LOG SUPPLY VALUATION AND ALLOCATION TO ALTERNATIVE CUTTING PROGRAMS USING LOG BOOM SCALING DATA

by

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B.Sc. (Forestry), The University of British Columbia, 1992

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

(Department of Forestry)

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

January 1996

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Date MARCH 13, 1996

DE-6 (2/88)

ABSTRACT

Numerous methods have been developed by forest companies to ensure that the right logs are processed by the right facility into the right products. Advances in computer technology have made possible the detailed analysis of vast amounts of electronically recorded data, such as log scaling data, and the effective and accurate prediction of lumber recovery from sawlogs using sawing simulation. This thesis describes the development of a method for improving the utilization of merchantable grade log booms through the preliminary analysis of log scaling data and the use of bucking and sawing simulation to predict the lumber value recoverable from various sizes of sawlogs. Potential benefits include preliminary prediction of lumber production, valuation of log booms to improve selling and purchasing accuracy in open log markets, and improved profitability through the specific allocation of a log boom supply to alternative product lines.

Based upon the results of a case study conducted on a Coastal British Columbia sawmill, the five step method can effectively predict the volumes and sizes of the lumber contained within a given log boom, as well as provide an estimate of the boom's dollar value. Overall profitability was also improved using a heuristic based allocation procedure on an entire month's log supply.

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ACKNOWLEDGMENTS

The contributions of several organizations and people to the preparation and completion of this research project should be acknowledged. Foremost are Pacific Forest Products Ltd., the Science Council of British Columbia, and Nanoose Systems Corporation, without whose financial, operational, and material support this research would not have been feasible. The author would especially like to thank Dr. Thomas C. Maness, research supervisor, for his invaluable advice and assistance. Special thanks must also go to Dallas Foley, Rick Forgaard, Robert Six, and "Team Tahsis".

I INTRODUCTION

The Forest Products Industry is one of continual change. Technological advances in harvesting and processing, combined with more demanding customers and uncertainty in raw material supply, have forced companies to continually strive to produce more value from the trees they harvest. The very survival of many companies has become contingent on their ability to produce market specific products quickly and efficiently. Few companies survive today by producing only one product line. Companies must switch between different products not only to meet customer demands but also to achieve maximum utilization of their raw materials. The log supplies for some operations, especially those on the coast of British Columbia (B.C.), often vary greatly in species, quality, and size. When faced with variation in both raw material supply and product mix, it becomes imperative that the different products are made from the appropriate raw material.

This process is called "raw material allocation" or "production planning". In the sawmill industry, this involves the process of ensuring that the right logs are cut into the right lumber. Several practical techniques, notably log sorting and log merchandising, have developed over time to address this issue. In some instances, however, external constraints make it difficult to achieve a high level of coordination between log supply and product mix. On the coast of B.C., sawmill log supplies consist almost entirely of water-borne groupings of logs called log booms (see Figure 1). Recent advances in computer technology provide companies with large amounts of information on their log supplies in the form of log scaling data. Computers have also made this information quickly and easily accessible. In certain situations, this information could open new opportunities in the field of log allocation.

The purpose of this thesis is to explore the possibility of using log scaling data to forecast the value of log booms for several different product lines (subsequently referred to as cutting programs). This would allow an operation to select specific booms from its log supply to match alternative product lines and to improve the forecast of the resulting production. This thesis contains a description of the development and testing of a workable method, or procedure, which could be implemented by coastal B.C. sawmills cutting merchantable grade logs. In this thesis, "merchantable grade" logs refer to small diameter, sound (no rot), knotty logs often called "gang" by coastal B.C. sawmills. The method was evaluated using extensive data provided by a coastal B.C. sawmill.

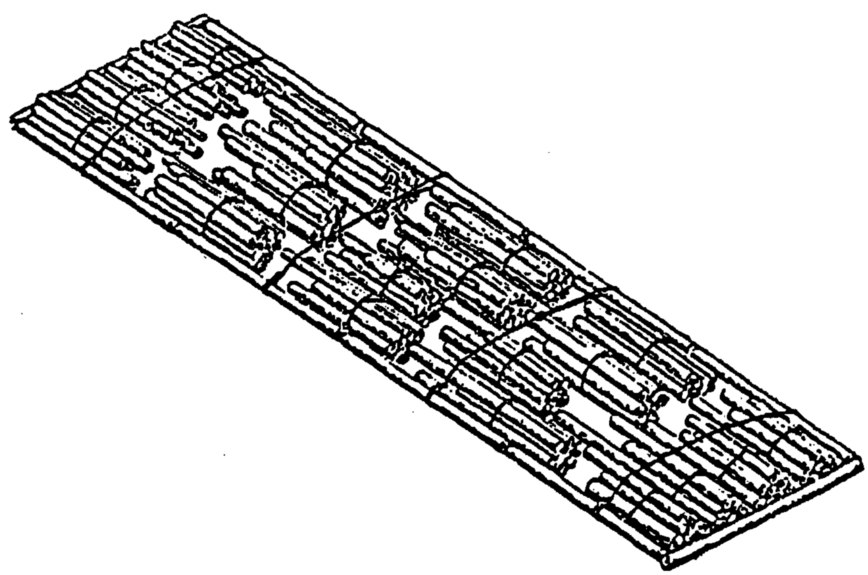


FIGURE 1. LOG BOOM EXAMPLE

This project was developed on the basis of two major assumptions, the first being that there is substantial variability in log size (diameter) among log booms which meet the same sort criteria. As a result of this variation, logs from different booms of the same sort will produce different numbers of sawlogs of specific diameters and lengths. These sawlogs are produced from the logs (usually several times longer than sawlogs) by the process of log bucking, in which each log is cut through the cross-section at various points along its length.

The second assumption is based on the theory that different cutting programs are better suited to certain sizes and lengths of sawlogs. In other words, each different product line that a given sawlog can be cut into will produce a different value of lumber, and the product line that produces the highest overall value for a given sawlog changes with the size and length of the sawlog. In the lumber industry, product lines are groupings of similar lumber products usually defined by thickness, widths, and grades. For example, dimension lumber is a product line, defined as 2" thick by 3", 4", 6", 8" 10" & 12" widths, and several different grades.

Product lines evolve into cutting programs for several reasons. The majority of B.C. coastal sawmills can produce numerous different product lines. Due to manufacturing limitations and the need to maintain certain production and recovery levels, all of these product lines cannot be cut at the same time. Thus, different production runs (cutting programs) are developed, each producing several product lines, which are usually related by market, and sawmills switch between these programs depending upon customer demands. Each cutting program produces lumber of different dimensions and often with slightly different length and grade requirements. For any given sawlog diameter, each cutting program will produce a different volume and value of lumber due to the size differences between the lumber products in each program. This can be clearly seen in Figure 2, which shows the same size sawlog cut into the various product lines associated with three different cutting programs. As a result, any given sawlog in a particular diameter and length class (e.g. 14.0"-14.9" by 4.8m) is worth a different value to each cutting program.

