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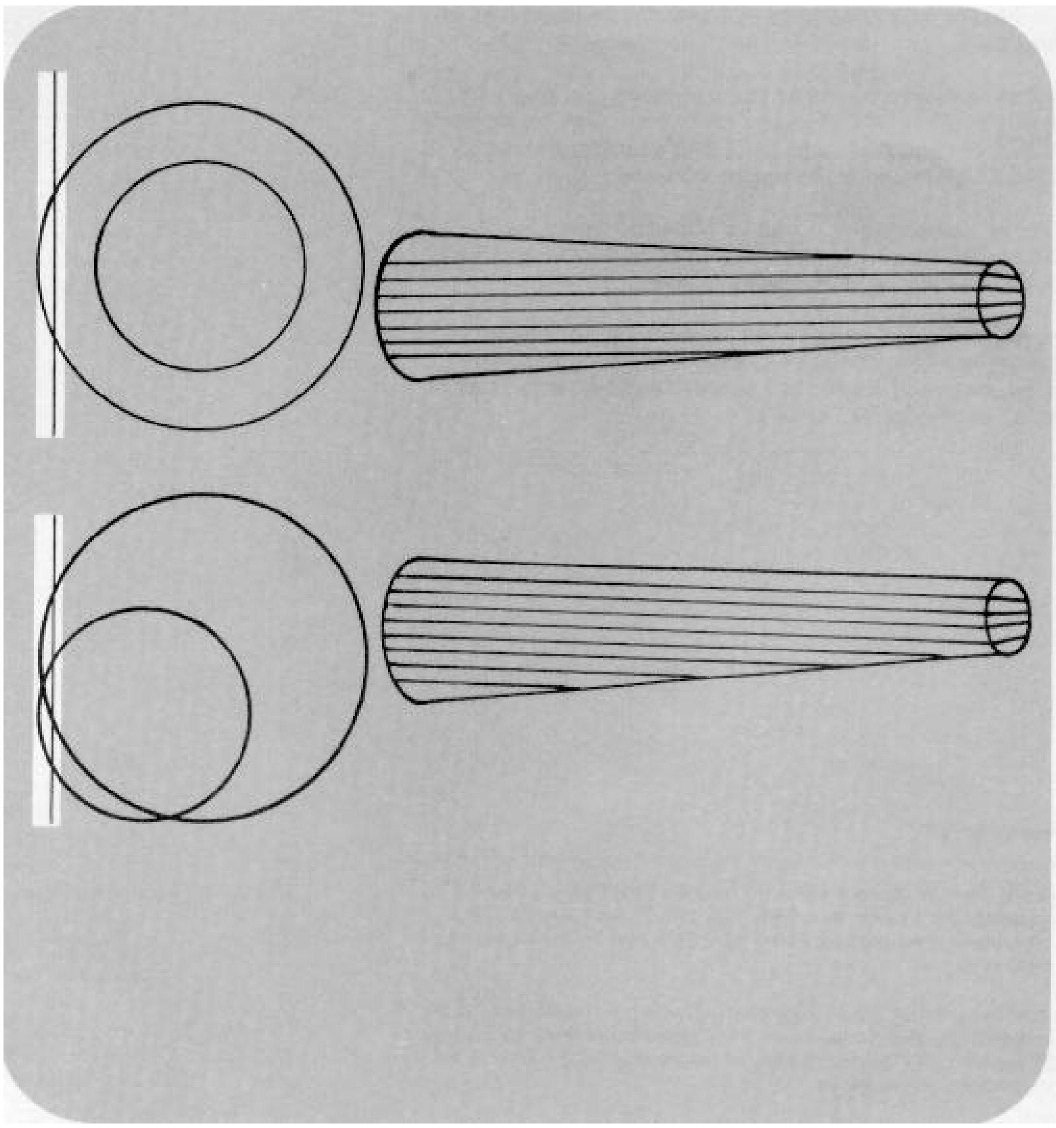
Sawmill Simulation and the Best Opening Face System

A User's Guide

David W. Lewis



Abstract

Computer sawmill simulation models are being used to increase lumber yield and improve management control. Although there are few managers or technical people in the sawmill industry who are not aware of the existence of these models, many do not realize the models' full potential.

The first section of this paper describes computerized sawmill simulation models and their use for those who have an interest in the subject, but who will not necessarily be involved in their implementation. The areas of use discussed include management planning and decisionmaking, engineering, automated control systems, and evaluating operating efficiency.

The second section details the Best Opening Face program (BOF), the most widely used of the sawmill models simulating the process of recovering dimension lumber from small-diameter, sound, softwood logs. The assumptions used in the program and the theoretical sawing process are discussed.

The third section describes the mechanics and possible pitfalls of using BOF. The sawmill configuration simulated by BOF is controlled by data describing a particular mill and options which control the program flow.

The appendices contain several formulas, examples of various BOF report formats, and a discussion of using BOF to simulate sawing metric-sized lumber.

Keywords: Best Opening Face; sawmilling; simulation; system analysis; computer techniques; sawing patterns; process control; automation; lumber recovery factor; lumber yield; log breakdown; models.

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Introduction

Computer sawmill simulation models are being used to increase lumber yield and improve management control. Their rapid, widespread acceptance in the past 15 years has resulted from sharply increased labor and raw material costs, a changing log supply, and technological advances in computers and optical scanning. Although most managers and technical people in the sawmill industry are aware of the existence of these models, many do not realize their full potential. Attempts to gain more information about sawing models, whether for a better understanding or wanting to use and/or modify a particular model, have frequently been frustrated, because the information has been either lacking or widely scattered. This report consolidates much of the information on sawmill simulation models for those interested.

Since the end of World War II, labor costs have risen steadily. Sawmill operators attempted to offset these rising costs in two ways. First, sawmills were mechanized and people replaced with mechanical devices. During the 1950's and 1960's devices that reduced labor requirements-such as mechanical log turners, hydraulic and electric setworks controls, slab and edging pickers, board turners, and mechanical lumber sorters and stackers-became common. Second, sawmill processing speeds were increased, spreading the high labor costs over a much larger volume of lumber.

A factor influencing processing speed was the change in the log supply. As much of the old-growth timber was cut and replaced by second-growth, the average sawlog size decreased. To maintain production rates-volume and piece count-required by high labor costs, processing equipment was specifically designed to make the primary log breakdown in one pass.

An unfortunate side effect of mechanization and increased processing speeds was loss of lumber recovery. Inaccurately manufactured lumber, resulting from saw snaking and log movement during sawing, required increased target sizes. In addition, the higher processing speeds made it impossible for machine operators to make consistently good breakdown decisions. This had a severe impact on recovery because, given the geometry of sawing small logs, poor sawing decisions have a much more adverse effect on the lumber yield.

As long as log prices were low, most sawmill operators were not concerned about the loss in recovery; to compensate they just increased processing speed. However, starting in the mid-1960's, log costs increased drastically, going from about 20 percent of product costs to as much as 80 percent today. As mechanization and increasing processing speed were approaching their practical limits, it quickly became obvious that the principal way to make a profit was to increase lumber recovery.

Sawmill Simulation Models

Mechanical refinements that increased sawing accuracy-such as ball-screw setworks and end-dogging carriages-allowed mills to reduce target sizes and improve recovery. However, these did not address the problem of losses due to poor operator decisions.

Around 1960, concern over recovery losses stimulated work into the effects of sawing factors such as sawline placement and kerf width on lumber yield. Although most of this was done by diagramming logs, some work was done on the mathematical relationships (Hallock 1962). While these approaches provided sawmill managers with insight into the relation of several sawing factors to lumber yield, they were cumbersome to use and not readily translated into information a machine operator could use.

The need for a quick, flexible means to model the log breakdown process was very apparent. By the mid-1970's several forest products companies (McAdoo 1969), consultants (Parnell et al. 1973), and research laboratories (Airth and Calvert 1973; Aune 1976; Hallock and Lewis 1971; Lewis 1978; Lewis and Hallock 1973; Maun 1977a; 1977b; Pneumaticos et al. 1974; Reynolds 1970; Singmin 1978; Skjelmerud 1973; Tsolakides and Wylie 1969; Van Niekerk 1975) had developed computerized sawmill simulation models. Although most of these models, including the *B*est *O*pening *F*ace (BOF) System (Hallock and Lewis 1971; Lewis 1978; Lewis and Hallock 1973), were originally developed to study the effect of sawing factors on lumber yield, they since have been used in many other applications.

The following discussion consolidates much of the information on sawing simulation models and is divided into three sections. The first section describes computerized simulation models and their use for those who are interested in the subject, but will not necessarily be involved directly in their implementation. The second section describes in detail the BOF program, the most widely used of the models. The third section describes the mechanics and possible pitfalls of using BOF. The appendices contain several formulas (App. A), examples of various BOF report formats (App. B), and a discussion of using BOF to simulate sawing metric-sized lumber (App. C).

Computer simulation models are widely used in the sawmill industry for the advantages they offer compared to traditional decisionmaking tools. The areas in which these models are most widely used include management planning, engineering and design, automated control systems, and evaluating operating efficiency.

Use in Management Planning

Corporate models, with sawmill simulation models as a component, are being used for long- and short-range planning and decisionmaking. Timberland planning models have a variety of applications ranging from studying forestry practices to considering investment returns of different utilization methods. Allocation models can distribute logs among alternative processing centers, considering such factors as capacity, product demand, selling prices, and conversion costs. Simulation models of the corporation or of individual facilities within it allow manipulation of management and operating practices to gain insights for developing future strategies.

Use of corporate models allows a look into the future, an opportunity to assess the effects of change before they happen. Such models can consider many more alternatives than would be possible using manual methods. A forest can be theoretically grown and harvested many times under different management and utilization assumptions, all within a relatively short time period. Plants can be theoretically built, operated, moved, or removed to find the most profitable type, number, and location of manufacturing and distribution facilities. It would be unreasonable to actually try all of these possibilities without simulation.

Marketing and product mix decisions can also be improved through the use of computer models. The effects of changes in product prices or product demand on mill productivity or profitability can be evaluated.

Computer simulation models are also very effective tools to aid in making decisions that directly affect mill operations, reducing the possibility of making a costly physical change that may have adverse effects. In the sawmill, operating changes such as reducing sawkerfs or target sizes, changing sawing methods, or using different bucking schedules can be simulated to evaluate their effect on yield. Simulations can avoid costly, production-disrupting test runs and can identify in advance the effects of changes in product mix, or of special orders, on mill productivity and profits. This allows the mill manager to plan for the changes or to turn down unprofitable orders.

Computer simulation models of sawmill operation can also predict what maximum recovery should be. This can help the sawmill manager identify reasons for not achieving maximum recovery as well as providing justification for necessary changes. The results of simulations are not confounded by external factors as mill tests can be. For example, mill tests made before and after a physical change in the mill may show unexpected differences due to change in log mix, different levels of operator efficiency, or machine variability, such as the difference between newly sharpened and dull saws.

Use in Engineering and Design

Computer simulation models are used to aid in the design of sawmills and sawmill equipment. Simulation models can help evaluate the new or remodeled sawmill early in the design stage. Theoretically running the mill allows the designer to identify bottlenecks, calculate utilization of personnel and equipment, and trace material flow for sizing transfers and surge areas. The designer can compare alternative layouts to find the most cost-effective design, and can identify such factors as the need for flexibility to handle changes in raw material or product mix.

Performance specifications can also be determined using computer models. The value of higher recovery or added flexibility can be compared to the costs of more accurate breakdown machinery or additional materials handling equipment. These give the engineer or designer the advantage of being able to look at and change designs early, before equipment has been ordered or construction contracted.

Use in Automated Control Systems

Automated control systems, with computer simulation models as components, are being used by the sawmill industry to augment or, in some cases, replace human observation and decisionmaking. Although these systems were first used to control primary log breakdown, they can now be found at most machine centers, including edging, trimming, and log bucking.

The basic elements of automated control systems, or “process control systems,” include sensors, a decision model, actuators, and feedback. Sensors measure the present state of the system. The decision model uses this information, along with other data pertinent to the process being controlled, to calculate the best course of action, which the actuators then implement. Finally, feedback reports the results of the action for comparison with the processing decision or system variables. In closed-loop control systems, the decision model uses feedback to automatically minimize variation in the results. In open-loop control systems-which most, if not all, sawmill systems are-there is no automatic feedback. Instead, the operator uses the information to make adjustments in the system as he or she sees fit.

In a typical sawmill primary log breakdown control system, scanners measure the length and diameters of a log and determine its position with respect to the processing system. This information, along with mill parameters and product values, is used by the control computer to determine the saw set and log position giving the highest yield. Setworks move the log and/or the saws, and when the proper positions are achieved the log is sawn.

Usually the amount of time required by the decision model to calculate the optimal sawing pattern and associated machine sets is so large it is not feasible to do these calculations as the log is ready to be broken down. Therefore, the decision model is used to calculate optimal sets for the entire range of logs expected in the mill, and these sets are stored in the control system computer. The best set for each log is “looked up,” on the basis of scanner measurements and/or operator decisions. However, in several systems controlling machines with a limited number of sets, models calculate the sawing pattern after the log has been scanned, eliminating lookup tables.

