sawing Position	Lumber Grade FAS %	No. 1C %	No. 2C %	No. 3A %	No. 3B %	Total Lumber Volume B.F.	Lumber Value MBF $	MBF Log Scale* $
Log No. 1								
Position A	0.0	0.0	41.0	15.4	43.6	31.3	65.7	37.5
Position B	0.0	0.0	78.7	14.4	6.9	31.3	75.3	42.9
Position C	0.0	0.0	73.4	26.6	0.0	31.3	74.7	42.5
Position D	0.0	22.3	14.4	40.4	22.9	31.3	79.5	45.3
Average	0.0	5.6	51.9	24.2	18.4	31.3	73.8	42.0
Log No. 2								
Position A	13.6	65.2	21.2	0.0	0.0	30.7	139.6	77.8
Position B	29.3	49.5	21.2	0.0	0.0	30.7	153.6	85.6
Position C	13.6	63.0	23.4	0.0	0.0	30.7	137.9	76.9
Position D	29.3	49.5	21.2	0.0	0.0	30.7	153.6	85.6
Average	21.5	56.8	21.8	0.0	0.0	30.7	146.2	81.4
Logs No. 1 & No. 2	10.7	31.2	36.8	12.1	9.2	62.0	109.5	61.7

*International 1/4 inch Log Scale.

Table 2. Lumber Grade Yields by Method 1 and Circular Saw, Log Grade No. 2

Log Grade and Sawing Position	Lumber Grade: FAS %	No. 1C %	No. 2C %	No. 3A %	No. 3B %	Total Lumber Volume B.F.	Lumber Value: MBF $	MBF Log Scale* $
Log No. 1								
Position A		26.5	43.3	0.0	30.2	27.7	87.8	69.4
Position B		9.0	17.5	56.0	17.5	27.7	69.8	55.1
Position C		26.5	17.5	33.7	22.3	27.7	83.1	65.7
Position D		0.0	25.4	74.6	0.0	27.7	65.1	51.4
Average		15.5	26.1	41.1	17.3	27.7	76.4	60.3
Log No. 2								
Position A		9.5	27.0	63.5	0.0	22.8	72.7	47.4
Position B		0.0	51.9	21.1	27.0	22.8	68.8	44.9
Position C		0.0	16.7	83.3	0.0	22.8	63.5	41.4
Position D		0.0	21.1	35.1	43.8	22.8	61.8	40.3
Average		2.3	29.2	50.8	17.7	22.8	66.7	43.4
Logs No. 1 & No. 2		8.9	27.7	45.9	17.5	50.5	71.9	51.9

*International 1/4 inch Log Scale.

Table 3. Lumber Grade Yields by Method 1 and Circular Saw, Log Grade No. 3

Log Grade and Sawing Position	Lumber Grade FAS %	No. 1C %	No. 2C %	No. 3A %	No. 3B %	Total Lumber Volume B.F.	Lumber Value MBF $	Lumber Value MBF Log Scale* $
Log No. 1								
Position A		15.1	31.1	21.8	32.0	54.2	76.4	55.2
Position B		12.6	22.2	60.6	4.6	54.2	74.2	53.6
Position C		0.0	24.6	62.5	12.9	54.2	64.2	46.4
Position D		9.5	45.9	32.0	12.6	54.2	76.1	54.9
Average		9.3	31.0	44.2	15.5	54.2	72.7	52.5
Log No. 2								
Position A		9.6	70.1	20.3	0.0	43.5	81.6	64.5
Position B		15.3	64.4	20.3	0.0	43.5	85.1	67.3
Position C		0.0	94.3	5.7	0.0	43.5	78.9	62.4
Position D		20.3	79.7	0.0	0.0	43.5	92.2	72.9
Average		11.3	77.1	11.6	0.0	43.5	84.4	66.7
Logs No. 1 & No. 2		10.3	54.1	27.9	7.7	97.7	77.9	59.6

*International 1/4 inch Log Scale.

Table 4. Lumber Grade Yields by Method 1 and Gang Saw, Log Grade No. 1

Log Grade and Sawing Position	Lumber Grade FAS %	No. 1C %	No. 2C %	No. 3A %	No. 3B %	Total Lumber Volume B.F.	Lumber Value MBF $	MBF Log Scale* $
Log No. 1								
Position A			31.2	31.6	37.2	35.8	63.9	41.6
Position B			56.3	37.0	6.0	35.8	70.9	46.2
Position C			55.8	44.2	0.0	35.8	71.2	46.4
Position D		28.4	0.0	37.2	34.4	35.8	80.6	52.5
Average		7.1	35.9	37.6	19.4	35.8	71.7	46.7
Log No. 2								
Position A	12.8	87.2	0.0	0.0	0.0	35.2	151.8	97.1
Position B	12.8	87.2	0.0	0.0	0.0	35.2	151.8	97.1
Position C	27.5	72.5	0.0	0.0	0.0	35.2	164.6	105.3
Position D	27.5	52.1	20.4	0.0	0.0	35.2	152.4	97.5
Average	20.1	74.8	5.1	0.0	0.0	35.2	155.2	99.3
Logs No. 1 & No. 2	10.1	40.9	20.5	18.8	9.7	71.0	113.7	73.0

*International 1/4 inch Log Scale.