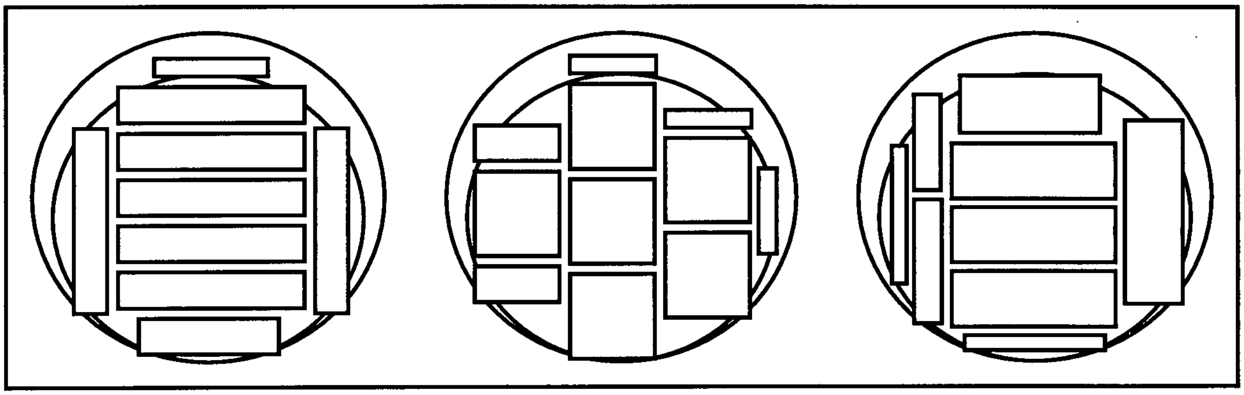


FIGURE 2. DIFFERENCES BETWEEN CUTTING PROGRAMS.

By using the log scaling data available on every boom to determine the quantity of various sawlog sizes and lengths, it can be determined which booms should be cut into which products so as to maximize the long term recovery of value from the mill's log supply.

There were three principle objectives of this study:

1. Develop a method of valuing booms for particular cutting programs based upon the knowledge of a boom's log characteristics (diameter and length distributions).
2. Use a case study analysis to determine whether value recovery gains can be achieved through the application of this method.
3. Develop a software package to automate the processes required by this method.

There are four more sections in this thesis. Section two provides insight into the different areas of research encompassed by this thesis and reviews previous work. Section three describes step-by-step the method developed. Section four describes the application of this method to a case study situation and presents the results. Section five provides conclusions on the results of this research.

II BACKGROUND

Due to the fact this research project incorporated data and techniques from several different fields, background information on the topics of log allocation, production planning, log scaling, log sorting, value recovery, and sawing simulation was reviewed.

Log Allocation and Production Planning

Determining how best to utilize a timber resource has been the subject of research for many years. Harvesting techniques, transportation technology, log merchandising, log bucking, and sawlog breakdown are continually studied and improvements are achieved. Many of these studies, such as those by Pearse and Sydneysmith (1966) and Mendoza and Bare (1986) attempted to determine the optimal allocation of a given log supply among several distinctly different manufacturing processes. These alternatives usually consist of one or more of the following: log export, peeling for veneer, chipping for pulp, sawing into lumber. With the assistance of operations research techniques (primarily linear programming), decisions are made that determine which logs should be used for each process to maximize profits. Widespread application of these techniques has been slow to occur in industry, although several commercial systems are now available and appear to slowly be gaining acceptance with some companies. These systems will aid in the allocation of timber from multiple stands to multiple production facilities and products.

On the coast of British Columbia, the primary method of log transport is by water. Trees are bucked into logs according to quality breaks, points along the tree where log quality changes. These logs are then further sorted, usually near the point of harvest, into groups (sorts) of similar species, quality, and size. These different sorts are then made into log booms. Once sorted, booms of logs of the same "sort" are considered to represent a log supply with little variability. Thus sawmills need only specialize in sawing one sort to effectively eliminate the need to decide which booms should be sawn into which products (Sorensen, 1992).

This method works reasonably well when dealing with the decreasing supply of large, high quality old growth logs currently consumed by many Coastal sawmills. However, variability within log sorts still occurs. Norton (1993) developed a production planning model which improved the overall product value derived from a log supply by selecting specific log booms for processing. This boom selection was attributed to the fact that different booms may have a distribution of logs better able to meet current market requirements. However, this work utilized x-ray scanning data on a few large, high quality sawlogs which were pre-bucked. Information such as this is not currently available on a continual basis for a large volume of logs.

A significant and increasing volume of the timber harvested on the coast is of merchantable quality. The sawlogs generated when these "gang" logs are bucked into shorter lengths primarily range in diameter from 10cm (4") through to 50cm (20"). These logs typically contain knots and little if any rot. As a result they are generally considered to be homogeneous in quality. This makes sawlog size, defined by diameter and length, the most important factor affecting the recovery of lumber. Recent research using log supplies of this type was focused on determining the optimal product mix produced from a sawmill given log supply, production, and marketing constraints. Maness and Adams (1991) described a production planning system which develops log bucking and sawing policies that enable a sawmill to produce the optimal product mix from a single cutting program.

Evaluating log supply distributions is of increasing importance to forest companies, especially those purchasing timber on the open market through competitive bidding. Some companies are attempting to better understand their log supply through the analysis of inventory data from stands of timber (Jamieson, 1993). The benefits to knowing what a stand of timber contains before it is harvested, as well as knowing what product value can be derived from sawlogs of specific sizes and lengths, include better planning of production and more accurate bidding for open market timber.

Regression equations are often used to predict lumber recovery as a function of log size (Carino & Foronda, 1987). Much of this data is empirically gathered through extensive sawmill tests. Howard (1989) described a method of determining values for sawlogs using a theoretical approach (through sawmill simulation), rather than an empirical approach.

Log Scaling

Log scaling is the process of estimating the gross and/or merchantable (useable) volume of a log. As noted by Dilworth (1975), "Scaling is not a guess but a scientific estimate based on certain fundamental rules tempered with experience." Although used for many purposes, there are two major reasons for log scaling. The first, harvest control, allows the measurement, and subsequent control, of the volume of logs harvested from timber stands. The second, valuation, determines the value of harvested timber, based upon species, size and quality. This log value is then used to determine the payment, or stumpage, due to the timber owner, which in B.C. is usually the provincial government. It is also used as the primary criterion for deciding what processing facility (i.e. sawmill, plywood mill, pulp & paper mill, shake mill, etc.) should process the log. As described in Larsen (1986), log scaling has evolved from the mere counting of stumps to various combinations of individual stick and/or weigh scaling. The B.C. Ministry of Forests (MOF) is responsible for licensing scalers and for developing and maintaining scaling guidelines.