The ability of an automated control system to maximize recovery from each log is only as good as the accuracy of the information provided to the decision model and the accuracy and repeatability of the mechanical and electronic components. Some important considerations in implementing automated control systems include:

1. The decision model should reflect, as closely as possible, the mill being controlled, and the effect of differences between the model and the actual mill should be recognized and quantified.

2. The precision of the decision model should match the accuracy of log measuring and the precision of the processing equipment. Thus, if the log diameter scanner is accurate to 0.250 inch, having the decision model calculate solutions to 0.100-inch accuracy gains nothing. Likewise, basing the diameter on scanner measurements taken on limb stubs or felling breaks negates the accuracy of the model.

3. The system should know where in space the log is located, and the log should be held *firmly* while being transported through the saws.

4. When taper classes are used, as is done in most stored pattern systems, the solutions should be calculated for the lowest taper rate in that class. This ensures that the predicted lumber volume can be recovered from all logs in the class. Using the average taper means that, for the lower taper logs in the class, the solution cannot be completely cut out.

5. Value tables, when used, should reflect not only selling prices, but also conversion costs, production limitations, and marketing constraints.

Use in Evaluating Sawmill Efficiency

Computer simulation models are being used to evaluate sawmill operating efficiency. The computer model calculates theoretical lumber yield using existing sawing factors such as kerfs and target sizes. It can then calculate yields attainable through better control of the mill. The ratio of these two theoretical recoveries is applied to the actual mill production to predict the yield increases possible by making the improvements.

The most widely known example of this approach to sawmill evaluation is the Sawmill Improvement Program (SIP), developed by the Research and State and Private Forestry branches of the USDA Forest Service. The Forest Service offers this program to individual sawmills, helping them improve utilization efficiency and, in turn, extending the forest resource. In conducting a SIP study, a sample of logs is run through the mill and the lumber output tallied. The theoretical lumber recovery from these sample logs is calculated using the mill's present sawing methods and sawing factors. The logs are then theoretically sawn using sawing factors attainable in the best mills of the same type. The ratio of the two theoretical recoveries is applied to the actual production to provide the mill with an estimate of the recovery gains possible.

A continuous approach to sawmill evaluation can be used in mills having automated controls on the headsaw and a lumber tallying system. The control system can provide a management report of predicted recovery from all logs processed during a shift. This predicted recovery, when compared to actual tally, can point out changes in mill performance early enough for the causes to be identified and corrected.

The Best Opening Face system (BOF) is a computer simulation model of the sawing process for recovering dimension lumber from small-diameter, sound logs. In all sawing processes, position of the first sawline on a log or cant establishes the position of all others. Because of the geometry of fitting specified sizes of rectangular lumber into varying sizes of essentially round logs, shifting the position of the first sawline–and therefore the entire sawing pattern-across the face of the log can result in significant differences in the yield and value of lumber produced.

The BOF model simulates the actual sawing process. For each log, the sawing algorithm positions the initial opening face to produce the smallest acceptable piece from that log. Once the opening face is established, successive cuts are made, the resulting flitches and/or cant are edged and resawn, and volume or value yield for the log is determined. The opening face is moved toward the center of the log and the sawing process repeated. This continues until the resulting slab is thick enough to resaw. At this point, the model has tested all reasonable possibilities and determined the best opening face for the log.

Assumptions in the BOF Model

Geometry of Logs and Pieces

Logs theoretically sawn by the BOF model are assumed to be truncated cones with no defects. These assumptions were made because BOF was designed for small-diameter, second-growth timber, which is usually straight with small sound knots and little rot; defect is generally not a consideration in sawline placement.

Small-end diameters are limited to approximately 24 inches. Above this, both lumber grade and log defect become important, and these are not considered by the model. In addition, the widest flitch that can be edged by BOF contains two 2 x 12's so the results will be invalid for larger logs.

Allowable log lengths are 8 to 30 feet in 2-foot multiples, as these include the lengths used by most sawmills. Trim allowance is not considered.

The shape of flitches and cants is calculated from the geometry of passing cutting planes through a truncated cone (fig. 1). In split taper sawing parallel to the log centerline, the flitches and cant are the shape of a hyperbola on both faces (fig. 2a). Pieces cut from the full length of the cant are rectangles, Those from the taper are also hyperbolas, but with the sides cut off by lines parallel to the centerline if the cant is sawn split taper. If the cant is sawn full taper, the full-length pieces are still rectangles while the pieces from the taper are shaped like parabolas with the sides cut off (fig. 2b).

The flitches and cant from a full taper sawn log are shaped like parabolas on both surfaces (fig. 2b). Pieces cut from the cant are the same as from split taper sawn logs, with the exception of pieces from the opening face side of full taper sawn cants. The shape of these pieces is more complicated, depending upon the amount of log taper and distance the cant is offset from center. Most pieces will be sections of parabolas, but with large taper and offset they may be wider at the small end of the log than at the large end. In a few cases they may be "boat-shaped," being wider in the center than at either end (fig. 2c).

Target Size Calculations

The BOF model calculates the rough green lumber sizes (target sizes) needed to produce finished lumber under the conditions given. The target sizes are found by adding dressing allowance, allowance for scant sawing variation-and, when required, shrinkage-to the finished sizes. For many mills the rough green sizes are calculated in multiples of the setworks setting increment. Each of these is explained in more detail below.

Although finished softwood sizes are normally American Lumber Standard (ALS) sizes for 2-inch dimension and 1-inch boards, users may supply their own finished sizes. However, in either case, only one target size is calculated for each thickness and width.

The dressing allowance is the minimum required for the planer to produce a satisfactory finished surface. For most planers this will be the sum of the fixed head cut plus whatever minimum cut is required for the thicknessing head to plane adequately (often considered to be 1/32-0.031-in.). The value actually used by BOF will be the total of the planer settings and the amount added to the minimum rough green size to bring it up to the setworks setting increment (see also below).

Because all sawing processes have some inherent machining variation, an allowance for these must be included in calculating the rough green sizes. In lumber manufacture, the objective is to have only a small percentage (usually less than 5 pct) of all pieces show planer skip or be undersize. The sawing variation allowance that should be used then is the difference between the average lumber size and the smallest size that allows only this portion to be undersize (fig. 14 and see p. 16). This allowance is frequently called scant sawing variation.

Percent shrinkage, as used in BOF, is based on the loss of dimension in drying divided by the original green size.

Many sawmill setworks operate in a finite series of small increments such as 1/16 inch or 1/32 inch. All the sets-i.e., rough green lumber size plus kerf–must be a multiple of the setting increment. For infinitely adjustable setworks such as ball-screw drives, a very small increment-for instance, 0.001 inch–may be used.

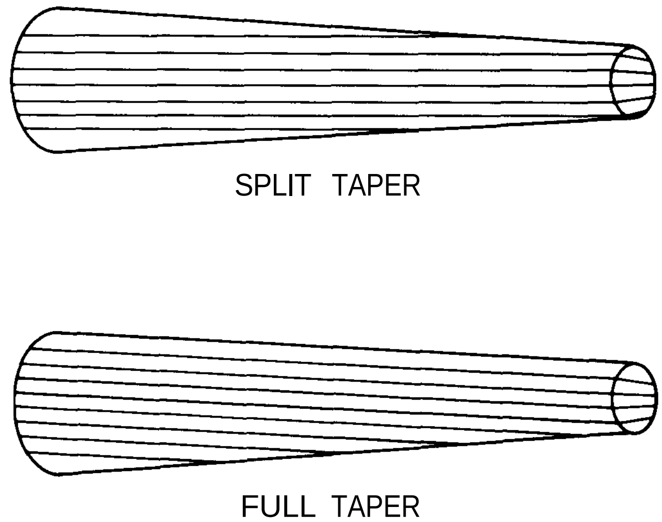

Figure 1.—Two methods of sawline orientation. (ML84 5594)

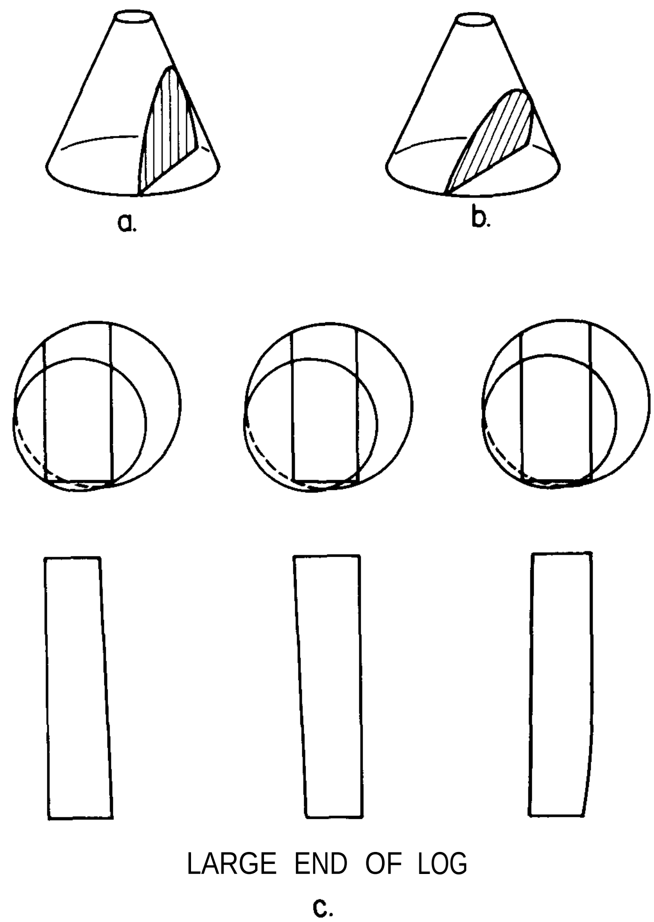

Figure 2.-Geometry of flitches and cants. (a) Split taper gives hyperbolic faces. (b) Full taper gives parabolic faces. (c) Flitches where both log and cant are broken down full taper. (ML84 5595)

Lumber Sizes

Either one or two lumber thicknesses, nominally 1 inch and 2 inches, are used by the BOF model. The log may be sawn into all 1-inch, all 2-inch, or a mixture of the two. If both sizes are being sawn, the 1-inch is considered a salvage size and recovered only from the opening cuts on the log or cant.

Five nominal widths–4, 6, 8, 10, and 12 inches-are required for use with BOF. In addition, 3-inch lumber may be salvaged, but 3-inch cants will not be produced. At least the five primary widths must be used when sawing only one thickness. They must also be used with the 2-inch thickness when recovering both 1-inch and 2-inch lumber. In this latter case, one or more widths of 1-inch lumber may be suppressed.

For mills that do not manufacture five widths, the standard practice is to rip wide flitches into two or more narrow pieces. Because BOF requires at least five widths, target sizes that are a combination of several smaller ones are used instead. For example, a mill that does not save 2 x 12's would instead rip a 12-inch flitch into three 2 x 4's, two 2 x 6's, or a 2 x 4 and a 2 x 8.

Wane

On finished lumber, up to 25 percent of the thickness and width may be wane. This amount is the limit allowed for Standard and Better light framing lumber. To make the calculations simpler, the wane is based on the green finished size. As shrinkage in drying can be assumed to be even across the piece, the percent of wane on the dry finished size will not change.

Both the faces and edges of the pieces are checked to ensure neither contains excessive wane.

Yield Maximization

The BOF model can maximize either lumber value or board foot volume. In general, value maximization will result in a more profitable and marketable product mix, but volume maximization will yield a higher lumber recovery.

Value Maximization In maximizing value, net sales return-i.e., selling price minus differential conversion costs-should be used rather than list selling price. This approach avoids bias toward products that have high selling prices and high production costs. For most mills, the list price adequately represents the selling price for all products, no matter what volume is produced. Other mills have a few items that command a very high selling price, but have very low demand for the product. In this case, the concept of volume discounted prices should be used to determine the selling price. The volume discounted price is the selling price at which extremely large volumes of each product could be moved or the selling price minus the cost of holding these items in inventory until sold. This concept avoids the problem of BOF theoretically producing excessive amounts of high-priced product that cannot be sold.

Differential conversion costs for each product size are not usually kept in sawmill accounting systems. However, these costs may be calculated knowing the average cost per thousand board feet of lumber in each production area of the mill, the total board footage of each size produced, and the product dimensions.

Green end conversion costs are relatively fixed in the short term, no matter what product mix is made. Whether logs are cut heavy to 2 x 4's or to 2 x 12's, the crew size remains the same, and other operating costs such as power and operating supplies change very little. Thus, the same green end cost per thousand board feet may be used for all products.

At the dry kiln, planer mill, and shipping departments conversion costs will vary among different products based on number of pieces or lineal feet in a thousand board feet of lumber.

Drying time is shorter for 1-inch lumber than 2-inch, but the board foot volume of 1-inch lumber that fits in a kiln charge is less because of sticker spacing. The kiln costs per thousand board feet, then, can be weighted between 1-inch and 2-inch lumber based on kiln capacity and drying time.

Planer production is limited by the lineal feet of lumber passing through the machine in a given period of time. For example, because a thousand board feet of 2 x 4's contain three times the lineal footage of a thousand board feet of 2 x 12's the planing costs would be three times higher. Further, thin, narrow pieces cause difficulty in manufacture by jamming or breaking up in the planer, so they should be assigned a higher cost.