Table 5. Lumber Grade Yields by Method 1 and Gang Saw, Log Grade No. 2

Log Grade and Sawing Position	Lumber Grade					Total Lumber Volume	Lumber Value	
	FAS %	No. 1C %	No. 2C %	No. 3A %	No. 3B %	B.F.	MBF $	MBF Log Scale* $
Log No. 1								
Position A		32.9	23.3	36.4	7.4	29.3	90.7	76.0
Position B		13.1	30.7	56.2	0.0	29.3	76.7	64.3
Position C		0.0	48.3	51.7	0.0	29.3	69.6	58.3
Position D		15.4	51.7	32.9	0.0	29.3	82.5	69.1
Average		15.4	38.5	44.3	1.8	29.3	79.8	66.9
Log No. 2								
Position A		18.3	65.2	16.5	0.0	27.3	87.8	68.6
Position B		18.3	34.1	25.0	22.6	27.3	80.1	62.6
Position C		10.4	64.0	25.6	0.0	27.3	81.2	63.4
Position D		0.0	59.1	30.5	10.4	27.3	71.0	55.4
Average		11.7	55.6	24.4	8.3	27.3	80.1	62.6
Logs No. 1 & No. 2		13.5	47.0	34.3	2.2	56.6	79.9	64.7

*International 1/4 inch Log Scale.

Table 6. Lumber Grade Yields by Method 1 and Gang Saw, Log Grade No. 3

Log Grade and Sawing Position	Lumber Grade					Total Lumber Volume	Lumber Value	
	FAS %	No. 1C %	No. 2C %	No. 3A %	No. 3B %	B.F.	MBF $	MBF Log Scale* $
Log No. 1								
Position A		0.0	66.6	29.3	4.1	61.3	73.1	59.7
Position B		10.6	26.4	55.4	7.6	61.3	73.2	59.9
Position C		0.0	35.0	48.1	16.9	61.3	66.0	54.0
Position D		0.0	74.5	25.5	0.0	61.3	74.8	61.2
Average		2.6	50.6	39.6	7.2	61.3	71.7	58.6
Log No. 2								
Position A		34.8	65.2	0.0	0.0	49.3	100.8	90.4
Position B		24.0	76.0	0.0	0.0	49.3	94.5	84.7
Position C		47.6	52.4	0.0	0.0	49.3	108.7	97.5
Position D		37.2	54.7	7.1	0.0	49.3	101.6	91.1
Average		35.9	62.3	1.8	0.0	49.3	101.3	90.9
Logs No. 1 & No. 2		19.2	56.5	20.7	3.6	110.6	84.9	74.7

*International 1/4 inch Log Scale.

Table 7. Lumber Grade Yields by Method 2, Log Grade No. 1

Log Grade and Sawing Position	Lumber Grade FAS %	No. 1C %	No. 2C %	No. 3A %	No. 3B %	Total Lumber Volume B.F.	Lumber Value MBF $	MBF Log Scale* $
Cant Size 4"								
Log No. 1	0.0	29.8	8.6	27.3	34.3	33.0	84.9	49.8
Log No. 2	27.3	39.6	8.3	0.0	24.8	34.1	137.7	85.4
Logs No. 1 & No. 2	13.6	34.7	8.5	13.6	29.6	67.1	111.3	67.6
Cant Size 6"								
Log No. 1	0.0	21.9	0.0	36.8	41.3	30.4	74.8	41.3
Log No. 2	14.8	30.2	13.8	27.5	13.7	30.4	110.7	61.1
Logs No. 1 & No. 2	7.4	26.0	6.9	32.2	27.5	60.8	92.7	51.2

*International 1/4 inch Log Scale.

Table 8. Lumber Grade Yields by Method 2, Log Grade No. 2

Log Grade and Sawing Position	Lumber Grade					Total Lumber Volume	Lumber Value	
	FAS %	No. 1C %	No. 2C %	No. 3A %	No. 3B %	B.F.	MBF $	MBF Log Scale* $
Cant Size 4"								
Log No. 1		34.8	10.4	23.2	31.6	27.3	88.0	68.6
Log No. 2		21.7	0.0	41.1	37.2	23.1	74.9	49.4
Logs No. 1 & No. 2		28.3	5.2	32.1	34.4	50.4	81.5	59.0
Cant Size 6"								
Log No. 1		9.4	18.1	36.3	36.2	23.0	68.6	45.1
Log No. 2		10.0	16.2	16.1	57.7	21.7	67.3	41.7
Logs No. 1 & No. 2		9.7	17.1	26.2	47.0	44.7	68.0	43.4

*International 1/4 inch Log Scale.

Table 9. Lumber Grade Yields by Method 2, Log Grade No. 3

Log Grade and Sawing Position	Lumber Grade					Total Lumber Volume	Lumber Value	
	FAS %	No. 1C %	No. 2C %	No. 3A %	No. 3B %	B.F.	MBF $	MBF Log Scale* $
Cant Size 4"								
Log No. 1		5.5	67.2	5.5	21.8	51.8	76.4	52.8
Log No. 2		47.1	15.1	15.1	22.7	37.5	99.2	67.6
Logs No. 1 & No. 2		26.3	41.2	10.3	22.2	89.3	87.8	60.2
Cant Size 6"								
Log No. 1		8.8	36.3	19.7	35.2	59.2	72.0	56.8
Log No. 2		19.8	53.6	26.6	0.0	39.5	86.5	62.2
Logs No. 1 & No. 2		14.2	44.9	23.3	17.6	98.7	79.2	59.5

*International 1/4 inch Log Scale.

Table 10. Lumber Grade Yields by Method 3; Log Grades 1, 2, and 3

Log Grade and Sawing Position	Lumber Grade					Total Lumber Volume	Lumber Value	
	FAS %	No. 1C %	No. 2C %	No. 3A %	No. 3B %	B.F.	MBF $	MBF Log Scale* $
Grade 1								
Log No. 1	0.0	21.2	12.8	15.9	50.1	28.3	76.4	39.3
Log No. 2	27.5	56.2	16.3	0.0	0.0	29.7	152.4	82.2
Logs No. 1 & No. 2	13.7	38.8	14.6	7.9	25.0	58.0	114.4	60.7
Grade 2								
Log No. 1	0.0	0.0	82.5	17.5	0.0	25.7	76.4	56.0
Log No. 2	0.0	21.8	15.5	62.7	0.0	22.6	80.6	52.0
Logs No. 1 & No. 2	0.0	10.9	49.0	40.1	0.0	48.3	78.5	54.0
Grade 3								
Log No. 1	0.0	13.7	36.1	23.6	26.6	59.5	75.8	60.1
Log No. 2	0.0	31.9	62.1	6.0	0.0	44.3	98.0	78.9
Logs No. 1 & No. 2	0.0	22.8	49.1	14.8	13.3	103.8	86.9	69.5

*International 1/4 inch Log Scale.