In coastal British Columbia, 100% stick scaling, in which every single log is individually assessed and measured by a qualified scaler (using a specially designed measuring stick), is still practiced by most operations. In the Interior of B.C., weigh scaling has become the dominant practice. Weigh scaling involves the piece by piece stick scale of randomly selected log samples from a population (stratum) to determine the volume to weight ratio and quality distribution. This information is then applied to all logs harvested (and weighed) from the population to determine the volume and value of the timber. This method is now being utilized by some coastal operations. Although considered by many to be the best method from a materials handling point of view (Larsen, 1986), many purchasers and log traders will not accept weight scaling due to the lack of comprehensive log grading. In addition, the remoteness of many logging operations, the diversity of timber being handled and environmental difficulties associated with excessively large log handling facilities (to be discussed later) make weigh scaling impractical and uneconomical to some operations. In this study, the information used to distinguish one log boom from the next was the log scaling data from 100% stick scaling.

Stick scaling involves both quantitative and qualitative measurements. The method of calculating the solid (cubic) volume of a log utilizes Smalian's formula. The value calculated for a given log using this equation is deemed the British Columbia metric scale for the log (B.C. MOF, 1995), and represents an estimate of the actual log volume. Smalian's formula is as follows:

$$V = \frac{A_1 + A_2}{2} \times L$$

where: V = volume of log in m3

A_1 = area of the small end of the log in m^2

A_2 = area of the large end of the log in m^2

L = the length of the log in m

The measuring procedure follows strict guidelines, which are outlined in the Forest Service Scaling Manual available from the B.C. Ministry of Forests. The Smalian formula assumes the log shape follows a paraboloid frustum (Marshall & LeMay, 1990). If necessary, the average of two or more measurements are taken to determine the diameter (inside bark) at each end. These diameters are the small end diameter (SED) and large end diameters (LED). Measurements are taken to the nearest centimetre of radius, called a rad. This provides diameter measurement precision of 2 centimetres. Provisions are also made to reduce the actual LED measure sufficiently to eliminate the flare, or butt swell, common on the butt (near the stump) of logs, but to still take into account the normal taper of the log. Lengths have traditionally been recorded to the nearest 0.2m. However, the 1995 B.C. scaling procedures now require length measurement to the nearest 0.1m.

The quantitative component of scaling is also impacted by volume deductions (through diameter or length reductions) for defects in the log such as rot. These defects and others are also used in the qualitative component of scaling, which determines the value of a log based upon quality (often called the grade), species, size, and length. Examples of these defects which impact log volume and/or grade include rot, the number, size, and location of knots, scarring from fire or disease, shake (natural splits inside the log), and number of annual rings per inch of diameter. For a thorough explanation of log scaling procedures, refer to the B.C. Forest Service Scaling Manual.

Log Sorting

After timber is scaled to determine its size and value, it is sorted into groups and routed to the appropriate manufacturing facility. The diversity of the forests on the B.C. Coast, and the great variety of products which can be produced from them creates the need for many different sorts. Sorting usually follows a hierarchy according to importance, in which logs are grouped according to species, then quality, then size. Logs are sometimes sorted according to the log grading criteria used by the MOF. However, many companies use their own species, quality, and size criteria, usually based upon the flexibility of their processing operations and size of their sorting operations.

One possible method of reducing diameter variability in log booms would be to increase the number of diameter sorts used at log dumps or sort yards. This poses both economic and environmental limitations. Many log dumps do not have the capacity on land, due to geographical constraints, or on the water, due to geographic and environmental constraints, to maintain a large number of sorts. Studies have shown that more sorts require more booming area and result in lower productivity and higher costs per m^3 (Sinclair, 1980). Higher costs can be offset through higher volume throughput, but this also results in increased area requirements and may not be feasible given harvest rate limitations.

Areas on the coast suitable for large sorting operations are often shallow/intertidal waters and natural estuaries. The recommendations, from a large environmental review in 1980 of coastal log handling impacts on the environment, clearly indicate that these locations are extremely sensitive and should be preserved (Duval, 1980). The use of deep water sites was encouraged, but they are often limited in size due to topographical constraints. As a result, efforts to increase the number of sorts at many logging sites would be difficult to achieve.

Another method of increasing the ability to sort logs by diameter class is to install a log sorting and/or merchandising system at the sawmill site. This alternative is also subject to many constraints on the coast of B.C.. Sawmills are often located in areas which are becoming increasingly used for other purposes: recreational, residential, environmental. Land availability for merchandising systems and subsequent log storage is either completely unavailable or extremely expensive (COFI steering committee, 1981). Although some mills on the lower mainland have found room for this, it is doubtful that many others can do the same. Many other mills could probably create more storage area through a costly landfill project, but the environmental damage would alone prevent this from becoming an option.

These limitations make it difficult for some operations to achieve comprehensive log sorting. This results in log sorts comprising large diameter ranges. In addition, log booms arriving at a mill are stored (subject to time limits) until needed. The entire log boom is then consumed by the sawmill. While these constraints are not inherently bad, they do make log booms more susceptible to large differences in SED and length distributions, and make it virtually impossible for sawmills to re-sort logs before consumption.

Value Recovery

The value of the lumber recovered from a given supply of logs is a major factor in the economic viability of an operation. Lumber value is measured using two different but not mutually exclusive ways: volume and grade. Lumber grade is determined by numerous factors (defects) similar to those used to grade logs, such as rot, shake, the size, number and location of knots, number of annual rings per inch of size, and wane (roundness of the lumber edges). The fewer the defects, the higher the lumber grade, and consequently the more the lumber is worth. Many coastal B.C. sawmills consume large old growth timber which contains a large percentage of defect free, or "clear" fibre. In order to obtain the highest value recovery from the log, these mills focus on grade recovery by converting as much of the clear fibre into lumber as possible.

On the other hand, some coastal B.C. and most interior B.C. sawmills utilize smaller, merchantable grade logs, which contain very little clear fibre and are virtually homogeneous in quality. The majority of lumber produced by these mills is of the same grade. In order to maximize value recovery, these mills focus on the amount of lumber, or volume, recovered from logs. In addition, these mills try to produce as much lumber of specific sizes as possible, since the size of the lumber has a substantial impact on its value.

These objectives are achieved by sawing lumber according to cross-sectional patterns which are fit within the circular shape of different sized sawlogs (i.e., cutting patterns). The various cutting patterns reflect the product lines produced by each cutting program followed by a sawmill. Each cutting program has its own unique set of cutting patterns. Cutting programs differ by the products produced, whereas cutting patterns differ by how products are cut from a log. Cutting patterns change constantly with both the size of the log and the relative value of the possible products. An example of this is Figure 3, which shows the same sawlog cut according to three different cutting patterns, with all the products coming from the same cutting program. The pattern producing the highest overall financial return, in terms of lumber value less associated costs, will most likely be used.