Dry storage, packing, and shipping costs are directly related to the number of pieces in a thousand board feet of lumber and can be allocated on this basis. A few operations may depend on lineal footage, so this should be considered where appropriate.

As an alternative to using net sales value, a system of assigning comparative values may be used. These values should reflect the relative net worth of each produced to the mill. Using this system, one product, say a 2 x 4, 8 feet long, is considered the base and assigned an arbitrary value, such as 100. All other products are ranked by their value relative to the base. For instance, a very slow moving or difficult to manufacture size may be ranked 50, while a highly profitable or desirable one could be 200.

The use of comparative values is quicker and requires less computation than compiling net sales returns. However, because these values are arbitrary, more skill and knowledge of the mill's production and sales are required if they are to be used effectively.

Volume Maximization Volume maximization will result in a higher lumber recovery. Although the edging done by the BOF model (see p. 9) favors wider widths, the product mix may be biased because geometry favors smaller sizes and because the actual cubic volume of wood fiber per nominal thousand board feet of lumber varies among product sizes. There is a fairly strong bias toward 2 x 4's as they require only 54.7 cubic feet of fiber to produce a nominal thousand board feet, compared to 58.6 cubic feet for 2 x 12's. Geometry also favors narrow cants over wide ones because, as can be seen in figure 3, less wood develops into edgings. The combination of these two factors may result in BOF producing an undesirably large volume of narrow width lumber.

To eliminate this bias toward narrow lumber so that BOF will maximize actual cubic foot volume, value maximization may be used, with the ratio

$$\frac{1{,}000 \text{ (actual thickness x actual width)}}{12 \text{ (nominal thickness x nominal width)}}$$

as the value for each product.

Theoretical Sawing Process

The BOF model was designed to simulate most common types of sawmill equipment. The only exceptions are chipper canters, which chip the outside of the log to a fixed profile, and optimizing or manual edgers, which rip wide boards into narrow widths based on value or grade.

Primary Log Breakdown

The log may be broken down either split taper, with the sawlines parallel to the pith, or full taper, with the sawlines parallel to one side of the log (fig. 1). The log may be live sawn, with all sawlines in one plane, or it may be cant sawn, making a center cant that is later resawn at right angles to the original sawlines (fig. 4).

All sawline placement is calculated relative to reference planes (fig. 5). In split taper sawing, the vertical reference plane is parallel to the log centerline. In full taper sawing, the vertical reference plane is parallel to one side of the log and just touching it. In sawing cants, a horizontal reference plane is used in the same manner as the vertical reference plane.

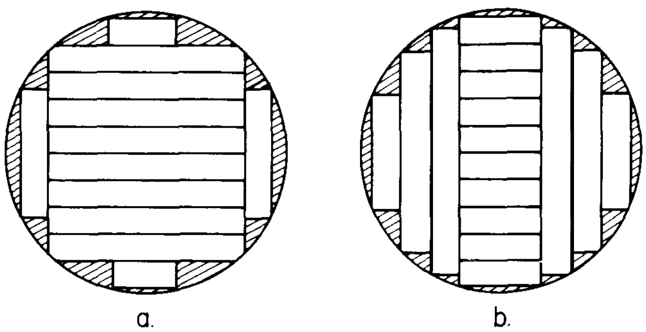

Figure 3.—Edging losses from different size cants. (a) Wide cant-more edging loss. (b) Narrow cant–less edging loss.

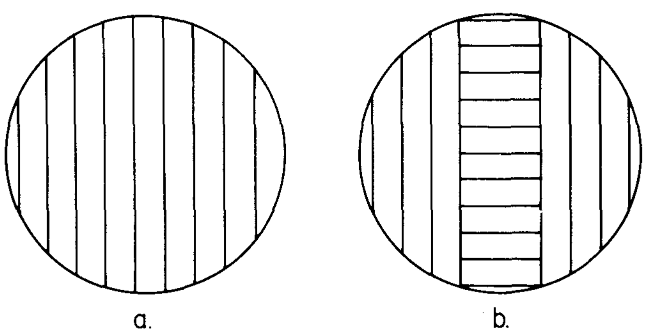

Figure 4.—Primary log breakdown methods. (a) Live sawing. (b) Cant sawing. (ML84 5596)

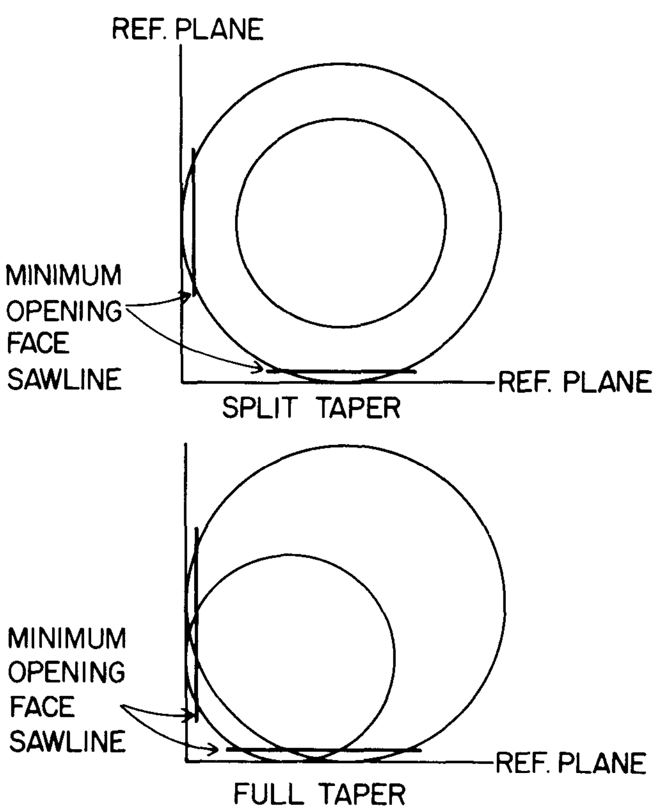

Figure 5.—Relation of sawlines and reference planes. (ML84 5597)

The BOF model can simulate sawing systems capable of placing the log in any position without regard to a fixed reference line, called variable opening face sawing. Alternatively, BOF can simulate systems in which the log is positioned with reference to the centerline of the system, called offset sawing (see also p. 19). The first opening face tried is calculated differently depending upon the sawing system being modeled.

For variable opening face sawing, the first opening face tried on the log is the one making the shortest, narrowest piece of lumber allowed with maximum wane. If two thicknesses are recovered, the first piece off the opening face is always the smaller thickness.

For offset sawing, the position of the first opening face tried is determined by calculating the maximum allowable offset. The center flitch in live sawing, or the cant in cant sawing, is shifted toward the opening face by the maximum offset. The number of thicker pieces that will fit between the center piece and the minimum opening face are determined, and the actual opening face distance is calculated (fig. 6). If a thinner piece will also fit, the opening face is further moved out to accommodate this piece.

Successive sawlines are placed across the log until one falls within a predetermined distance from the center. Then the model skips across the cant, or center flitch, and continues placing sawlines on the opposite side.

The greatest amount the cant or center flitch may be offset is one-half the thickness of the thickest piece plus one-half of a sawkerf. In live sawing, a centered sawline will result at one extreme of offset and a centered flitch at the other.

After the log has been broken down using the first opening face, the opening face is moved towards the center of the log in variable opening face sawing. In offset sawing, the cant is shifted to the right, and the distance to the opening face is recalculated. The sawing process is then repeated.

This is continued until all allowable opening faces or offsets have been simulated. The distance the sawing pattern can be shifted is the smaller of the maximum allowable offset or the thickness of the thickest piece plus a kerf. The latter restriction stops the program when the slab contains a usable piece, and the sawing pattern repeats itself.

The distance the sawing pattern is shifted each time (opening face or offset increment) should generally be the same as the saw setting increment. However, when the setworks are capable of 0.001-inch accuracy, this small opening face increment would require large amounts of computer running time. In this case, a compromise between computer time and modeling accuracy can be made by using a larger opening face increment such as 0.025 inch.

The cant placement and total number of sidepieces may be restricted if necessary to simulate the equipment configuration of a particular mill. For example, some chain-feed multiple bandsaw systems require 4-inch cants to be centered to avoid sets that would run the saws into the feed chain, while wider cants may be offset. This situation can be simulated by the BOF model.

Some mills with multiple saw headsaws cannot resaw sidepieces in the same plane as the headsaw. Therefore, they are limited to a cant and as many additional lines as there are additional saws or chipper heads. Examples are two sidepieces for a quad bandsaw or for a twin bandsaw with slab chippers, four for a quad bandsaw with chippers, and none for a chipper canter without saws. To simulate these conditions, the BOF model allows the number of sidepieces to be limited. BOF only checks the total number of sidepieces and, in rare instances, may find a solution containing a different number of sidepieces on each side of the cant-for example, two boards on one side and none on the other. If this situation occurs in a critical application, such as calculating sets for an automated control system, it can easily be corrected by rerunning those few logs with the allowed number of offsets limited to force a more centered pattern.

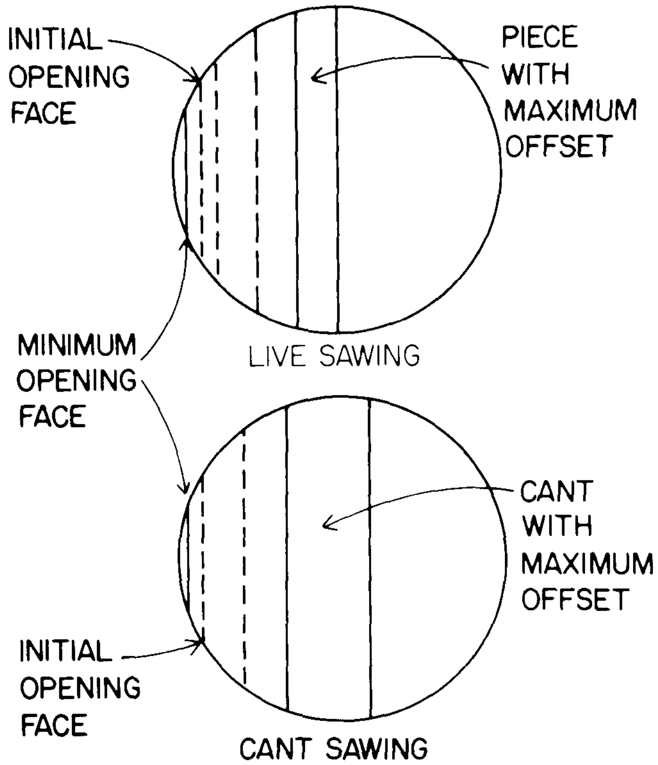

Figure 6.—Determining initial opening face for offset sawing. (ML84 5598)

Edging and Trimming

Flitches are edged parallel to a line joining the wane edge at one side of the large end of the flitch with the wane edge at the end of the longest piece of lumber (fig. 7). This most closely simulates edging with laser lines and provides the greatest yield.

The BOF model uses one of two edging methods. In full-length edging, the widest possible full-length board, or pair of boards if the flitch is wide enough, is cut from the flitch. If possible, a piece of the narrowest width is then cut from the remaining triangle, and the value and/or volume of the pieces is determined (fig. 7). This method simulates the usual situation in which the edger operator cuts the widest full-length piece possible.

In trim-back edging, the full-length flitch is tested as in full-length edging. Then the flitch is trimmed back 2 feet and a new edging solution found. The flitch is progressively trimmed back in 2-foot increments and the solution with the highest yields is saved. As in full-length edging, a narrow piece is salvaged if possible. For example, a flitch edged full length would yield a 2 x 6, 16 feet long (fig. 8). To determine the maximum yield of this flitch the model trims the flitch back 2 feet and edges the resulting pieces according to the wane rules. It then calculates the volume and/or value for this piece. This process is continued until the shortest piece allowed is processed. The piece that gives the highest volume or the highest value is then selected. In this case the best solution is a 2 x 8, 14 feet long. It contains 2-2/3 more board feet and is worth more than any other piece. In some cases in which value maximizing is used, a piece with a higher value but a lower volume will be chosen. In this example, a 2 x 6, 16 feet long, has less volume but is worth more than a 2 x 10, 10 feet long.

Two pieces may be produced from flitches wider than 12 inches. When two pieces will fit in a flitch, the wider piece is always the longer-for example, a flitch, which, when edged full length, yields a 2 x 12, 16 feet long, can also better be edged to yield a 2 x 10, 16 feet long, and a 2 x 4, 10 feet long (fig. 9). As before, the model tries the full-length and successively shorter pieces in the flitch and finds the one that gives the best yield. This method simulates a simple automated optimizing edger when only combinations based on the widest pieces are cut. The combinations used in BOF edging are as follows:

Index	Nominal widths
1	3
2	4
3	6
4	8
5	10
6	12
7	4 + 10
8	4 + 12
9	6 + 12
10	8 + 12
11	10 + 12
12	12 + 12

In determining which widths can be cut from a flitch, both edging methods use a precalculated array containing the face and edge, with and without wane, required for each allowable edging combination. The flitch is checked to ensure it meets the allowance for both face and edge wane. The piece of lumber is assumed to be centered in the thickness of the flitch. For the lumber to fit, the flitch must be wider than the width required by that product size with maximum wane (fig. 10). For example, to cut a finished 2 x 4, 3-1/2 inches wide, assuming 5 percent shrinkage, and 25 percent wane, the flitch must be at least

$$\frac{3.5}{1.00 - 0.05} \times (1.00 - 0.25) = 2.763 \text{ inches}$$

wide on the green finished face of the lumber. At the point of maximum allowable edge wane that flitch must be wider than the green finished lumber size. This point is inside the green finished face a distance that can be found by multiplying the edge wane factor by the green finished thickness. In live sawing, the wane on the center flitch is checked on the side farthest from the center of the log.