Table 11. Gross Lumber Yield Values Per MBF Log Scale,* by Methods and Grades of Logs

Method \ Material	Log Grade No. 1 (Average of Two Logs) $	Log Grade No. 2 (Average of Two Logs) $	Log Grade No. 3 (Average of Two Logs) $
Method 1			
1. Circular Saw	61.70	51.90	59.60
2. Gang Saw	73.00	64.70	74.70
Method 2			
1. Gang Saw			
Cant Size 4"	67.60	59.00	60.20
Cant Size 6"	51.20	43.40	59.50
Method 3			
1. Circular Saw	60.70	54.00	69.50

*International 1/4 inch Log Scale.

Note: The dollar figures shown above are for illustrative purposes only. Variations in lumber prices would alter these figures. Also, errors in yield estimates undoubtedly arise, due to scale adjustments; grading rules used; and the possibility of recording errors.

Table 12. Net Lumber Yield Values Per MBF Log Scale,*
by Methods and Grades of Logs (After Subtracting the Cost of Logs)

Method \ Material	Log Grade No. 1 (Average of Two Logs) $	Log Grade No. 2 (Average of Two Logs) $	Log Grade No. 3 (Average of Two Logs) $
Method 1			
1. Circular Saw	8.70	11.90	26.50
2. Gang Saw	20.00	24.70	41.70
Method 2			
1. Gang Saw			
Cant Size 4"	14.60	19.00	27.20
Cant Size 6"	-2.80	3.40	26.50
Method 3			
1. Circular Saw	7.70	14.00	36.50

*International 1/4 inch Log Scale.

Note: The dollar figures shown above are for illustrative purposes only. Variations in lumber prices would alter these figures. Also, errors in yield estimates undoubtedly arise, due to scale adjustments; grading rules used; and the possibility of recording errors.