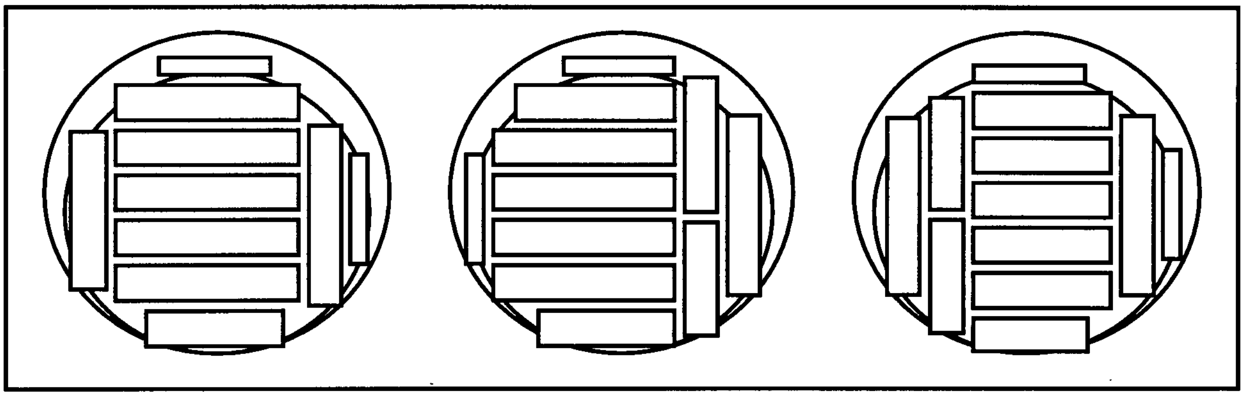


FIGURE 3. DIFFERENCES BETWEEN CUTTING PATTERNS.

Determining the cutting patterns to follow when cutting up sawlogs has advanced from pencil and paper sketches through to the use of computer programs. As shown in Figures 2 and 3, for any given sawlog diameter and length, each cutting program will produce a different cutting pattern with a different level of lumber recovery due to the size differences between the lumber products in each program. This translates into a different value of products cut from the sawlog.

Sawing Simulation

Determining the resulting volume of lumber for any given sawlog can be achieved both empirically and theoretically. Empirical methods involve obtaining several sample sets (one for each cutting program) of sawlogs from all relevant diameter and length classes. The lumber produced by each sawlog is then tallied as it is processed. A simpler, more cost effective and flexible method is to use a sawing simulation program to determine how much lumber can be recovered. Simulation models are used by the sawmill industry in a variety of applications including: management planning, engineering and design, automated control, and evaluating sawmill efficiency (Lewis, 1985). Two well known simulation models that are used extensively are SAWSIM™ (Leach, 1990) and Best Opening Face (Hallock and Lewis, 1971). The objective of a simulation procedure is to predict the lumber recoverable from a sample of sawlogs, represented by geometric shapes, by "sawing" them one at a time. When repeated using different lumber products (cutting programs), the lumber recovered from each alternative scenario can be predicted.

III METHODS

Although some of the theory and procedures developed by the previously discussed works was incorporated, this research differs in several ways.

1. The focus was on alternative cutting programs at a single facility, not alternative manufacturing facilities.
2. A constantly changing log supply distribution rather than a stable long term log distribution was considered.
3. Log boom scaling data was utilized, rather than x-ray scan data or cruise data.
4. A heuristic, rather than linear programming, was used to make allocation decisions, and the aim was to provide a small scale, practical tool used by one sawmill rather than an entire corporation.

By combining scaling information with bucking strategies, sawlog breakdown simulation, grade out-turn information, production costs, and sales information, a method for determining the suitability (or value) of a log boom for a particular cutting program was developed. For clarity, this method will be described in several distinct steps:

1. Acquisition and analysis of log scaling data.
2. Conversion to sawlog data (log bucking simulation).
3. Cutting program simulation.
4. Log boom valuation.
5. Log boom allocation.

Figure 4 presents a simple graphical outline of this method. In this section, the assumptions, or conditions, necessary for this method to work are stated, followed by a separate description of each step.