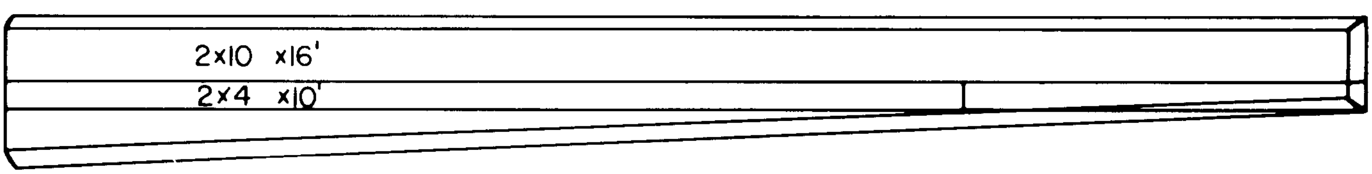

Figure 7.—Full-length edging method. (ML84 5599)

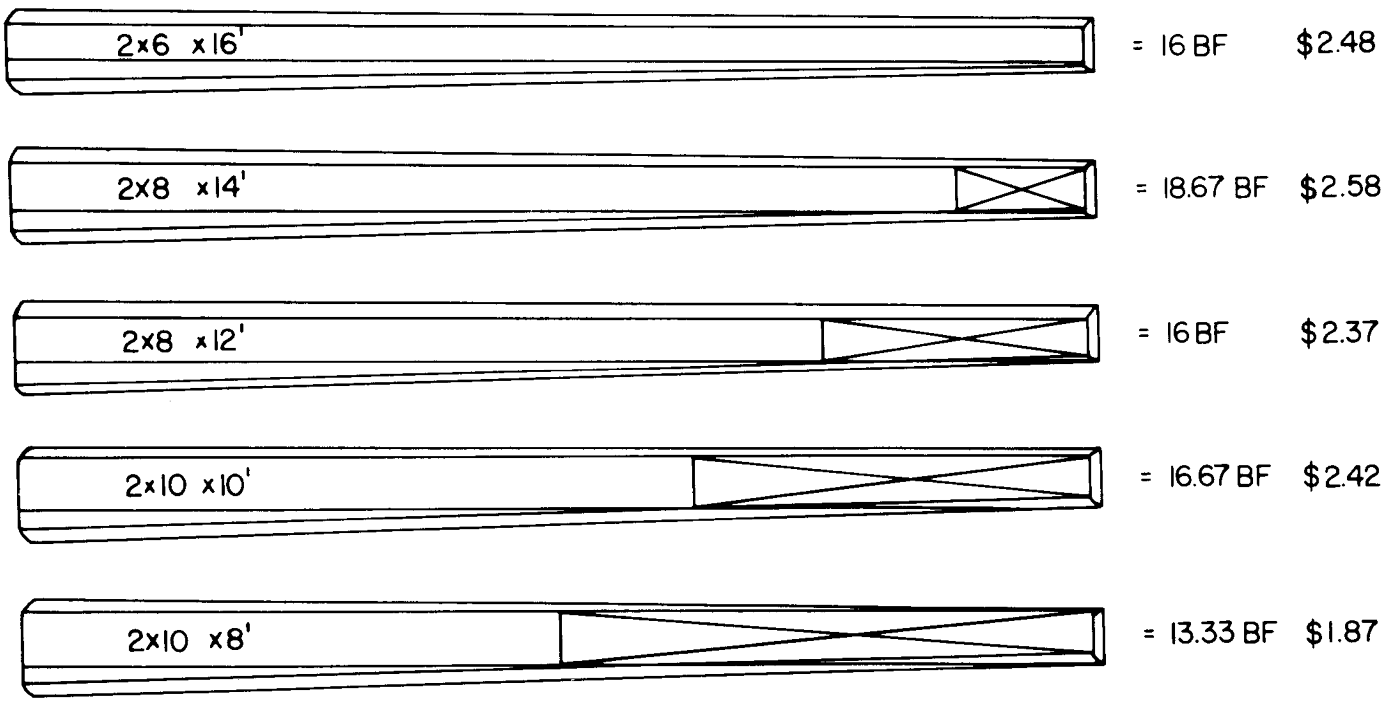

Figure 8.—Trim back edging method-narrow pieces. (ML84 5600)

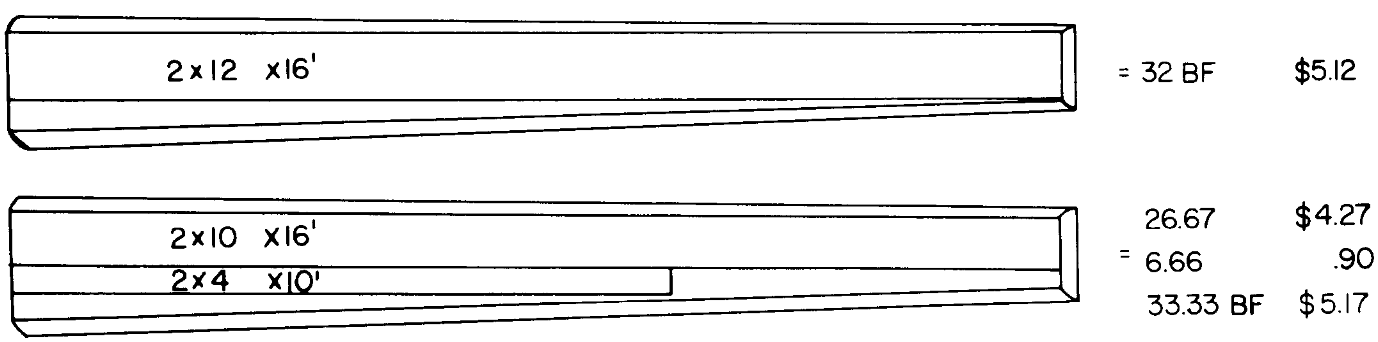

Figure 9.—Trim back edging method-wide pieces. (ML84 5601)

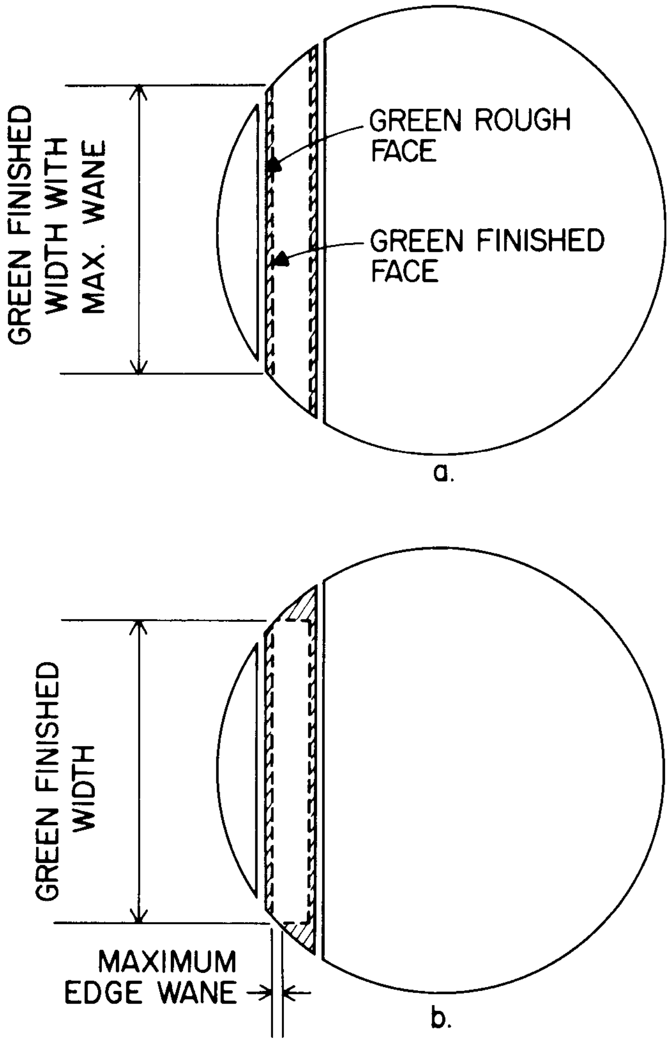

Figure 10.—Checks for face and edge wane when edging. (ML84 5602)

Cant Breakdown

Cants may be broken down either split taper or full taper, as with sawing a log (fig. 1).

In split taper sawing the cant, the initial opening face is the one that gives the shortest, narrowest piece with maximum allowable wane. Pieces are placed and the opening face moved in the same manner as for variable opening face sawing.

Full taper sawing assumes the cant is pushed against a fence and run through the saws as with rotary gang edgers and linebar resaws. The BOF model simulates several different types of fences.

With a fixed fence the distance from the fence to the first, or zero, saw is fixed. The same distance from the fence to the inside of the zero saw-i.e., the sawn surfaces of the first piece from the cant-is used for all cant sizes and all log diameters (fig. 11 and see p. 17).

A two-position fence can be simulated by using the smallest fence-to-zero saw distance as the initial fence setting and the amount of fence movement as the cant opening face (fence) increment.

Finally, the fence may be completely variable with the minimum fence setting either supplied by the user or calculated by the model to yield the smallest allowable piece.

In simulating chipper canters-i.e., for full taper sawing-the initial fence setting is the distance from the bottom of the log to the first usable face on the bottom of the cant. Thus, if a spline profiled for transporting the log through the canter is always chipped off, the initial fence setting includes both the minimum bed setting and the depth of the spline (fig. 12a). If the spline is sawn into lumber, the initial fence setting is the depth chipped off to the bottom of the spline (fig. 12b).

If two lumber thicknesses are being used, all pieces from the cant are of the thicker size except for the outside pieces. These two jacket boards may have their thicknesses specified, allowing simulation of different types of cant breakdown equipment.

Both the fence and the back pieces may be of a nominal 2-inch thickness. This simulates a rotary gang edger with all saws fixed at 2-inch spacing. Alternatively, the back piece may be either thickness, reflecting the ability to resaw a narrow 2-inch piece into a wider, more valuable 1-inch. If the piece on the fence side of the cant is too small to make an acceptable piece of 2-inch lumber because of the fence distance, BOF will attempt to resaw it to salvage a piece of 1-inch lumber if possible.

The fence piece may be specified as a 1 x 4 to simulate chipper canters that make a 4-inch spline. The back piece (actually the top of the cant in the canter) may be specified as a 2-inch or it may be resawn for a more valuable 1-inch.

The maximum distance the opening face is allowed to shift for either split taper sawing or full taper sawing with a variable fence is the larger target thickness plus a cant breakdown kerf.

Sometimes it is desirable to calculate the minimum fence setting for a given log diameter and cant size. This is discussed in more detail in Appendix A.

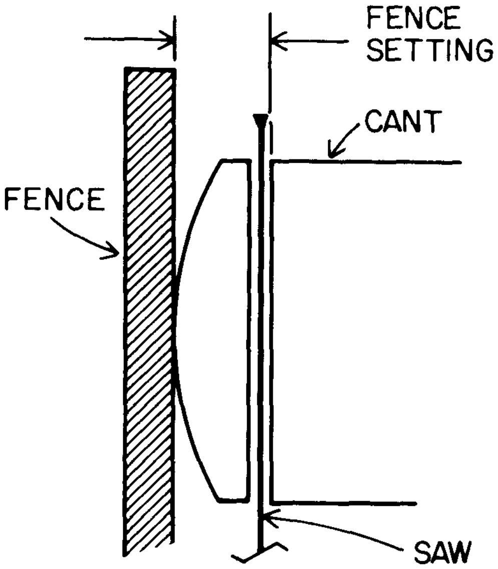

Figure 11.—Relation of fence setting distance and first face on cant. (ML84 5603)

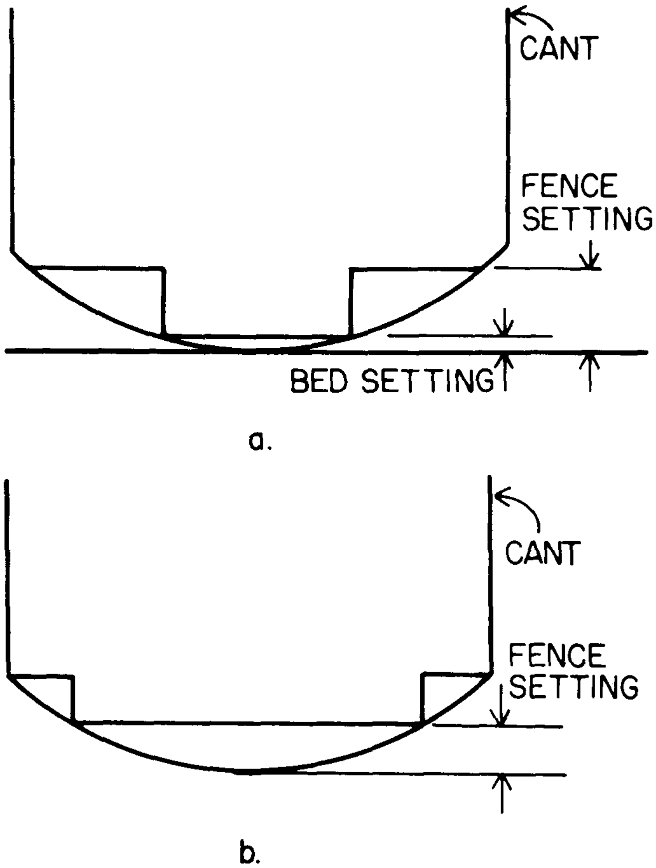

Figure 12.—Determining fence setting distance when simulating chipper canters. (a) Spline is always chipped off. (b) Spline is made into lumber. (ML85 5604)

In cant sawing, the solution giving the highest yield is found by calculating solutions using all five cant sizes (4, 6, 8, 10, and 12 in.). In some circumstances, however, it may be necessary to limit the production of some lumber widths or to reduce computer running time. Both of these can be accomplished by limiting the number of cant sizes used. In addition, equipment limitations may prevent manufacture of some cants, as in a mill where the only cant breakdown machine is a 6-inch rotary gang edger. To simulate this case, BOF can be instructed not to make 8-, 10-, or 12-inch cants. Any cant size may be suppressed to reduce production of that size.