APPENDIX B

```
*EQUIP,02=60
*FAMILY(2),1=60
*EQUIP,03=61
*FAMILY(2),2=61
*FAMILY(2),3=69
*FORTRAN,LIST=61,XECUTE=69,INPUT=60,*,REFERENCE,Q-OPTION.
      PROGRAM SAWLOG
      INTEGER DEF (160)
      DIMENSION             MED(100,2),INPUT(16),A(20)
      COMMON DEFECT(96,160)
      EQUIVALENCE (DEFECT(1),A(1))
      READ 18, IO,I1,ANGLEDEG,ICANT1,ICANT2,INCREMNT
   18 FORMAT(2(I4,1X),F4.0,1X,3(I3,2X))
      PRINT 19, ANGLEDEG,ICANT1,ICANT2,INCREMNT,IO,I1
   19 FORMAT(*-ROTATE LOG *,F4.1,* DEGREES COUNTERCLOCKWISE.  THE CANTS
     1ARE FROM *,I3,* INCHES TO *,I3,* INCHES, INCREMENTED BY *,I3,* INC
     2HES.*,/* THE LOG WILL BEGIN FROM *,I3,* DEGREES AND BE ROTATED UNT
     3IL *,I3,* DEGREES IS PROCESSED.*)
      IF (ICANT1.GT.2.AND.ICANT2.GE.ICANT1.AND.ICANT2.LT.26.AND.ANGLEDEG
     1.GE.1..AND.ANGLEDEG.LE.180..AND.IO.GT.-1.AND.I1.LT.360)20,21
   21 PRINT 22
   22 FORMAT(*-PARAMETER ERROR(S) EXIST ON FIRST CARD.*)
      STOP
   20 WRITE(3,203)
  203 FORMAT(1H1,50X,8HCOMMENTS,/*-*)
      I2=ANGLEDEG $ ANGLEDEG=.0174532925*ANGLEDEG
      ICANT1=4*ICANT1 $ ICANT2=4*ICANT2 $ INCREMNT=4*INCREMNT
      DO 2 I=1,10
      READ(2,201)A
  201 FORMAT(20A4)
    2 WRITE(3,202)A
  202 FORMAT(28X,20A4)
      DO 77 NEWDATA=1,6
      N=0
      DO 3 I=1,15360,1
    3 DEFECT(I)=0.
```

```
    1 READ (02,200) INPUT
  200 FORMAT(16I5)                                          2
      IF (EOF,60)4,17
   17 IF (INPUT(1).EQ.22222)191,101
  101 IF (INPUT(1).EQ.0)11,9
    9 IF (N.LE.0)8,7
    7 DEF(160)=K
      DO 85 II=1,160
   85 DEFECT(N,II)=DEF(II)
    8 N=N+1
      DO 16 JA=1,160
   16 DEF(JA)=0
      LABEL=INPUT(1)/100
      LAB2=LABEL-LABEL/10*10
      LAB1=LABEL/10-LABEL/100*10
      K=1
      IT=0
      DO 10 J=2,16,1
      DEF(K)=INPUT(J)
      IF(J-12)40,41,6
    6 IF (INPUT(J).GT.9999)13,56
   56 K=K+1
      GO TO 10
   41 DEF(K)=5050
      K=K+1
      DEF(K)=INPUT(J)
      GO TO 6
   40 DEF(K)=DEF(K)-20000
      IF (DEF(K).LE.0) DEF(K)=5050
      GO TO 56
   13 INPUT(J)=INPUT(J)-10000                               2
      DO 15 M=1,4                                           2
      I=0
      DO 14 L=I,3,1
      DEF(K)=100*L+INPUT(J)
   14 K=K+1                                                 2
```

```
 15 INPUT(J)=INPUT(J)+1                                              2
    IF (IT.NE.0)12,10
 10 CONTINUE
    GO TO 1
 11 IT=1
    DO 12 J=2,16,1
    IF (INPUT(J).GT.9999)13,5
  5 DEF(K)=INPUT(J)
    K=K+1
 12 CONTINUE
    GO TO 1                                                          2
191 CALL BORD (DEF,MED,ICENH,ICENV,TOTL)
    IF (IO.GT.0) CALL ROT (DEF,ICENH,ICENV,ANGLEDEG)
    DO 77 ITRN=IO,I1,I2
    CALL CUTM (DEF,MED,ICENH,ICENV,LAB1,LAB2,ITRN,TOTL)
    CALL CUTL (DEF,MED,ICENH,ICENV,LAB1,LAB2,ITRN,TOTL)
    DO 103 ICANT=ICANT1,ICANT2,INCREMNT
    CALL CUTR (DEF,MED,ICENH,LAB1,LAB2,ICANT,ITRN,IEND1,IEND2,BF)
103 CALL CANT (DEF,ICANT,IEND1,IEND2,ITRN,LAB1,LAB2,BF,TOTL)
 77 CALL ROT (DEF,ICENH,ICENV,ANGLEDEG)
  4 END SAWLOG
    SUBROUTINE ROT (DEF,ICENH,ICENV,ANGLEDEG)
    INTEGER DEF (160)
    DIMENSION               MED(100,2)
    COMMON DEFECT(96,160)
    DO 86 K=1,96,1
    DO 85 II=1,160
 85 DEF(II)=DEFECT(K,II)
    DO 4 I=1,159,1
    IF (DEF(I).LE.0)4,5
  5 X=DEF(I)/100-ICENH $ Y=DEF(I)-DEF(I)/100*100-ICENV
    DEF(I)=COSF(ANGLEDEG)*X-SINF(ANGLEDEG)*Y+ICENH+.5
    DEF(I)=SINF(ANGLEDEG)*X+COSF(ANGLEDEG)*Y+ICENV+.5+100.*DEF(I)
  4 CONTINUE
    DO 86 II=1,160
 86 DEFECT(K,II)=DEF(II)
```

```
      END ROT
      SUBROUTINE BORD(DEF,MED,ICENH,ICENV,TOTL)
      INTEGER DEF(160),DET(4,96)
      DIMENSION              MED(100,2),IEDGE(4)
      COMMON DEFECT(96,160)
      DO 3 N=1,96
      M=N
      DO 86 II=1,160
   86 DEF(II)=DEFECT(M,II)
      IEDGE(1)=10000
      IEDGE(2)=99
      IEDGE(3)=IEDGE(4)=0
      DO 1 I=1,10
      IF (DEF(I).EQ.0)1,31
   31 IF (DEF(I).LT.IEDGE(1)) IEDGE(1)=DEF(I)
      IF (DEF(I).GT.IEDGE(4)) IEDGE(4)=DEF(I)
      MAR=DEF(I)-DEF(I)/100*100
      IHLD2=IEDGE(2)-IEDGE(2)/100*100
      IHLD3=IEDGE(3)-IEDGE(3)/100*100
      IF (MAR.LT.IHLD2) IEDGE(2)=DEF(I)
    1 IF (MAR.GT.IHLD3) IEDGE(3)=DEF(I)
      M=N-1
      DO 3 J=1,4
      JT=J-1
      DET(J,N)=DET(JT,N)
    3 IF (IEDGE(J).LE.10000) DET(J,N)=IEDGE(J)
      IAVR1=IAVR2=IAVR3=IAVR4=IBVR1=IBVR2=IBVR3=IBVR4=0
      DO 4 I=1,96
      IAVR1=IAVR1+(DET(1,I)- DET(1,I)/100*100)
      IAVR2=IAVR2+(DET(2,I)- DET(2,I)/100*100)
      IAVR3=IAVR3+(DET(3,I)- DET(3,I)/100*100)