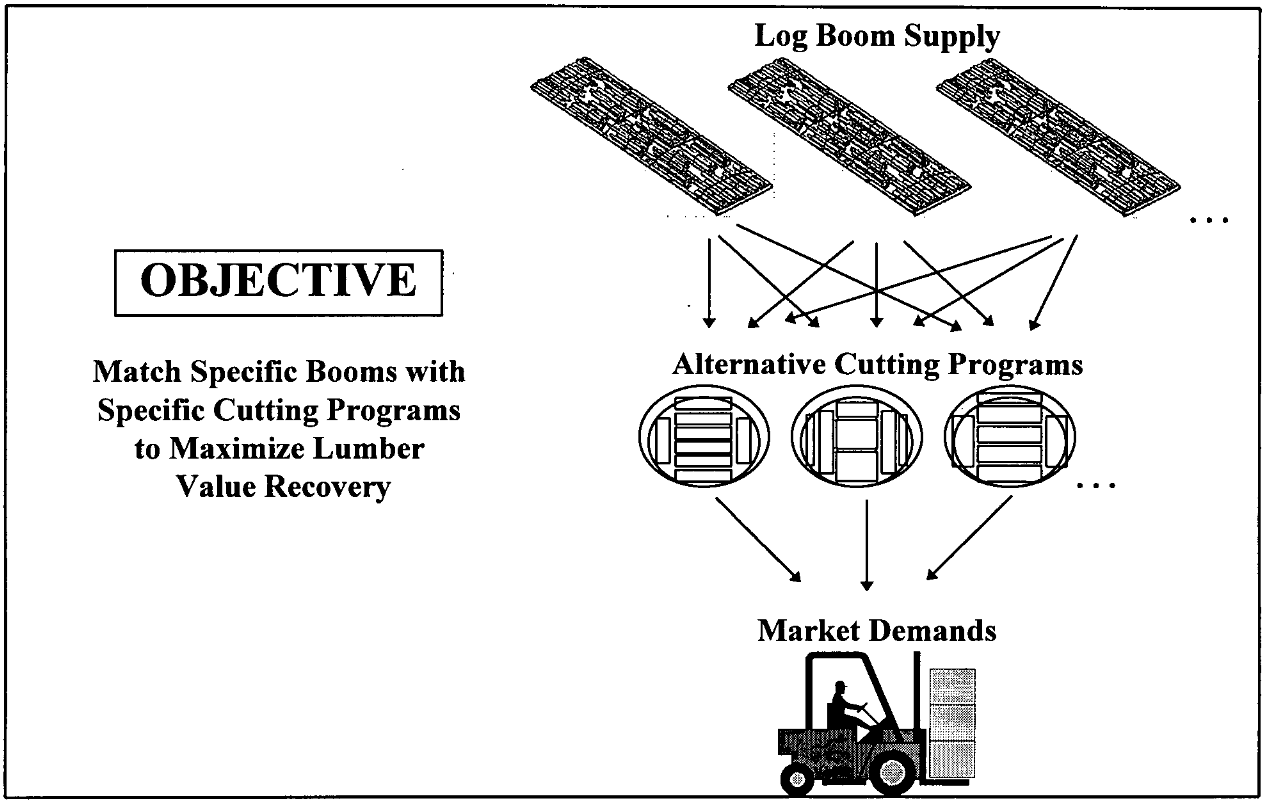


FIGURE 4 - METHOD

Assumptions

Application of this method to an actual situation relies upon several operating conditions. The primary assumptions, which were outlined in the introduction, both involve a reliance on variability. This variability must occur in the form of log diameter/length distributions as well as value recovery from different sizes and lengths of sawlogs for different cutting programs. The other assumptions of this method were as follows:

1. Homogeneity in log grade.

   The grade (quality) of the log supply must be considered homogeneous. This assumption has important ramifications. First, the same traditional lumber quality distributions (grade out-turns) achieved by an operation for each cutting program can be applied to the predicted lumber sawn from every log boom. Second, the scaling data can be considered to represent an accurate measure of the dimensions of each log in the log booms, as very few deductions (diameter or length) for defect are required for this log grade. It should be noted that these measurements are still subject to the measurement precision of the scaling stick (SED and LED) and measuring tape (length).

2. Adherence to bucking guidelines.

   The conversion of logs into sawlogs must accurately reflect actual mill procedures.

3. Sawmill simulation accuracy.

   The simulation of sawlog breakdown must accurately reflect the actual breakdown and recovery of lumber from specific log diameters and lengths.

STEP 1 - Acquisition and Analysis of Log Scaling Data

The presence of substantial variability in log size among log booms meeting the same sort criteria is a key requirement for the successful application of this method. If all the booms had the same distribution of log sizes, there would be no benefit to valuing booms for alternative cutting programs, as random selection would be just as effective. The log size variables of diameter and length could both be used to distinguish booms from one another. However, the majority of logs are bucked to the longest possible length (to improve handling, sorting and processing ease and productivity), and as often as possible to certain specific lengths (to minimize waste and produce preferred lumber lengths). This similarity negates most of the effect log length could have on log size variation. Variability in log size among log booms is therefore almost entirely dependent upon differences in log diameter distributions. Thus, log small end diameter (SED) was chosen as the delineating criterion.

Log diameter is dependent upon the size and/or quality of timber being harvested. Because log booms usually come from different logging camps (operating areas) and thus different timber stands, the SED distributions can be very different among booms of the same sort criteria. It is clear from Figure 5 that different long log diameter distributions will result in different sawlog diameter distributions. For example, boom 2 will produce a larger proportion of small diameter sawlogs than booms 1 or 3 because there is a larger proportion of small diameter long logs in the boom.

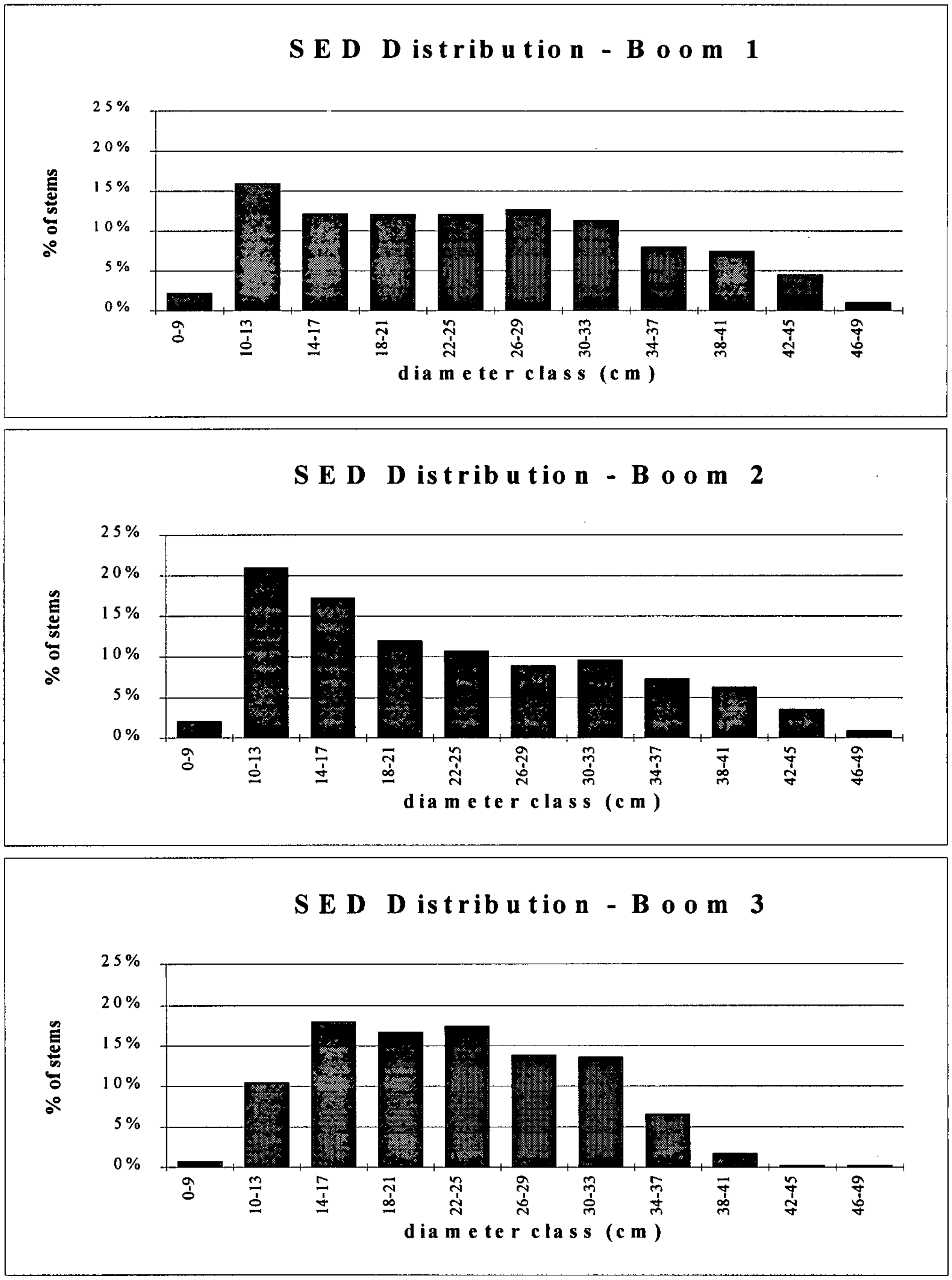


FIGURE 5 - SED DISTRIBUTION VARIATION

Thanks to recent advances in computer technology, data to determine these distributions can be readily available from the log scaling information gathered on every log in every boom. These log scaling data (Table 1), which include diameter, length, species and grade, are usually available several weeks prior to the use of a boom and could be accessed via computer.