For maximizing volume, the model can be directed to cut the largest cant size possible. This forces the production of wider-width lumber. A side effect is the loss of recovery when wide cants are cut from small logs. This particular recovery loss can be minimized by specifying the smallest diameter log from which a particular cant size may be cut. Increasing the smallest acceptable diameter log to one that yields a cant and two side pieces will provide a balance between the advantages of cutting the widest cant and the recovery losses associated with small logs.

A similar means of restricting the cants is available for maximizing value. The program ranks the cants by an efficiency factor reflecting the actual wood used to saw each cant size and the value of each length. This factor is:

$$\text{Efficiency factor} = \frac{\text{nominal cant thickness}}{\text{actual cant thickness + headsaw kerf}}$$

The weighted value of each cant size and length is calculated by:

Weighted value = efficiency factor x value/MBF

Thus, if less actual wood is used for a given nominal size, that size is relatively more valuable. Within each length, the cants are ranked in order of highest weighted value. For example (table 1), a 6-inch cant is nominally more valuable than a 4-inch cant. However, when wood-use efficiency is considered, the 4-inch cant is more valuable and should be used.

In sawing each log, the model selects the highest ranked cant size that will fit in the log. For the example in table 2, BOF will select 12-inch cants for all logs large enough. The second choice would be a 10-inch cant. For 8-, 10-, and 16-foot logs too small to fit a 10-inch cant, a 4-inch cant would always be cut. No 8-, 10-, 16-foot, 6-, or 8-inch cants would be cut using this ranking table. The 12- and 14-foot logs would be cut with an 8-inch cant if too small for a 10, a 6-inch cant if too small for an 8, and finally a 4-inch cant if too small for a 6.

Yield *Maximization*

After the log has been theoretically sawn using each opening face, the volume or value of the resulting solution is compared to that of the previously saved best solution, and the larger of the two is saved. Only the volume or value, if applicable, and offset of the center piece are saved for each successive best solution. After all allowable opening faces have been tried and the best solution found, the log is sawn once more using the best opening face, and this solution is printed.

If a number of consecutive opening faces all have the same maximum yield, the sawing solution printed will be the one closest to the center of the range. This approach was taken because, in using the BOF model to calculate sets for automated sawing systems, it provides the widest latitude in positioning the log to recover the maximum yield.

In maximizing value, an occasional anomaly can occur in the printout in which the total lumber volume does not equal the sum of the individual pieces. Because the lumber volume printed is saved from the last solution within the range and the pieces printed are from the solution in the center of the range, the two solutions may not equal each other if made up of differing product mixes.

Table 1.—Relation of nominal values, efficiency factors, and weighted values for 16-foot cants

Nominal cant size	Nominal		Efficiency factor	Weighted	
	Value	Rank		Value	Rank
	Per 1,000 fbm			Per 1,000 fbm	
4	187	4	1.025	191.79	3
6	190	3	1.004	190.79	4
8	174	5	1.027	178.69	5
10	200	2	1.014	202.84	2
12	225	1	.946	212.85	1

Table 2.—Nominal cant sizes ranked by weighted values

Rank	Size for specified lengths (feet) of				
	8	10	12	14	16
			In.		
1	12	12	12	12	12
2	10	10	10	10	10
3	4	4	8	8	4
4	6	8	6	6	6
5	8	6	4	4	8

The sawmill configuration simulated by BOF is controlled by data describing a particular mill and options that control the program flow. Those interested in modifying the program or in getting a better understanding of how the data are used can obtain a FORTRAN listing of BOF from State and Private Forestry, Madison, WI. Certain information is required and must be supplied. Other information has default values that may be overridden.

Table 3 summarizes the options available and the information required for using BOF. The necessary data cards are illustrated in figure 13. The first two cards contain information that changes from mill to mill and allows various processing options to be selected.

Required Information

Minimum and Maximum Small-End Log Diameter

The minimum small-end log diameter should be no smaller than will produce one piece of the smallest size lumber. However, if a smaller log is specified, the program will calculate the minimum diameter and skip any logs that are too small. The maximum small-end log diameter is limited partly by the widest flitch the program can edge. This flitch contains two 2 x 12's and one salvage piece of the narrowest width specified, either a 2 x 4 or 2 x 3. The limit also depends on the sawing method, maximum log length, and amount of taper. For live sawing long logs with appreciable taper, the maximum diameter should not exceed 21 inches. When cant sawing short, low-taper logs and recovering the widest cant, the upper limit is about 28 inches. Because the program does not check for very large logs, some flitches from logs exceeding these units will not be edged correctly, and the yield will be underestimated.

Taper

Taper is the difference between the large- and small-end diameters of a log. It is entered as decimal inches per 16 feet of log length.

Saw Setting Increment

Saw setting increment is the minimum amount by which the setworks move a log with respect to the saws. For setworks that move in finite steps, such as hydraulic stack cylinders, this increment should be used. For continuously adjustable setworks, such as ball-screw setworks, a small increment-e.g., 0.001 inch-should be used.

Table 3.—Summary of Best Opening Face system data[1]

Options	Action	
	Not set	Set
1. Processing control	BOF solutions	*1* = tables only *9* = end of control set
2. Sawing method	Cant	Live
3. Lumber sizes	Dry	Green
4. Maximization	Value[2]	Volume
5. Cant sawing maximization method	Uses selected cant size	*1* = largest cant when maximizing value *5* = tries all cant sizes
6. Cant breakdown method	Split taper	Full taper[3,4]
7. Cant breakdown fence	Fixed	*1* = variable fence *2-9* = 2-9 fence positions only
8. Edging method	Trim back	Full length
9. Piece count	Not printed	*1* = offset, sequence printed *2* = all tables printed
10. Narrowest piece allowed (in.)[5]	4	*1* = 3-in. *2* = stud mill with 4-in. *3* = stud mill with 3-in.
11. Shortest piece allowed (ft.)[5]	8	(Must enter)
12. Minimum and maximum log length (ft.)[5]	8 to 16	(Must enter)
13. Log diameter increment (in.)	0.1	(Must enter)
14. Log and cant face opening increments (in.)	0.050 and 0.050	(Must enter)
15. Shrinkage (pct)	5.0	(Must enter)
16. Minimum log required for cant	Cant contains at least two 2 × 4's, two 2 × 6's, three 2 × 8's, three 2 × 10's, or three 2 × 12's	*1* = normal log breakdown[6] *2, 4, 6*, or *8* = only 2, 4, 6, or 8 side pieces on log[6] *9* = no side pieces[6]
17. Offset positions	Variable	*1* = selected positions only[7] *2* = 4-in. cant centered
18. Lumber dimensions	ALS	(Must enter)
19. Log breakdown method	Split taper	*1* = full taper *2* = both split and full taper
20. Jacket board thickness	(Must be set)	*1* = all 1-in. lumber *2* = all 2-in. lumber *3* = 2-in. with 1-in. jacket board

[1]Required information: Jacket board thickness (in.) (see text for limits), minimum and maximum log diameter (in.) (see text for limits), taper (in./16 ft), saw setting increment (in.), head saw kerf (in.), cant breakdown kerf (in.), dressing allowance (in.), sawing variation (in.).

[2]If *not* set, must provide price table.

[3]If set, must provide initial fence setting.

[4]For Option 6 (when jacket board thickness in 1 in.):
1 = 1 × 4 on fence side of cant, 1 or 2 in. on back.
2 = 2-in. piece on fence side of cant, 1 or 2 in. on back.
3 = 1 × 4 on fence side of cant, 2 in. on back.
4 = 2-in. piece on both sides of cant.

[5]See text for limits.

[6]If set, minimum log diameters for cant sizes are entered on card 3.

[7]If set, must provide number of positions; also log face opening increment is used as offset increment.

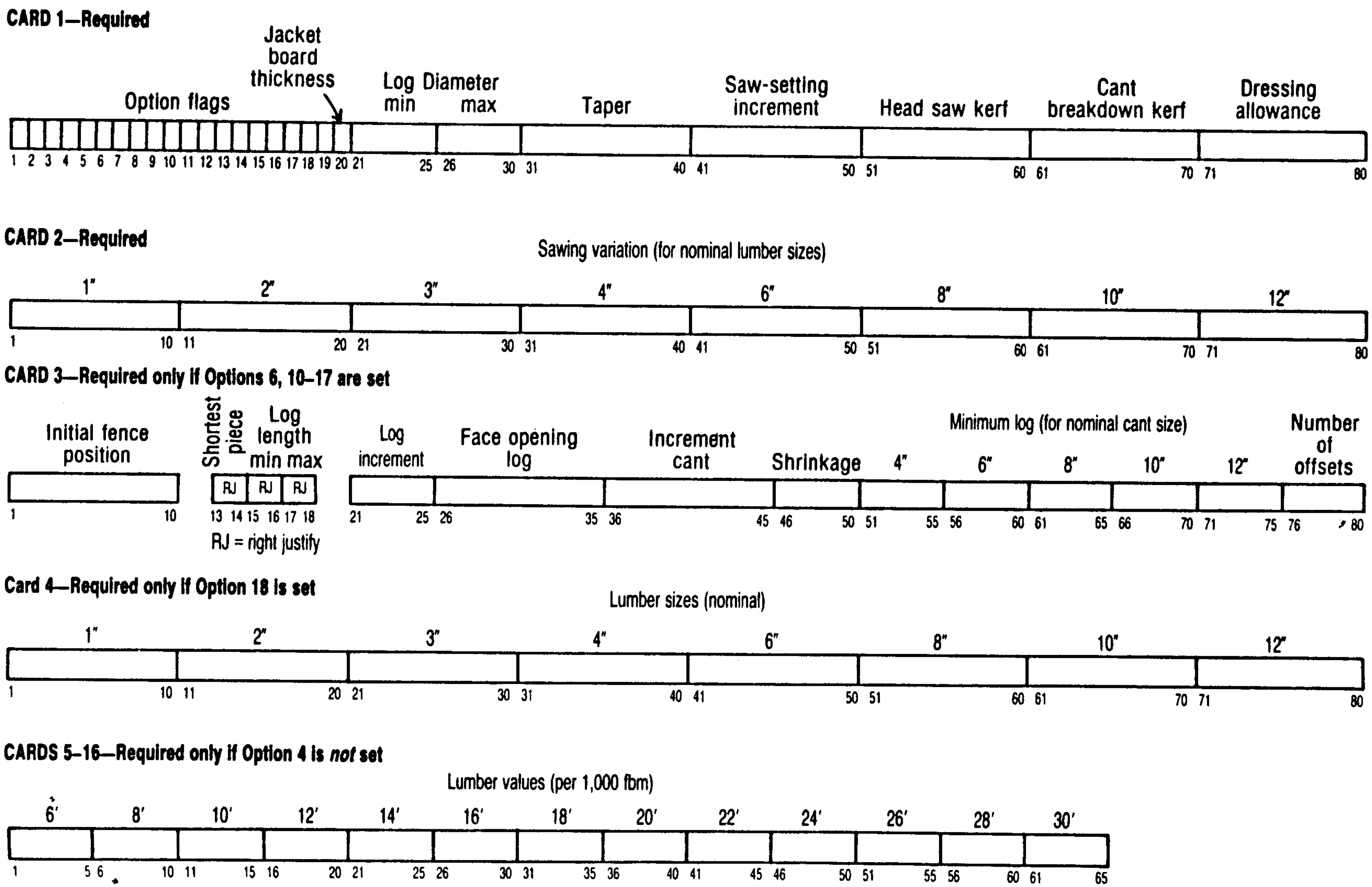

Figure 13.—BOF input data formats. Except as noted, the information may be entered as decimal numbers anywhere within the indicated field limits. Those values requiring right justification are indicated by the letters RJ appearing in the field.