      IAVR4=IAVR4+(DET(4,I)- DET(4,I)/100*100)
      IBVR1=IBVR1+DET(1,I)/100
      IBVR2=IBVR2+DET(2,I)/100
      IBVR3=IBVR3+DET(3,I)/100
    4 IBVR4=IBVR4+DET(4,I)/100
```

```
      DET(1,1)=IBVR1/96*100+IAVR1/96+100
      DET(2,1)=IBVR2/96*100+IAVR2/96+1
      DET(3,1)=IBVR3/96*100+IAVR3/96-1
      DET(4,1)=IBVR4/96*100+IAVR4/96-100
      LEGH=(DET(4,1)-DET(1,1))/200
      LEGV=((DET(3,1)-DET(3,1)/100*100)-(DET(2,1)-DET(2,1)/100*100))/2
      ICENV=(DET(2,1)-DET(2,1)/100*100+DET(3,1)-DET(3,1)/100*100)/2
      IGAP=LEGH-LEGV
      ICENH=(DET(1,1)/100+DET(4,1)/100)/2
      LDEF=          DET(4,1)/100
      IDEF=           DET(1,1)/100
      DO 192 I=1,100                                                      2
      MED(I,1)=7500                                                       2
  192 MED(I,2)=2500                                                       2
C     WRITE(3,990)ICENH,ICENV,IDEF,LDEF,IGAP,(DET(I,1),I=1,4)
C 990 FORMAT(*1*,19X,9(1X,I10))
      DO 19 I=1,100                                                       2
      IF (I.LT.IDEF.OR.I.GT.LDEF)19,30
   30 EDGE=I-IDEF
      IF (I.GT.ICENH) EDGE=LDEF-I
      F=EDGE/(ICENH-IDEF)*1.570795
      IBND=LEGH*SINF(F)-IGAP*F*.63662031
      MED(I,1)=100*I+ICENV-IBND
      MED(I,2)=MED   (I,1)+IBND*2
   19 CONTINUE                                                            2
C     WRITE (03,759) ((MED(I,J),I=1,100,1),J=1,2,1)
C 759 FORMAT(4(10X,I10))
      R=(LEGV+LEGH)/8.0
      TOTL=2.094393333*R*R
      END BORD
      SUBROUTINE GRADER (SM)
      N=.25*SM
      IF (N.LT.1)1,4
    4 I=10.*SM
      PRINT 200, I,N
    1 N=(SM+1.0)/3.0
```

```
      IF (N.LT.1)2.5
    5 I=8.*SM
      PRINT 201. I.N
    2 N=.5*SM
      IF (N.LT.1)3.6
    6 I=6.*SM
      PRINT 202. I.N
    3 I=SM*4.0
      PRINT 203. I
      I=SM*3.0
      PRINT 204. I
  200 FORMAT(*-FOR FAS WE NEED AT LEAST*.I4.* UNITS IN*.I3.* CUTS.  MINI
     1MUM CUT SIZES ARE--4 IN. BY 5 FT. OR 3 IN. BY 7 FT.*)
  201 FORMAT(*-FOR 1 COMMON WE NEED AT LEAST *.I4.* UNITS IN*.I3.* CUTS
     1(LESS THAN 5 ).  MINIMUMS ARE--4 IN. BY 2 FT. OR 3 IN. BY 3 FT.*)
  202 FORMAT(*-FOR 2 COMMON WE NEED AT LEAST*.I4.* UNITS IN*.I3.* CUTS (
     1LESS THAN 7).  THE MINIMUM IS 3 IN. BY 2 FT.*)
  203 FORMAT(*-FOR 3A COMMON WE NEED AT LEAST*.I4.* UNITS. UNLIMITED CUT
     1S.  THE MINIMUM SIZE IS 3 IN. BY 2 FT.*)
  204 FORMAT(*-FOR 3B COMMON WE NEED AT LEAST*.I4.* UNITS. UNLIMITED CUT
     1S.  MINIMUM WIDTH IS 1-1/2 IN.  MUST CONTAIN AT LEAST 36 SQ. IN.*)
      END GRADER
      SUBROUTINE CANT (DEF.ICANT.IEND1.IEND2.IROT.ID1.ID2.BF.TOTL)
      INTEGER DEF(160)
      COMMON DEFECT(96.160). ISTOR(100.96)
      IEND=MM=LABEL=1 $ KP=0 $ BRDFT=BF $ ILFT=DEF(1) $ IUP=ILFT/100
      IRGT=100*ICANT+ILFT $ IO=IRGT/100 $ IDOWN=IO-1
   10 IEND1=IEND1+5
      IF (IEND1.GT.IEND2)199.11
   11 LAB=MM=1 $ SIZE=0. $ KP=KP+1
      DO 1 I=1.96
      DO 86 II=1.160
   86 DEF(II)=DEFECT(I.II)
      DO 2 J=1.100.1
    2 ISTOR(J.I)=1H
      DO 1 J=1.159.1
```

```
      IF (DEF(J).LE.0.OR.DEF(J).LT.ILFT.OR.DEF(J).GT.IRGT+99)1,6
    6 K=DEF(J)/100 $ ID=DEF(J)-100*K
      IF (ID.GT.IEND1-5.AND.ID.LE.IEND1) ISTOR(K,I)=1H-
    1 CONTINUE
      PRINT 225, ID1,ID2,(I,I=1,8,1)
  225 FORMAT(1H1,30X,*THIS REPRESENTS AN EIGHT FOOT BOARD, CUT FROM LOG
     1QUALITY *,I3,*, NUMBER *,I3,/*-*,/14X,8(6X,R1,5H FOOT),/12X,8(11X,
     21HV))
      PRINT 220
  220 FORMAT(11X,98(1H*))
      DO 3 I=IUP,IDOWN,1
      PRINT 221, (ISTOR(I,II),II=1,96,1)
  221 FORMAT(11X,1H*,96A1,1H*)
      MM=MM+1 $ KO=MM-LABEL $ SIZE=SIZE+1.
      IF (KO/4.NE.(KO+3)/4)3,38
   38 PRINT 222, LAB
  222 FORMAT(1H+,3X,I2,4H IN.)
      LAB=LAB+1
    3 CONTINUE
      PRINT 220
      AREA=.1666666666*SIZE $ BRDFT=BRDFT+AREA $ IENDS=IEND1-4
      PRINT 223, KP,AREA,BRDFT
  223 FORMAT(*0THIS IS BOARD *,I3,* WITH *,F6.2,* BOARD FEET.  SO FAR *,
     1F6.2,* BOARD FEET HAVE BEEN CUT FROM THIS LOG.*)
      PRINT 229, IUP,IO,IENDS,IEND1,IROT
  229 FORMAT(* THIS BOARD EXTENDS FROM *,I3,* TO *,I3,* ON THE X-AXIS.
     1IT IS ONE-1/8 INCH THICK BETWEEN *,I3,* AND *,I3,* ON THE Y-AXIS.*
     2,/* THIS IS THE CANT AND IS CUT WITH A SASH-GANG SAW.  IT HAS A 1/
     38 INCH KERF, AND HAS BEEN ROTATED *,I4,* DEGREES.*)
      CALL GRADER (AREA)
      GO TO 10
  199 PERCT=BRDFT/TOTL*100. $ DEF(1)=ILFT
      PRINT 230, BRDFT,TOTL,PERCT
  230 FORMAT(1X,F8.2,* BOARD FEET WERE CUT OUT OF A POSSIBLE *,F7.2,*, F
     1OR A YIELD OF *,F5.1,* PERCENT.*)
```