Log #	Length(m)	Top diam(m)	Butt diam(m)	Vol(m3)	sort code	spec/grade
1	6.2	0.16	0.20	0.160	24	BAJ
2	5.6	0.18	0.22	0.178	24	BAJ
3	8.0	0.14	0.20	0.187	24	BAU
4	12.4	0.16	0.24	0.405	24	BAJ
5	7.0	0.20	0.24	0.268	24	HEJ
6	11.2	0.22	0.32	0.663	24	HEJ
7	10.0	0.26	0.36	0.774	24	BAJ
8	10.0	0.32	0.40	1.030	24	HEJ
9	12.6	0.36	0.44	1.599	24	HEJ
10	6.6	0.40	0.48	1.012	24	HEI

TABLE 1 - EXAMPLE OF LOG BOOM SCALING DATA

These data can then be analyzed to assess whether significant variability exists among log booms. In the situation where data on every log are available, each boom can be considered a population. Thus statistical tests are not appropriate, as all possible data are available. Whether the differences between distributions are substantial enough to make the allocation portion of this method effective becomes apparent from subsequent analysis. The case study scenario in this research used comprehensive (100%) stick scaling, in which every log is individually stick scaled and the data recorded.

If comprehensive stick scaling is not conducted (i.e., only representative samples are stick scaled) the method can still be applied. For this situation, a sampling scheme must be used to determine the diameter/length distributions of specific log booms, and statistical tests must be performed to test for differences in the underlying population distribution of logs in the booms.

If statistical testing is required, the r x c contingency tables using the χ^2 approximation test are particularly suited to this analysis. This test checks whether or not the probabilities of c classifications of data vary among r populations (Conover, 1980). With respect to this method, the null hypothesis for this test can be restated as "the distributions of log SED's do not vary from boom to boom".

STEP 2 - Conversion to Sawlog Data

Once log scaling data has been gathered and evaluated, these logs must be converted into simulated (theoretical) sawlogs. Sawlogs, essentially shorter segments of logs, are actually processed by sawmills into lumber. To determine the volume and value of lumber recoverable from a given log boom, each log in the boom must be cross-cut into a number of sawlogs. This conversion process, called log bucking, can be done several ways depending upon the type of bucking system used by the mill under evaluation.

In the case of a manual bucking system, a set of bucking rules is followed by an operator, in which the sawlog lengths are specified for each log length. This is shown in Figure 6, where a 12.6m log is bucked into three 4.13m sawlogs. If a computerized bucking system is in place, a computer program, not a person, determines what lengths of sawlogs are cut from each log. The computer program requires a table of sawlog segment values. After obtaining a scanned image of a log, the computer determines the combination of sawlog segments which will result in the highest value being recovered from the log. If a computerized log bucking system is being used, the next step in this method, step 3, must be conducted before this step, because log bucking cannot occur unless the values of all the sawlog segments are known. Step 3 calculates the value of all applicable sawlog diameters and lengths (segments), for each cutting program. These values would then be entered into the computer program to "drive" the bucking solutions.

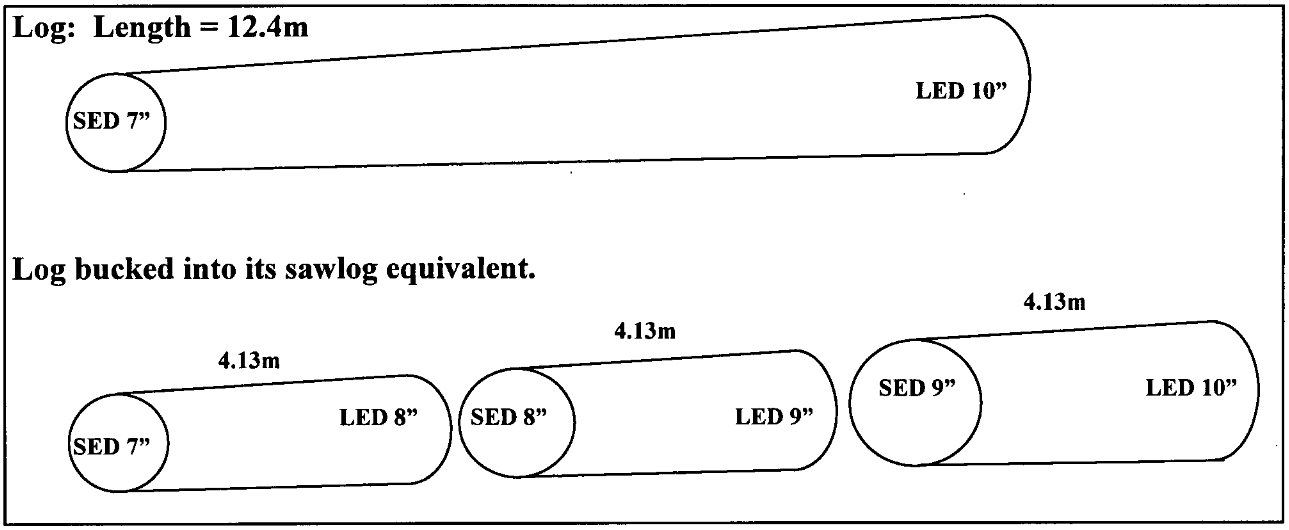


FIGURE 6 - LOG BUCKING PROCESS

However, scanned images of logs are not available from log scaling data. Diameter information is available only at each end of a log. A procedure is required to predict the diameter of logs at points between the ends in order to predict the SED's and LED's of the theoretical sawlogs bucked from them. In the case of a computerized bucking system, these diameters can be based upon scanned images of actual logs with the same log SED, LED, and length combination. When only a manual bucking system is available, the problem becomes more difficult. The scaling procedure used in B.C. provides three measurements of size, namely small end diameter, large end diameter, and length. This amount of data should be considered the minimum requirement for using this method. This information will provide an estimate of the taper of a log (the % change in diameter per unit of length), which can then be used to estimate the diameters of the resulting sawlogs.