Headsaw Kerf

Headsaw kerf is the kerf width of the first saw used to break down the log. In many cases, such as twin and quad bandsaw headrigs, several saws are involved, but all have the same kerf and saw the log in parallel planes generally considered to be vertical (fig. 4). If standard mill practice is to take a minimal number of lines at the headsaw, produce flitches that contain multiple pieces, and further break these flitches down in the same plane on another saw with a different kerf, the weighted average of the two kerfs should be entered. This will introduce a small amount of error, but in most cases it will not be as significant as if only one kerf value were used.

Cant Breakdown Kerf

Cant breakdown kerf is the kerf width of the saw or saws used to break down the cant and is also used as the kerf for edging flitches. If different kerf widths are used for cant breakdown and for board edging, the cant breakdown kerf should be used as this normally covers a larger volume of lumber. The sawlines in the cant are perpendicular to the sawlines in the log and are generally considered to be horizontal (see option 2 on p. 17 and fig. 4). If two or more cant breakdown machines are used interchangeably, their kerfs should be pro-rated.

Dressing Allowance

Dressing allowance is the additional thickness or width dimension necessary to obtain a satisfactory dressed surface on finished lumber. It is determined by adding the cut of the fixed planer head to the minimum cut (often considered to be 1/32 in.) required by the thicknessing head to obtain a satisfactory finish. For example, a fixed head cut of 0.062 inch plus minimum cut for thicknessing head of 0.031 inch means 0.093 is used. If the lumber is not to be dressed, a very small value such as 0.000001 should be used.

Sawing Variation

Sawing variation is an expression of the sizing variation above (+) and below (-) the average target thickness or width of lumber. In determining the required target size for rough green lumber an allowance for the scant or negative sawing variation must be made. Figure 14 shows what scant sawing variation is and how it can be determined. For example, if the average target size of nominal 4-inch is 3.950 and 95 percent of the 4-inch pieces are found to be thicker than 3.750, then the scant sawing variation is 0.200. The scant sawing variation is added to the minimum rough green size to determine the necessary average target size to stay within a prescribed sizing tolerance–e.g., 95 percent.

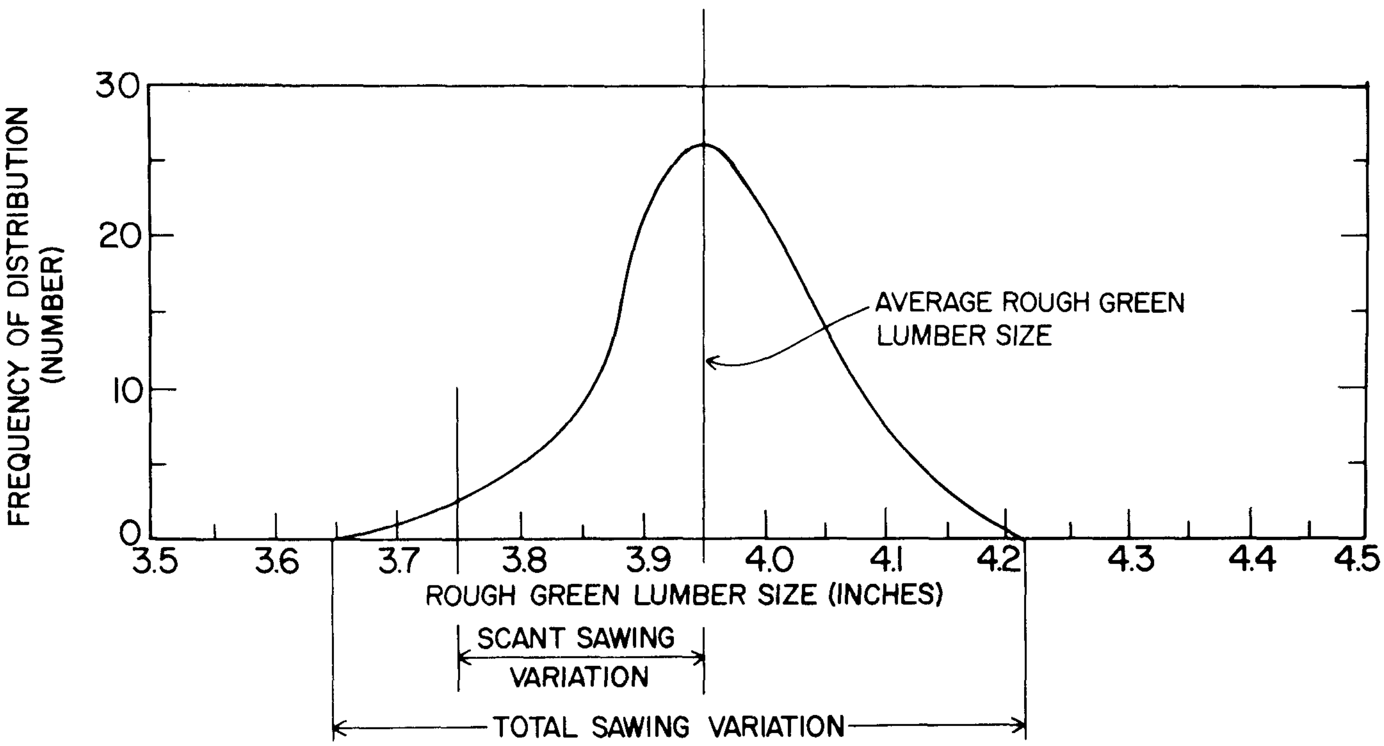

Figure 14.—Scant sawing variation is the difference between the average rough green lumber size and 95 percent of the low end of the total sawing variation. (ML84 5605)

Program Control Options

BOF can be made to simulate individual mill configurations by specifying various options and entering supplementary information where necessary. These options are set by entering values in the appropriate columns of the first card. If an option is not set, either a blank or 0 (zero) may be entered. Options should be set by entering a 1 unless otherwise specified under the individual option.

Option 1. Processing Control

Not set: The program is run and the solutions are output.

Set: Enter 1. The input information will be listed, but the individual log solutions will not be calculated. This allows the user to check the accuracy of the input data without actually calculating the BOF solutions

Enter *9.* A *9* tells the BOF program that all data have been run and processing should be terminated. If more than one set of data are to be run, the last data card of one set should be immediately followed by the first card of the next set. Whether one data set or multiple sets are run, the last card should contain a *9* in column 1 to terminate processing.

Option 2. Sawing Method (fig. 4)

Not set: The cant sawing method will be used. A center cant and side lumber will be produced in the "vertical" plane. The cant is then further broken down by sawlines in the "horizontal" plane.

Set: The live sawing method will be used. All log breakdown lines are in the vertical plane.

Option 3. Lumber Sizes

Not set: The finished sizes are assumed to be dry, and shrinkage will be considered in calculation of target sizes. The shrinkage percentage is controlled by Option 15.

Set: The finished sizes are assumed to be green, and shrinkage is not considered.

Option 4. Yield Maximization

Not set: BOF calculates the solutions yielding the greatest values. These may or may not be the highest volume solutions. Values per thousand board feet are used for each lumber size and length being cut. The number of values used depends on the jacket board thickness (Option 20) and the narrowest piece allowed (Option 10). Values for all lengths for each lumber size are entered on one card. For each thickness the values are entered in order of increasing width. If two thicknesses are cut, the value cards for the 1-inch thickness are entered first, followed by those for the 2-inch thickness (see fig. 13). If both 1-inch and 2-inch lumber are cut and certain sizes of 1-inch lumber are not desired, these may be suppressed by entering a very small value such as 0.10 per thousand board foot for those sizes. Note that 2-inch lumber and 1 x 4's, when Option 6 is set with *1* or *3,* SHOULD NOT be suppressed in this way. In addition, when only one thickness is used no lumber should be suppressed.

Set: BOF calculates solutions yielding the greatest nominal board foot volumes. They may or may not be the highest values.

Option 5. Cant Sawing Maximization Method (used only if cant sawing-i.e., Option 2–is not set)

Not set: (a) Option 4 not set. The cant with the highest weighted value that can be cut from the log will be used. (See p. 12 for explanation of "weighted" value.)
(b) Option 4 set. The largest cant that can be cut from the log will be used. Either BOF will calculate the smallest log diameter in which a given cant size will fit, or the user may specify the smallest diameter to be used. This is defined by Option 16.

Set: Enter *1.* The largest cant that can be cut from the log will be used. Note that if Option 4 is set, this has no effect.

Enter 5. Solutions will be calculated for all possible cant sizes that can be sawn from the log, and the one giving the highest total volume or value yield will be chosen.

Option 6. Cant Breakdown Method (used only if cant sawing–i.e., Option 2–is not set) (fig. 1)

Not set: Split taper. The sawlines will be parallel to the centerline of the cant.

Set: Full taper. The sawlines in the cant will be parallel to one of the unsawn faces–i.e., when using a fence.

Enter *1.* A 1 x 4 is taken from the fence side of the cant, a 1- or 2-inch on the back. Even if the cant is wider, only a 1 x 4 will be taken on the fence side.

Enter *2.* A 2-inch piece will be taken from the fence side, a 1- or 2-inch on the back.

Enter *3.* A 1 x 4 will be taken from the fence side of cant, a 2-inch on the back.

Enter *4.* A 2-inch piece will be taken from the fence side and a 2-inch on the back.

Option 7. Cant Breakdown Fence (full taper cant sawing-i.e., Options 2 and 6 set)

The initial fence position is the distance from where the side of the cant touches the fence to the first usable face of the cant (figs. 11 and 12).

Not set: The fence position is fixed, and the same distance will be used for all cant sizes. The fence position must be entered on card 3.

Set: The fence position is variable, and the program will calculate the position that maximizes lumber value or volume from the cant. The cant opening face increment should be supplied as described under Option 14.

Enter 1. The fence may be shifted up to the target size of the greater thickness plus a kerf.

Enter 2-9. The fence can only be moved into 2, 3, . . ., 9 positions.

Whenever Option *7* is set *>0,* two situations exist with respect to the initial fence position: If there is a minimum distance, it should be entered on card 3; if there is no prescribed minimum, a - *1* should be entered on card 3, and the program will calculate the initial fence position that will yield the smallest acceptable piece from each cant.

Option 8. Edging Method

Not set: Flitches will be edged by the trim-back method (figs. 8 and 9). Using this method, the program first finds the widest full-length piece the flitch will yield. Then it trims back the flitch by successive 2-foot increments and edges the pieces according to the wane rules. The piece or pieces that yield the highest volume or value are determined.

Set: Flitches will be edged by the full-length method (fig. 7). Using this method, the program finds the widest full-length piece and then checks the remaining triangle for a shorter piece of the narrowest width.

Option 9. Yield Reports

This option controls which report format (App. B) will be used.

Not *set:* The opening face distances, cant size (if applicable), and lumber yield will be printed.

Set: Enter *1.* In addition to the above, the log and cant offsets and the nominal sawing sequences will be printed.

Enter *2.* In addition to the above items, the piece tally will be printed.

Option 10. Narrowest Widths

Not Set: The mill cuts five nominal widths. Nothing narrower than a nominal 4-inch width will be saved.

Set: Enter *1.* In addition to the five standard widths, nominal 3-inch lumber will be salvaged.

Enter *2.* This will simulate a stud mill recovering only nominal 4-inch lumber.

Enter *3.* This will simulate a stud mill that also salvages 3-inch lumber.

Option 11. Shortest Lumber Length

Not set: No lumber shorter than 8 feet will be recovered.

Set: Any even length between 6 and 30 feet can be entered on card 3, but it must not be greater than the shortest log length defined by Option 12.

Option 12. Minimum and Maximum Log Length

Not set: Even log lengths 8 through 16 feet will be processed.

Set: Even log lengths in the range of 6 to 30 feet are entered on card 3, and all lengths in this range are processed.

Option 13, Log Diameter Increment

Not set: The program will process all log diameters from the minimum to maximum specified in 0.1-inch increments.

Set: The log diameter increment is entered on card 3.

Option 14. Log and Cant Opening Face Increment

The opening face increment is the distance the opening face is shifted between trials. It is also called “offset increment” when sawing the log, and “fence-setting increment” when sawing the cant.

Not set: Successive trial opening faces will be separated by 0.050 inch on both the log and the cant.

Set: Enter *1.* An increment other than 0.050 inch may be entered on card 3. A different increment may be used for the log and the cant. Normally these values reflect the setting capability of the log and cant breakdown equipment.

Enter *2.* The opening face increments are defined as when set with a 7. However, the saw setting increment is doubled in calculating target sizes to model equipment with opposing cylinders-i.e., some twin and quad bandsaws-which doubles the setting increment.

NOTE: If live sawing with this option set, a value must be entered for cant opening face increment, even though it is not used.

Option 15. Shrinkage (used only for dry sizes-i.e., Option 3 is not set)

Not set: A shrinkage value of 5 percent will be used in calculating rough green lumber sizes.

Set: The shrinkage from green to rough dry at the time of planing is used. The value as a percent is entered-i.e., 3.8 percent is entered as 3.8, not 0.038.

Option 16. Minimum Log Required for a Cant

Not set: The program will calculate the minimum log diameter that will produce a cant containing one of the following: two 2 x 4's, two 2 x 6's, three 2 x 8's, three 2 x 10's, or three 2 x 12's.