2

```
      END CANT
      SUBROUTINE CUTR (DEF,MED,ICENH,ID1,ID2,ICANT,IROT,IND1,IND2,BRDFT)
      INTEGER DEF (160)
      DIMENSION MED(100,2)
      COMMON DEFECT(96,160), ISTOR(100), IBRD(100,96)
      I=ICANT/2 $ LAPSE=ICENH-I-5 $ JUMP=ICENH+I
      IO=NM=BRDFT=0. $ LM=2 $ INDEX=1
   60 IF (MED(INDEX,2)-MED(INDEX,1)-12.GT.0)62,61
   61 INDEX=INDEX+1
      GO TO 60
   62 DO 30 KP=1,10,1
      SIZE=0. $ LAB=1
      IF (INDEX-5.LT.LAPSE)54,64
   64 IF (INDEX.GE.JUMP)53,63
   63 IO=NNDEX $ INDEX=INDEX+ICANT+1
      IND1=MED(INDEX,1)+1
      IND1=IND1-IND1/100*100
      IND2=MED(INDEX,2)-1
      IND2=IND2-IND2/100*100
   53 INDEX=INDEX+5
      IDOWN=MED(INDEX,2)-1
      IUP=MED(INDEX,1)+1
      IUP=IUP-500
      IDOWN=IDOWN-500
      GO TO 55
   54 IDOWN=MED(INDEX,2)-1
      IUP=MED(INDEX,1)+1
      INDEX=INDEX+5
   55 IF (KP.NE.1.AND.IDOWN-IUP-15.LE.0)199,198
  198 WRITE (03,225) ID1,ID2,(I,I=1,8,1)
  225 FORMAT(1H1,30X,*THIS REPRESENTS AN EIGHT FOOT BOARD, CUT FROM LOG
     1QUALITY *,I3,*, NUMBER *,I3,*.*,/*-*,/14X,8(6X,R1,5H FOOT),/12X,8(
     21HX,1HV))
      WRITE(3,220)
      DO 3 I=1,96
      DO 86 II=1,160
```

```
86 DEF(II)=DEFECT(I,II)
   DO 20 IJ=1,100
20 ISTOR(IJ)=1H
   DO 2 J=1,160
   IF (DEF(J).LE.0.OR.DEF(J).LT.IUP.OR.DEF(J).GT.IUP+400)2,9
 9 JJ=DEF(J)   -DEF(J)   /100*100
   ISTOR(JJ)=1H-
 2 CONTINUE
   NM=NM+1
   DO 10 IK=1,100
10 IBRD(IK,NM)=ISTOR(IK)
 3 LM=LM+1
   NM=0
   LM=2 $ LABEL=MM=IUP-IUP/100*100-1
   DO 37 KC=IUP,IDOWN
   KL=KC-KC/100*100
   SIZE=SIZE+1.0
   WRITE (03,221) (IBRD(KL,I),I=1,96,1)
221 FORMAT(11X,1H*,96A1,1H*)
   MM=MM+1
   KO=MM-LABEL
   IF (KO/4.NE.(KO+3)/4)37,38
38 WRITE(3,222)LAB
222 FORMAT(1H+,3X,I2,4H IN.)
   LAB=LAB+1
37 CONTINUE                                                        2
   WRITE(3,220)
220 FORMAT(11X,98(1H*))                                            2
   AREA=.1666666666*SIZE
   BRDFT=BRDFT+AREA
   WRITE(3,223)KP,AREA,BRDFT
223 FORMAT(*0THIS IS BOARD *,I3,* WITH *,F6.2,* BOARD FEET.  SO FAR *,
  1F6.2,* BOARD FEET HAVE BEEN CUT FROM THIS LOG.*)
   ITOP=IUP-IUP/100*100
   NDEX=INDEX-5
   NNDEX=NDEX+4
```