Substantial research has been done on determining the taper of trees (Demaerschalk & Kozak, 1977; Grosenbaugh, 1966; Kozak, 1988). However, this research was focused on estimating the taper and volume of standing trees. The equations developed can predict diameter inside bark (d) at any point along the length (h) of the bole, given the diameter at breast height (DBH) and total height (HT) (James & Kozak, 1984). When logs are scaled, they often do not represent whole trees, as trees are usually cut into several sections (logs) soon after felling to facilitate easier handling and transport. As a result, these taper equations are not applicable. There are two main options available at this point. The first would be to measure in detail a large sample of logs from the log supply either by hand or using scanners. These results could then be used to predict the taper of the scaled logs much the same as would be done if a computerized bucking system was available. The second option is to make some general assumptions about log taper based upon knowledge of the log supply being processed, and then use these assumptions to predict the diameter at points between log ends. The case study analysis presented in Section IV uses the second option.

STEP 3 - Cutting Program Simulation

Determining the value of products obtainable from given sizes of sawlogs for several different cutting programs is of central importance to this study. Empirical methods involve obtaining samples of sawlogs from all relevant diameter and length classes, sawing them into the appropriate products, and tabulating the volume and value recovered. Using this method, a given sawlog sample can only be sawn once, making it impossible to determine the best cutting pattern to use on each sawlog for several different cutting programs. The simple, cost effective and flexible alternative is to use computerized sawlog breakdown software to determine the cutting patterns and resulting lumber recovery for any given sawlog and for all the different cutting programs. Sawing simulation has long been considered an efficient and accurate method of determining what products are cut from a given sawlog (Hallock and Lewis, 1971; Howard, 1989 & 1993; Maness and Adams, 1991).

Sawing simulation requires a physical representation of log shape. Many studies have been done using truncated cones to represent sawlogs. While this may have been necessary at the time due to limitations in scanning equipment and simulation software, it is now possible to gather three dimensional scanned images of sawlogs. These images provide a far more accurate representation of actual lumber recovery, as recovery losses due to defects, sweep, and positioning are incorporated into the analysis. (Wang et al., 1992) Thus, it is recommended that actual scan data be utilized for the sawing simulation to improve accuracy. (Maness and Donald, 1994) In addition, the same sawlog sample should be used by each program, further reducing bias resulting from different sawlog samples, and reducing the number of samples required.

STEP 4 - Log Boom Valuation

Once all cutting programs have been simulated, each log boom is valued by calculating the estimated value for each alternative cutting program. The best measure of value to assign to a boom is the net earnings per m^3 of log achievable from the sawing of the log boom. Using this approach, production speeds, manufacturing and handling costs, and by-product revenues can be incorporated into the procedure. Thus, the value of each log boom to an operation is known. This knowledge forms the basis for deciding which cutting program should be applied to the boom. It also provides a production forecast for the boom. The marketing department will have an excellent idea of what will be cut out of the boom before it is actually processed. This facilitates a pro-active rather than reactive approach to determining what orders can be taken and how long it will take to produce them.

STEP 5 - Log Boom Allocation

As mentioned in Step 4, boom valuation provides concrete information on the value of alternative cutting scenarios. Thus, sawmill personnel may be able to assign booms to specific cutting programs, rather than just randomly consume them, to achieve an overall net increase in earnings. This requires the valuation of log booms as they arrive at the operation and consideration of the future production requirements of the sawmill.

The opportunity for this process to occur can be illustrated by the following example. Suppose a sawmill has 20 log booms in the water and lumber orders which require lumber to be cut from two different cutting programs. Should the mill just randomly consume booms one after the other for each program, or should it first valuate each boom for the two cutting programs and then specify which booms to process under each cutting program? If a net overall increase in earnings can be achieved, the second option should be pursued. This example is similar to the situation which will be evaluated in the case study described in the next section.

IV CASE STUDY

In order to clearly show how the method developed by this research can be put into practice, a case study operation is used as an example. This operation, subsequently referred to as the "test sawmill", is that of a coastal B.C. small log sawmill which processes merchantable grade Hemlock (*Tsuga heterophylla* [Raf] Sarg.) and Balsam (*Abies amabilis* [Dougl.] Forbes) sawlogs from 10cm (4") to 43cm (17") in small end diameter. Log booms each containing up to several thousand logs arrive constantly throughout the year. With few exceptions these booms are processed by the test sawmill within three to four weeks. Each boom is specific to one of up to a dozen logging camps, and thus can be usually be traced to a specific stand of timber. Every log is hand scaled (100% stick scaling) before it is placed in a boom. These data are recorded via a hand held computer keypad and is usually available as soon as the boom is made. Due to transport and storage time, this log scaling data is usually available for analysis at least one week prior to a boom's consumption.

The test sawmill utilizes manual bucking, in which an operator bucks the logs into sawlogs according to a set of bucking rules. Logs are fed both top (smaller end) and butt (larger end) first to the sawmill. The primary breakdown unit consists of a QUAD (4-saw) bandmill with side chipping heads and a sharp chain transport system. The sawing is determined by a computerized sawlog breakdown system which uses two axis scan data gathered on each sawlog. Downstream processing is carried out by a gang edger, a manual shifting edger, two board edgers, and a horizontal resaw. The production from three different cutting programs used by the test sawmill, called CP 1, CP 2 & CP 3, will be simulated.

Consistent with the method developed, various raw data from this operation will be introduced at each of the five distinct steps. These data include:

1. Boom scaling data.
2. Bucking rules data.
3. Two axis sawlog image data.
4. Cutting program data.
5. Mill production data.
6. Lumber grade out-turn data.
7. Lumber price data.

Due to the proprietary nature of the data to the test sawmill, some data will not be presented in its raw form. However, the key results of all analysis based upon this data will be presented in their entirety.

Acquisition and Analysis of Log Scaling Data

Log boom scaling data was obtained on 72 log booms which arrived and were consumed during a three month period by the test sawmill. These booms contain between 1000 and 4000 logs and represent 100% of the log population. Since data on the entire population were available, statistical sampling to determine the presence or absence of significant variation differences among the booms was not appropriate. However, in the initial stages of this project it was crucial to establish the presence or absence of variation. For this reason statistical tests were conducted, in which each log boom was considered to be a simple random sample from an independent population (timber stand) of logs.

Before conducting any tests, a series of Microsoft Excel© macros were written to access the data for each boom, extract the small end diameter data, and sort this data into a frequency distribution with 4cm diameter classes. This information was then used to graphically assess the SED distributions of the log booms. Figure 7 shows the SED distributions of two booms from the sample of 72. The percentage of logs in each diameter class is shown, not the actual number, since each boom contains a different number of logs. It is clear from these graphs that substantial variation in the distributions is present. However, statistical tests were still conducted to determine if the underlying population distributions are likely different.