Set: When set >*0,* for each cant size the user can, on card 3, specify the minimum log diameter required, can direct the program to calculate the minimum log diameter, or can suppress the cant size.

(a) The minimum log diameter from which the cant size will be recovered can be entered. This diameter must be large enough to recover at least one piece of lumber the width of the cant.

(b) If a *0* (zero) is entered, the program will calculate the minimum log diameter for that cant size, as if Option 16 were not set.

(c) If a - *1* is entered, the program will ignore that cant size.

(d) If *30* or greater is entered, that cant size and any larger cant sizes will be ignored. This option should be used to suppress cants larger than largest desired size, while (c) should be used to suppress those smaller.

Enter *1.* Cant sizes will be controlled as described above.

Enter *2, 4, 6,* or *8.* Cant sizes will be controlled as described above. In addition, the maximum number of side boards allowed will be 2, 4, 6, or 8.

Enter *9.* Cants will be controlled as above. In addition, no sideboards will be produced.

Option 17. Variable Opening Face and Offset Positions

Not set: Variable opening face sawing. Starting with the opening face yielding the smallest acceptable piece, all opening faces within the limits calculated by the program will be tried. If two thicknesses are used, the first piece next to the opening face will always be the smaller thickness.

Set: Offset sawing. This allows the user to specify the number of positions to which the log may be shifted off the center-line of the system. This number includes the centered position and should reflect the mechanical capability of the log setting equipment. Thus, if the log movement is limited to the centered position and four offsets, the number of offsets entered on card 3 is 5. For center sawing systems with no offset capability, the number of offsets is *1.*

Enter *1.* All cant sizes will be offset as limited above.

Enter *2.* Nominal 4-inch cants will be centered on the small end of the log, whereas larger cants will be offset as limited above.

Option 18. Lumber Dimensions

Not set: The dressed lumber will be American Lumber Standard (ALS) sizes. If Option 3 is not set (dry lumber), the ALS dry sizes will be used. If Option 3 is set (green lumber), ALS green sizes will be used.

Set: The user may enter finished sizes on card 4.

When multiple piece sizes are being entered, the following formulas can be used. For combining two pieces, the equation for calculating the rough dry size is:

$$SIZE_f = SIZE_1 + SIZE_2 + DRESS + (1 - SHRINK)\left(\frac{SAWVAR_1 + SAWVAR_2}{2} + KERF\right)$$

or for three pieces, where Size, is the middle:

$$SIZE_f = SIZE_1 + SIZE_2 + SIZE_3 + 2(DRESS) + (1 - SHRINK)\left(\frac{SAWVAR_1}{2} + SAWVAR_2 + \frac{SAWVAR_3}{2} + 2{*}KERF\right)$$

where

$SIZE_f$ = dry finished size of the combined piece,

$SIZE_{1,2,3}$ = dry finished sizes of the pieces to be ripped from the flitch,

DRESS = dressing allowance,

$SAWVAR_{1,2,3}$ = scant sawing variation associated with each size,

KERF = sawkerf width for ripping the flitches, and

SHRINK = shrinkage factor.

In the above formulas, sawing variation and sawkerf are "shrunken" to bring them down to the dry size as the program lumber size calculations will "swell" them up to the green size. In the case in which the composite size is made up of two pieces, the sawing variation is only that on one side of each piece, while for three pieces, the entire variation is added in for the middle piece and half the total variation for each side piece. When the BOF program is run, the two unused half sawing variations are added and entered as total sawing variation.

These calculations are performed automatically by the program if the option is set to run a stud mill with all sizes 2 x 4 or smaller.

Option 19. Log Breakdown Method (fig. 1)

Not set: Split taper. The log is sawn parallel to the centerline.

Set: Enter *1.* Full taper. The log is sawn parallel to the opening face side.

Enter *2.* Both split taper and full taper will be tried and the best solution printed.

Option 20. Jacket Board and Lumber Thickness

This option must be set.

Enter *1.* All lumber will be nominally 1 inch thick.

Enter *2.* All lumber will be nominally 2 inches thick.

Enter *3.* Primary production will be nominally 2 inches with the jacket boards on the log and cants 1 or 2 inches depending upon Options 17 and 6.

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Appendix A
Calculating the Minimum Cant Breakdown Fence Setting

For setting up the fence on a rotary gangsaw or other cant breakdown equipment, it is desirable to have the initial fence-to-zero-saw distance be the smallest possible to allow recovery of a usable piece from the minimum-diameter log. The formulas below will calculate the setting that will recover the narrowest, shortest piece from the fence side of the cant. This piece will have the maximum wane allowed.

In practice, irregularities in log shape will probably result in excessive wane on pieces from minimum-diameter logs. However, use of these formulas provides a starting point for judging the best initial fence setting to minimize edging waste (fig. Al).

Let:

R = log radius at the shortest lumber length from the large end of the log.
F = minimum face width being considered on the fence side of the cant.
D = distance from the center of the log to face F at the point at which R is determined.
W = dry finished width of the smallest allowable piece of lumber.
T = dry finished thickness.
S = shrinkage factor.
WA = wane allowance factor.

Step 1. Calculate the distance from the log center to the green finished face with maximum wane:

$$D_1 = \sqrt{R^2 - F_1^2}$$

where

$$F_1 = \frac{W}{(1-S)} \times (1-WA) \times 0.5$$

Step 2. Calculate the distance from the log center to the green finished face allowing maximum edge wane:

$$D_2 = \sqrt{R^2 - F_2^2} + \left[\frac{T}{(1-S)} \times WA\right]$$

where

$$F_2 = \frac{W}{(1-S)} \times 0.5$$

Step 3. Calculate the distance to the sawn face allowing maximum wane:

$$D = \text{the smaller of} \begin{Bmatrix} D_1 \\ D_2 \end{Bmatrix} + 0.5\left[\frac{DR}{(1-S)} + SV\right]$$

where DR = dressing allowance.
SV = sawing variation of thickness, T.

Step 4. The minimum fence setting (FS) is then:

$$FS = R - D$$

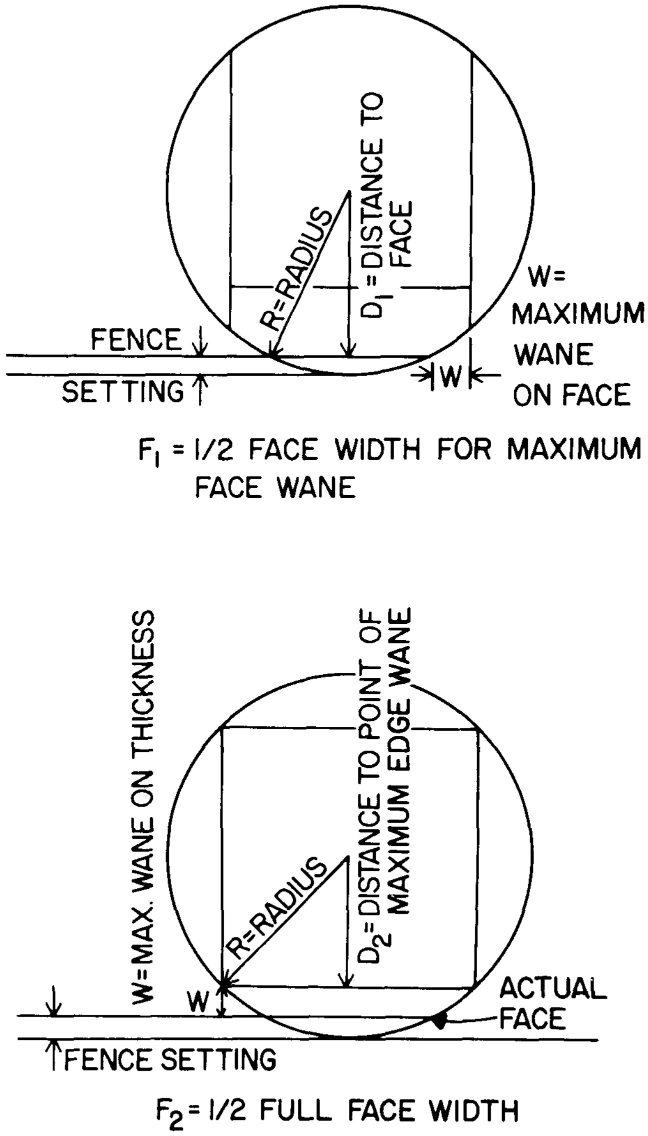

Figure A1.—The larger fence setting will meet both face and edge wane restrictions. (ML84 5606)

Appendix B
Best Opening Face Reports

The following reports are examples of those generated by the BOF program. Most of the information in them is self-explanatory, but those items that could be ambiguous are explained below.

Report B.1 shows the values used in calculating the rough lumber sizes. Dressing allowance, as printed, contains the minimum dressing allowance and the oversizing needed to come up to a multiple of the saw setting increment. Shrinkage is the loss from green to dry of the rough lumber and dressing allowance. It does not include sawing variation.

Report B.3 lists the smallest log diameter from which each cant size can be sawn. Unless the diameter is specified, the log is large enough to fit a cant containing two 2 x 4's, two 2 x 6's, three 2 x 8's, three 2 x 10's, or three 2 x 12's.

Report B.5 lists the weighted ranking of each cant size by length. It is printed only when maximizing value, and when using the highest ranked cant. It is not printed when selecting the largest cant or when testing all cant sizes. Within each length, the highest ranked cant that meets the minimum log diameter restriction will be chosen.

Reports B.6 through B.11 illustrate various levels of detail in presenting the results of the BOF calculations.

The *B*est *O*pening *F*ace distances are from the center of the small end of the log to the sawn surface of the outer pieces. Figure B1 shows the locations of these distances.

Range is the number of consecutive opening faces that give the maximum yield. When the range is an odd number, the solution printed is based on the opening face in the middle of the range. If range is even, the rightmost of the center two opening faces is used. FT or ST next to the range tells whether the log or cant was sawn full taper or split taper.

Lumber Recovery Factor is the ratio of board feet lumber recovered divided by the actual cubic foot log volume. Cubic foot volume is calculated using Smalian's formula.

Sawing Sequence, shown in Reports B.7, B.8, B.10, and B.11, is the nominal thickness of the sawlines going from the left opening face to the right opening face. Offset, in these reports, is the distance the center of the cant or center piece is shifted off the center of the small end. The shift is to the left when offset is negative and to the right when offset is positive.

Fence is shown only when the cant is full taper sawn. It is the distance from the outside of the log to the sawn surface of the cant left opening face.

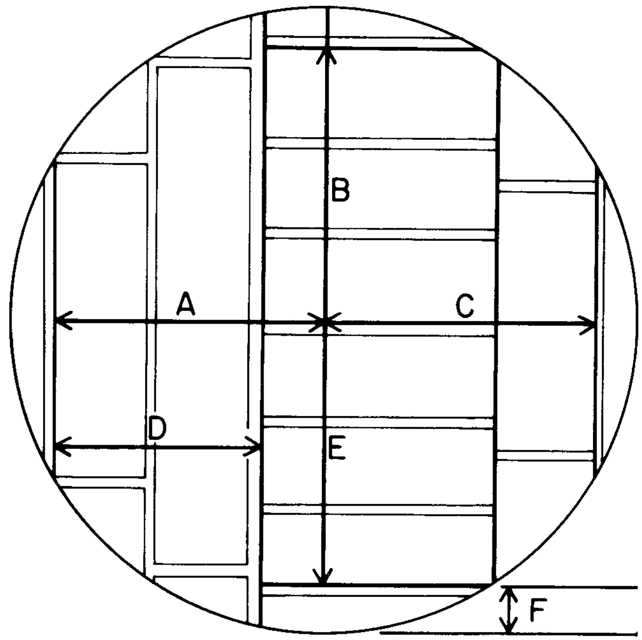

Figure B1.—Location of opening faces looking at the small end of the log, (A) Best Opening Face, distance from center, left; (B) cant opening face, distance from center, right; Best Opening Face, distance from center, right; (D) distance, left face to cant; (E) cant opening face, distance from center, left; and (F) fence. (ML84 5607)

BEST OPENING FACE SYSTEM (BOF)

POSITIONS OF OPENING FACE FOR MAXIMUM VALUE
YIELDS ARE BASED ON THE FOLLOWING ASSUMPTIONS:

LUMBER SIZES

NOMINAL (IN.)	DRY DRESSED (IN.)	DRESSING ALLOWANCE (IN.)	SHRINKAGE (IN.)	SAWING VARIATION (IN.)	ROUGH GREEN (IN.)
THICKNESS					
1	.750	.079	.025	.031	.885
2	1.500	.082	.047	.031	1.660
WIDTH					
3	2.500	.082	.077	.031	2.690
4	3.500	.077	.107	.031	3.715
6	5.500	.078	.167	.045	5.790
8	7.250	.080	.219	.056	7.605
10	9.250	.078	.279	.068	9.675
12	11.250	.079	.338	.083	11.750

Report B.1.—Calculation of lumber sizes

EDGING METHOD	FULL LENGTH
NARROWEST NOMINAL WIDTH ALLOWED	3 IN.
SHORTEST PIECE ALLOWED	6 FT.
TAPER (PER 16 FEET)	1.90 IN.
SETTING INCREMENT	.005 IN.
HEAD SAW KERF	.185 IN.
CANT BREAKDOWN KERF	.135 IN.
OPENING FACE INCREMENT	.063 IN.
SHRINKAGE (PERCENT)	2.9
LOG BREAKDOWN METHOD	FULL TAPER
CANT BREAKDOWN METHOD	FULL TAPER
CANT BREAKDOWN FENCE	FIXED
INITIAL FENCE SETTING	.500 IN.