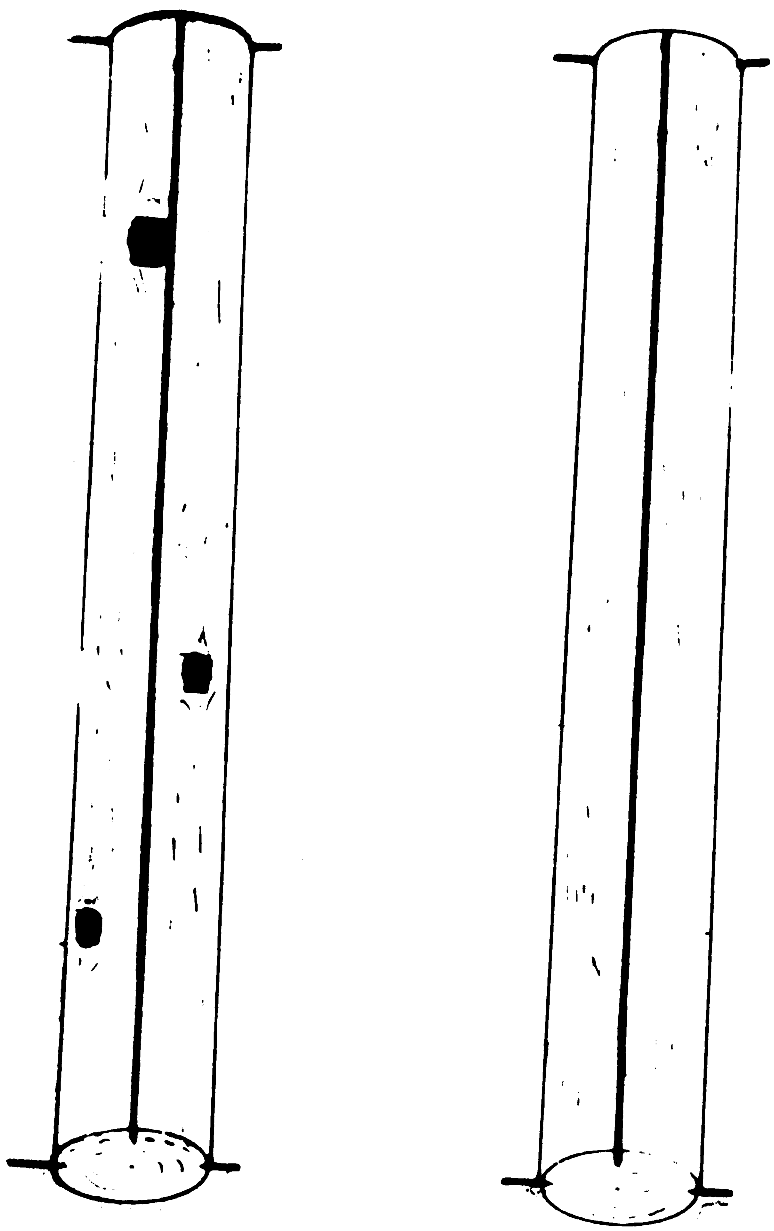
```
      WRITE (03,224) NDEX,NNDEX,ITOP,IROT
  224 FORMAT(* THIS BOARD IS ONE-1/8 INCH THICK FROM *,I3,* THROUGH *,I3
     1,* ON THE X-AXIS.  THE TOP IS AT *,I3,* ON THE Y-AXIS.*,/* THE LOG
     2 HAS BEEN ROTATED *,I4,* DEGREES.  THIS LOG WAS CUT WITH A SASH-GA
     3NG SAW, LEAVING A CANT, AND HAVING 1/8 INCH KERFS.*)
   30 CALL GRADER (AREA)
  199 IF (IO.EQ.0) IO=NNDEX
      DEF(1)=100*IO+100
      END CUTR
      SUBROUTINE CUTM    (DEF   ,MED   ,ICEN H,ICEN V,ID1,ID2,IROT,TOTL)
      INTEGER DEF (160)
      DIMENSION MED(100,2)
      COMMON DEFECT(96,160), ISTOR(100), IBRD(100,96)
      IO=1 $ I1=8HCIRCULAR $ I2=3H1/4
      GO TO 1
      ENTRY CUTL
      IO=0 $ I1=8HSASHGANG $ I2=3H1/8
    1 INDET=INDEX=1
      NM=BRDFT=0.
      LM=2
   60 IF (MED(INDEX,2)-MED(INDEX,1)-12.GT.0)62,61
   61 INDEX=INDEX+1
      GO TO 60
   62 DO 30 KP=1,20,1
      INDET=INDET+1
      NDEFC=NSAVE=SIZE=0.
      LAB=1
      IF (INDEX.LE.ICENH)54,53
   53 INDEX=INDEX+5
      ISHRI=400
      IF (INDET.NE.INDET/2*2)13,12
   12 ISHRI=500
      INDEX=INDEX+IO
   13 IDOWN=MED(INDEX,2)-1
      IUP=MED(INDEX,1)+1
      IUP=IUP-500
```

```
      IDOWN=IDOWN-500
      GO TO 55
   54 IDOWN=MED(INDEX,2)-1
      IUP=MED(INDEX,1)+1
      ISHRI=400
      INDEX=INDEX+5
      IF (INDET.NE.INDET/2*2)55,79
   79 ISHRI=500
      INDEX=INDEX+10
   55 IF (KP.NE.1) IF (IDOWN-IUP-12)199,199,198
  198 WRITE (03,225) ID1,ID2,(I,I=1,8,1)
  225 FORMAT(1H1,30X,*THIS REPRESENTS AN EIGHT FOOT BOARD, CUT FROM LOG
     1QUALITY *,I3,*, NUMBER *,I3,/*-*,/14X,8(6X,R1,5H FOOT),/*9*,11X,8(
     211X,1HV))
      WRITE(3,220)
  220 FORMAT(11X,98(1H*))
      IDN=IDOWN-IDOWN/100*100
      IUPN=IUP-IUP/100*100
      DO 3 I=1,96
      DO 86 II=10,160
   86 DEF(II)=DEFECT(I,II)
      DO 20 IJ=1,100
   20 ISTOR(IJ)=48
      DO 2 J=1,160
      IF (DEF(J).LE.0)2,5
    5 NDEFC=NDEFC+1
      IF (DEF(J).LT.IUP.OR.DEF(J).GT.IUP+ISHRI)2,9
    9 JJ=DEF(J)   -DEF(J)   /100*100
      IF (JJ.LT.IUPN.OR.JJ.GT.IDN)2,4
    4 ISTOR(JJ)=32
      NSAVE=NSAVE+1
    2 CONTINUE
      NM=I
      DO 10 IK=1,100
```

```
   10 IBRD(IK,NM)=ISTOR(IK)
      LM=LM+1
    3 CONTINUE
      LM=2
      LABEL=MM=IUP-IUP/100*100-I
      DO 37 KC=IUPN,IDN
      KL=KC
      SIZE=SIZE+1.0
      WRITE (03,221) (IBRD(KL,I),I=1,96,1)
  221 FORMAT(11X,1H*,96R1,1H*)
      MM=MM+1
      KO=MM-LABEL
      IF (KO/4.NE.(KO+3)/4)37,38
   38 WRITE(3,222)LAB
  222 FORMAT(1H+,3X,I2,4H IN.)
      LAB=LAB+1
   37 CONTINUE
      WRITE(3,220)
      PRINT 800
  800 FORMAT(* *)
      AREA=.1666666666*SIZE
      BRDFT=BRDFT+AREA
      WRITE(3,223)KP,AREA,BRDFT
  223 FORMAT(*8THIS IS BOARD *,I3,* WITH *,F6.2,* BOARD FEET.  SO FAR *,
     1F6.2,* BOARD FEET HAVE BEEN CUT FROM THIS LOG.*)
      ITOP=IUP-IUP/100*100
      NDEX=INDEX-5
      NNDEX=NDEX+4
      WRITE (03,224) NDEX,NNDEX,ITOP,IROT,NSAVE,NDEFC,I1,I2
  224 FORMAT(* THIS BOARD IS ONE-1/8 INCH THICK FROM *,I3,* THROUGH *,I3
     1,* ON THE X-AXIS.  THE TOP IS AT *,I3,* ON THE Y-AXIS.*,/* THE LOG
     2 HAS BEEN ROTATED *,I4,* DEGREES.  THERE WERE *,I5,* DEFECTS FOUND
     3 IN THIS BOARD OUT OF *,I5,* DEFECT UNITS (1/4 INCH SQUARE)*,/* IN
     4 THE LOG.  THE LOG WAS CUT BY THE *,A8,* SAW.  IT HAS *,A3,* INCH
     5KERFS.*)
```

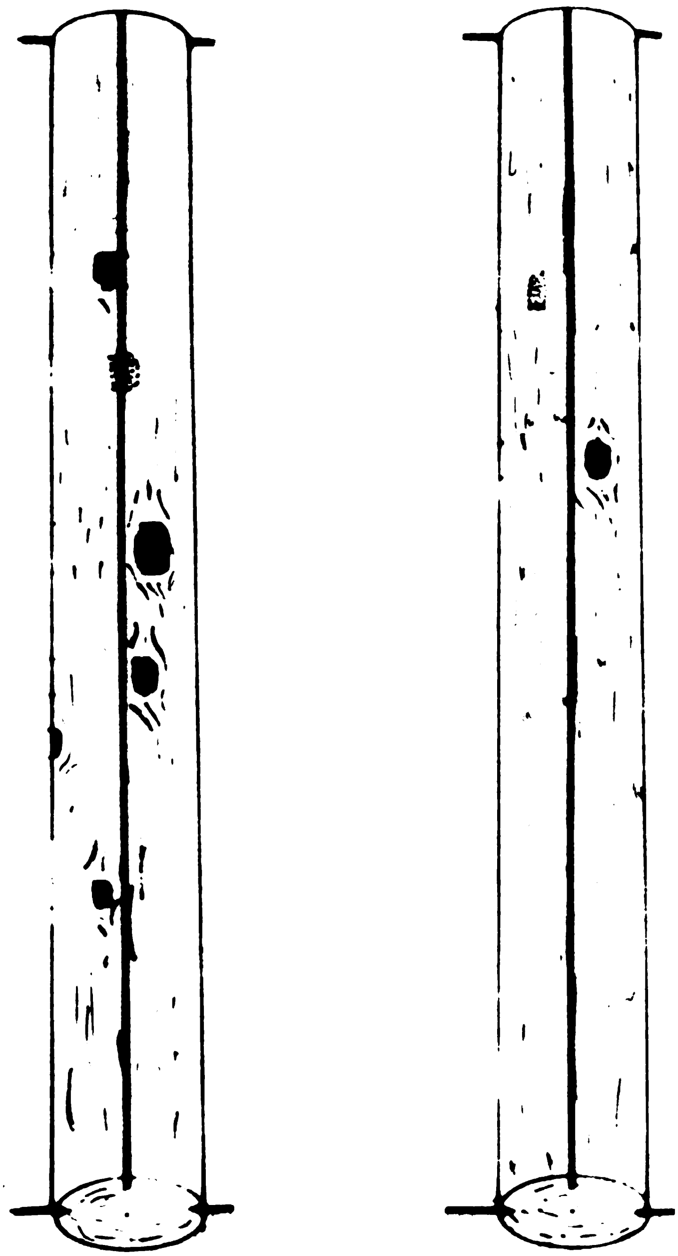
```
   30 CALL GRADER (AREA)
  199 PERCT=BRDFT/TOTL*100.0
      IF (INDET.NE.INDET/2*2) WRITE (03,231)
  231 FORMAT(* THIS LAST BOARD WAS THE FIRST OF A PAIR, SO NO KERF ALLOW
     1ANCE WAS MADE.*)
      WRITE (03,230) BRDFT,TOTL,PERCT
  230 FORMAT(1X,F8.2,* BOARD FEET WERE CUT OUT OF A POSSIBLE *,F7.2,*, F
     1OR A YIELD OF *,F5.1,* PERCENT.*)
      END CUTM
         SCOPE
'LOAD,69
'RUN,5,00,36000,0,M,R
   0 +135 +45.  +3   +6   +1
THIS IS A TRIAL TO DETERMINE THE BEST WAY TO PROCEED IN A SIMULATED LOG BREAK-
DOWN OPERATION.  THREE(3) LOG GRADES WERE TESTED WITH TWO(2) LOGS ASSIGNED FOR
EACH GRADE.  A TOTAL OF SIX(6) LOGS WERE USED FOR THIS EXPERIMENT.  A CIRCULAR
SAW AND THE SASH-GANG SAW WERE USED FOR THE SAWING OF THE LOGS WITH DIFFERENT
METHODS.
```

CARD COUNT

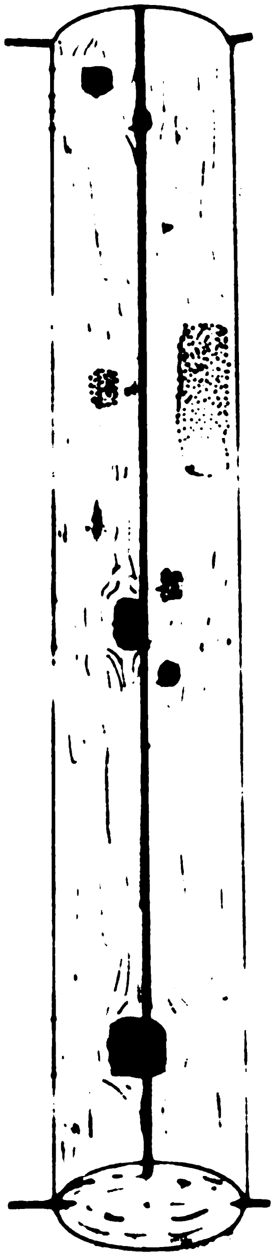


1.1 1.2

2.1 2.2



3.1



3.2