Report B.2.—Summary of input information

NOMINAL CANT SIZE (IN.)	MINIMUM LOG DIAMETER (IN.)
4	4.43
6	6.22
8	8.65
10	10.48
12	12.38

Report B.3.—Minimum log diameter for each nominal cant size

LUMBER VALUES (PER THOUSAND BOARD FEET)

	SPECIFIED LENGTHS (FEET)					
	6	8	10	12	14	16
1X3	157.	157.	157.	157.	157.	157.
1X4	165.	165.	165.	165.	165.	165.
1X6	168.	168.	168.	168.	168.	168.
1X8	170.	170.	170.	170.	170.	170.
1X10	173.	173.	173.	173.	173.	173.
1X12	195.	195.	195.	195.	195.	195.
2X3	94.	152.	134.	159.	159.	179.
2X4	102.	152.	142.	167.	167.	187.
2X6	99.	134.	142.	174.	174.	191.
2X8	99.	129.	139.	189.	179.	174.
2X10	125.	160.	165.	195.	205.	200.
2X12	140.	180.	180.	210.	220.	225.

Report B.4.—Lumber value table

NOMINAL CANT SIZES RANKED BY WEIGHTED VALUE

	SPECIFIED LENGTHS (FEET)				
RANK	8	10	12	14	16
1	12	12	12	12	12
2	10	10	10	10	10
3	4	4	8	8	6
4	6	8	6	6	4
5	8	6	4	4	8

Report B.5.—Weighted rank of nominal cant sizes by length

LOG DIAMETER (IN.)	LOG LENGTH (FEET)	BEST OPENING FACE DISTANCE FROM CENTER LEFT (IN.)	BEST OPENING FACE DISTANCE FROM CENTER RIGHT (IN.)	RANGE	DISTANCE LEFT FACE TO CANT (IN.)	NOMINAL CANT SIZE (IN.)	CANT OPENING FACE DISTANCE FROM CENTER LEFT (IN.)	CANT OPENING FACE DISTANCE FROM CENTER RIGHT (IN.)	RANGE	LUMBER RECOVERY FACTOR	LUMBER TALLY (BD.FT.)	LUMBER VALUE
12.4	8	5.869	5.861	3 FT	.000	12	5.700	5.955	1 FT	10.68	77	12.65
	10	5.870	5.830	3 FT	.000	12	5.700	5.955	1 FT	10.48	97	16.05
	12	5.934	6.866	1 FT	.000	12	5.700	5.955	1 FT	10.41	118	23.14
	14	5.810	7.010	2 FT	.000	12	5.700	6.975	1 FT	10.38	139	28.22
	16	5.811	7.009	2 FT	.000	12	5.700	6.975	1 FT	10.24	160	32.53

Report B.6.—Summary report when maximizing value

LOG DIAMETER (IN.)	LOG LENGTH (FEET)	BEST OPENING FACE DISTANCE FROM CENTER LEFT (IN.)	BEST OPENING FACE DISTANCE FROM CENTER RIGHT (IN.)	RANGE	DISTANCE LEFT FACE TO CANT (IN.)	NOMINAL CANT SIZE (IN.)	CANT OPENING FACE DISTANCE FROM CENTER LEFT (IN.)	CANT OPENING FACE DISTANCE FROM CENTER RIGHT (IN.)	RANGE	LUMBER RECOVERY FACTOR	LUMBER TALLY (BD.FT.)	LUMBER VALUE
12.4	16	5.811	7.009	2 FT	.000	12	5.700	6.975	1 FT	10.24	160	32.53

SAWING SEQUENCE (LOG): 12 1 OFFSET: -.064 IN. FENCE: .500 IN.

(CANT): 1 2 2 2 2 2 2 1 CANT LUMBER TALLY: 157 BD.FT.

Report B.7.—Summary report plus sawing sequences and offsets when maximizing value

LOG DIAMETER (IN.)	LOG LENGTH (FEET)	BEST OPENING FACE DISTANCE FROM CENTER LEFT (IN.)	BEST OPENING FACE DISTANCE FROM CENTER RIGHT (IN.)	RANGE	DISTANCE LEFT FACE TO CANT (IN.)	NOMINAL CANT SIZE (IN.)	CANT OPENING FACE DISTANCE FROM CENTER LEFT (IN.)	CANT OPENING FACE DISTANCE FROM CENTER RIGHT (IN.)	RANGE	LUMBER RECOVERY FACTOR	LUMBER TALLY (BD.FT.)	LUMBER VALUE
12.4	16	5.811	7.009	2 FT	.000	12	5.700	6.975	1 FT	10.24	160	32.53

SAWING SEQUENCE (LOG): 12 1 OFFSET: -.064 IN. FENCE: .500 IN.

(CANT): 1 2 2 2 2 2 2 1 CANT LUMBER TALLY: 157 BD.FT.

NUMBER OF PIECES

	8 FT	10 FT	12 FT	14 FT	16 FT
1X4	2	0	0	0	1
2X4	0	0	0	0	1
2X6	0	0	0	0	0
2X8	0	0	0	0	1
2X10	0	0	0	0	2
2X12	0	0	0	0	2

Report B.8.—Full report when maximizing value

LOG DIAMETER (IN.)	LOG LENGTH (FEET)	BEST OPENING FACE DISTANCE FROM CENTER LEFT (IN.)	BEST OPENING FACE DISTANCE FROM CENTER RIGHT (IN.)	RANGE	DISTANCE LEFT FACE TO CANT (IN.)	NOMINAL CANT SIZE (IN.)	CANT OPENING FACE DISTANCE FROM CENTER LEFT (IN.)	CANT OPENING FACE DISTANCE FROM CENTER RIGHT (IN.)	RANGE	LUMBER RECOVERY FACTOR	LUMBER TALLY (BD.FT.)
12.4	8	5.119	6.271	2 FT	2.915	4	5.700	5.955	1 FT	10.95	79
	10	5.120	6.045	1 FT	4.760	4	5.700	5.955	1 FT	11.07	102
	12	6.059	6.106	1 FT	4.760	4	5.700	5.955	1 FT	10.99	124
	14	5.185	6.205	1 FT	2.915	4	5.700	6.975	1 FT	11.09	149
	16	6.061	7.174	1 FT	4.760	4	5.700	6.975	1 FT	10.92	171

Report B.9.—Summary report when maximizing volume

LOG DIAMETER (IN.)	LOG LENGTH (FEET)	BEST OPENING FACE DISTANCE FROM CENTER LEFT (IN.)	RIGHT (IN.)	RANGE	DISTANCE LEFT FACE TO CANT (IN.)	NOMINAL CANT SIZE (IN.)	CANT OPENING FACE DISTANCE FROM CENTER LEFT (IN.)	RIGHT (IN.)	RANGE	LUMBER RECOVERY FACTOR	LUMBER TALLY (BD.FT.)
12.4	16	6.061	7.174	1 FT	4.760	4	5.700	6.975	1 FT	10.92	171

SAWING SEQUENCE (LOG): 1 2 2 4 2 2 1   OFFSET: -.556 IN.   FENCE: .500 IN.

(CANT): 1 2 2 2 2 2 2 1   CANT LUMBER TALLY: 72 BD.FT.

Report B.10.—Summary report plus sawing sequences and offsets when maximizing volume

LOG DIAMETER (IN.)	LOG LENGTH (FEET)	BEST OPENING FACE DISTANCE FROM CENTER LEFT (IN.)	RIGHT (IN.)	RANGE	DISTANCE LEFT FACE TO CANT (IN.)	NOMINAL CANT SIZE (IN.)	CANT OPENING FACE DISTANCE FROM CENTER LEFT (IN.)	RIGHT (IN.)	RANGE	LUMBER RECOVERY FACTOR	LUMBER TALLY (BD.FT.)
12.4	16	6.061	7.174	1 FT	4.760	4	5.700	6.975	1 FT	10.92	171

SAWING SEQUENCE (LOG): 1 2 2 4 2 2 1   OFFSET: -.556 IN.   FENCE: .500 IN.

(CANT): 1 2 2 2 2 2 2 1   CANT LUMBER TALLY: 72 BD.FT.

NUMBER OF PIECES

	6 FT	8 FT	10 FT	12 FT	14 FT	16 FT
1X4	1	1	0	0	0	2
2X3	0	0	0	1	0	0
2X4	0	0	0	0	0	7
2X6	0	0	0	0	0	0
2X8	0	0	0	0	0	1
2X10	0	0	0	0	0	2

Report B.11.—Full report when maximizing volume

Appendix C
Considerations for Using Best Opening Face to Simulate Sawmills Producing Metric-Sized Lumber

Sawmillers from countries where lumber is produced to metric standards have expressed interest in using BOF to simulate their operations. This use of BOF is possible, but certain assumptions in the model must be clearly understood to avoid misleading results.

BOF was written to simulate North American sawmills sawing small, second-growth softwood timber into lumber suitable for light-frame construction. The type of timber, products recovered, and North American sawing practices influence the logic of the computer model.

Second-growth softwood timber usually grows quite straight, with sound, tight knots, and little other defect such as decay or splits. Therefore, BOF does not consider sawing practices needed to minimize the effect of defect like, for example, boxing the brashy heart found in some radiata pine.

The only lumber products considered are those suitable for light-frame construction, graded under the U.S. National Grading Rule for Dimension Lumber (WCLIB 1980). Most of the lumber is nominally 2 inches (38 mm) thick. Optionally, 1-inch (19-mm) boards may be recovered from the first piece on each of the four log faces. The 1-inch lumber is generally regarded as a salvage size, to be recovered only if a more valuable 2-inch piece cannot be sawn. In addition, standard lumber lengths are in multiples of 2 feet (approximately 600 mm). These practices are modeled in BOF and may differ significantly from standard practice in sawmills outside North America.

The other assumptions in BOF–such as wane allowance and sawing methods-that are described in this publication should also be recognized when using the program. In particular, it should be recognized that BOF maximizes lumber board foot volume or value. The board footage of a piece of lumber is calculated by the nominal thickness by the nominal width (both in inches) times the length in feet, and dividing this product by 12. Since the actual lumber thickness and width are less than the nominal, the board footage does not measure the true cubic fiber content of each piece.

Thus, to maximize either volume or value in cubic meters, the value tables must be used to compensate for BOF's internal use of board feet.

When maximizing volume, the conversion from nominal thousand board feet to cubic meters is entered in the value table. This conversion factor is:

$$\frac{12{,}000 \times m^3}{NT \times NW \times L}$$

where
NT = nominal thickness of that size in the value table
NW = nominal width of that size in the value table
L = lumber length in feet
m^3 = *cubic meters per piece of that size*

The value table is set up with each nominal size and length in a particular location as described in the text under Option 4. The nominal sizes used for each product size are the ones for the location in the value table for the particular size being considered.

To maximize value, the entry in the value table is the value per cubic meter times the conversion factor calculated above.

Many mills producing lumber to metric sizes make fewer than the five lumber widths required by BOF for each thickness. This practice can be simulated by creating widths made up of a combination of two or more smaller widths as was described in the section on using the Best Opening Face program.

However, the practice of recovering three or more thicknesses from each log cannot be modeled using BOF. The most successful approach to this problem has been to make multiple BOF runs using all combinations of thicknesses, two at a time. For example, if a mill saws 19-, 38-, and 45-mm lumber, three runs would be made, first using the 38 mm and 19 mm together, then 45 mm and 38 mm. The smaller thickness should be considered the salvage size, just as BOF considers 1-inch lumber. The choice of alternative results to use for any one particular log is based on the log grade and characteristics, lumber value, volume yield, and desired product mix.

If the results of the BOF program run in this manner are used in empirical studies, the lumber output will usually be within the accuracy of other data used, such as the estimated log volumes used in economic analysis.

When BOF solutions are to be used to calculate sets for automated control systems, it is recommended that two or three solutions be stored for each log. The operator can then choose a set based on log characteristics and desired product mix.

When used in an appropriate manner, BOF can be a valuable tool for sawmills producing metric-sized lumber.

Acknowledgments

Simulation models often evolve, with each improvement being the result of questions and comments from knowledgeable people. At times contributions are even more direct. For their help, I thank my coworkers-particularly Jeanne Danielson, for contributing the appendices and for many useful discussions, ideas, and suggestions, and Hiram Hallock, now retired, who conceived the idea for and jointly develped the original version of BOF.

I would also like to thank the many people in the sawmill industry and the Forest Service whose questions and comments on the practical side of sawmilling helped make the information in this paper possible.

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Program

The FORTRAN source for the BOF program is available in electronically readable form from:

U.S. Department of Agriculture, Forest Service
State and Private Forestry
One Gifford Pinchot Drive
Madison, WI 53705-2398

It is titled "FORTRAN Listing of the Best Opening Face System."

1.5-2/86