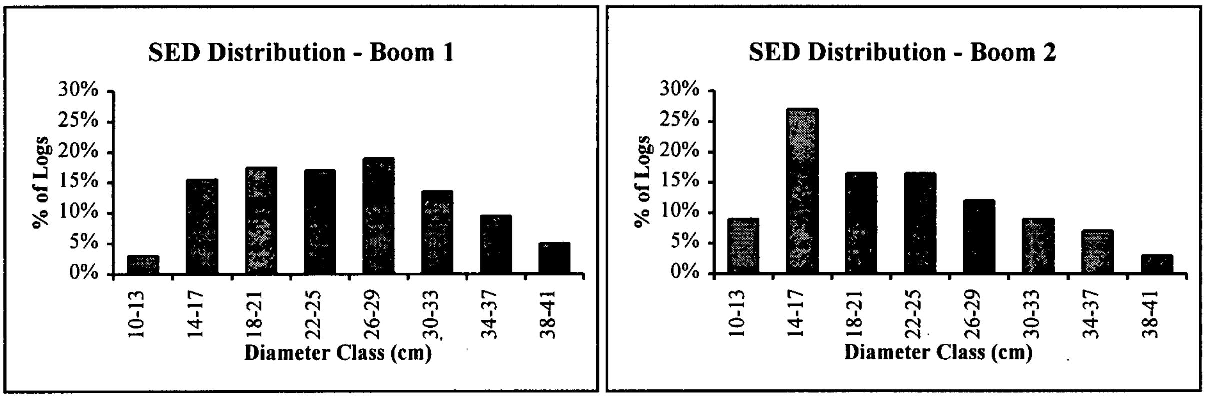


FIGURE 7 - SED DISTRIBUTIONS OF TWO TEST SAWMILL LOG BOOMS.

The r x c contingency tables using the χ^2 approximation test are particularly suited to this analysis. The test procedure, which is outlined in detail in Appendix I, followed the guidelines specified in Conover (1980). Table 2 summarizes the results of the analysis conducted on all the booms and for the booms of each logging camp. Since the potential benefits of log boom allocation are contingent upon variability being present among the log booms, it was crucial to minimize the probability of committing a type I error, in which a true null hypothesis is falsely rejected. For all tests, α was set at 0.01. The following hypothesis was tested on all the log booms for which data was gathered:

H_0: All 72 log booms have the same small end diameter distribution

H_1: At least one pair of the log booms have different small end diameter distributions

Camp code:	All	A	B	C	D	E	F	G	H	I	J
r (# booms)	72	5	13	20	6	5	4	3	4	6	6
χ^2	4441.5	164.9	299.8	300.2	649.8	54.3	50.9	25.1	192.0	98.9	170.4
χ^2crit	573.3	48.3	117.1	173.9	57.3.	48.3	38.9	29.1	38.9	57.3	57.3
Decision	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Accept	Reject	Reject	Reject

TABLE 2 - RESULTS OF R X C CONTINGENCY TESTS ON SED DISTRIBUTION VARIABILITY.

Unfortunately, rejection of the null hypothesis only indicates that at least one pair of booms is different, and does not identify which pairs differ. To improve the resolution of this analysis, the 72 booms were subdivided into groups based on the ten different logging camps from which they came. Although each boom is considered to be a sample from a separate population, booms from the same logging camp may have similar SED distributions due to similarities in stands of timber. Thus ten separate analyses tested the following hypotheses:

H_{oq}: *All r_q log booms from camp q have the same distribution*

H_{1q}: *At least one pair of the r_q log booms from camp q have different distributions*

where: r_q = the number of booms from camp q, and q = 1...s, with s = 10.

Several conclusions were drawn from these results. Of all ten logging camps tested, only camp G failed to reject the null hypothesis. Thus for this camp, one can conclude that the populations from which each of these three sample booms came from are actually all from one "super" population, or at least three different populations which likely have identical small end diameter distributions. For the other nine camps, one can conclude with 99% confidence that at least one pair of the booms in each camp has different small end diameter distributions. One cannot state that specific booms from one logging camp have different distributions than booms from other camps, because a "between camp" analysis was not conducted. However, the results clearly showed that significant small end diameter distribution differences (with 99% confidence) exists among the log booms in this analysis. This suggested that value recovery benefits from valuing test sawmill logs booms for alternative cutting programs may be achievable.

Conversion to Sawlogs

Once the presence of variation in diameter distributions among log booms was verified, the distributions of theoretical sawlogs resulting from each boom was required. This was done as accurately as possible given the limitations in data and measurement accuracy. The use of log scaling data limits the application of this method to log supplies in which the dimensional stick scales of logs closely resemble their actual physical size. As shown in Figure 8, the merchantable grade Hemlock and Balsam logs used by the test sawmill primarily produce sawlogs which are knotty and sound (no rot).

FIGURE 8 - EXAMPLE OF MERCH SAWLOG QUALITY

Logs are bucked by an operator according to pre-determined bucking rules developed and maintained by the test sawmill. Specific sawlog lengths, including trim allowances, are: 3.14, 3.74, 4.11, 4.36, 4.97, 5.58, and 6.19 metres. The test sawmill uses two different sets of bucking guidelines, subsequently referred to as the "short" and "long" programs. Cutting programs (CP) 1 & 2 use the short program, while CP 3 uses the short program on very small diameter logs, and the long program on the rest. Table 3 provides a sample of the bucking rules used. The bucking of each log boom was simulated twice, once for each set of rules. In order to satisfy the objectives of accurate modeling of the bucking process, several parameters needed to be determined. These included the proportion of logs fed top first vs. butt first into the sawmill, the bucking rules followed for each log length entering the mill, and the log taper used to predict the diameters of the sawlogs bucked from each log.

	SHORT GUIDELINES (CP 1 & CP 2) Sawlog Lengths (m)				LONG GUIDELINES (CP 3) Sawlog Lengths (m)		
Stem Lengths (m)	1	2	3	4	1	2	3
...							
6.0	6.00				6.00		
6.2	6.20				6.20		
6.4	3.14	3.26			3.14	3.26	
6.6	3.14	3.46			3.14	3.46	
6.8	3.14	3.66			3.14	3.66	
...							
11.0	4.11	3.14	3.75		5.58	5.42	
11.2	4.11	3.14	3.95		5.58	5.62	
11.4	4.11	3.14	4.15		5.58	5.82	
11.6	4.11	3.14	4.35		5.58	6.02	
11.8	4.11	3.14	4.55		6.19	5.61	
...							
14.0	4.11	4.11	5.78		4.97	4.97	4.06
14.2	4.11	4.11	5.98		4.97	4.97	4.26
14.4	4.11	3.74	3.14	3.41	5.58	4.36	4.46
14.6	4.11	4.11	3.14	3.24	4.97	4.97	4.66
14.8	4.11	4.11	3.14	3.44	4.97	4.97	4.86
...							

TABLE 3 - SAMPLE OF TEST SAWMILL BUCKING RULES

Logs can arrive at the bucking station either top first or butt first. At the test sawmill this does not affect the lengths of the resulting sawlogs. However, it does affect the SED and LED of these sawlogs due to the increasing (top first) or decreasing (butt first) taper of a log as it is cut. The test sawmill does not have the ability to purposely orient logs in a particular direction, thus logs arrive in a random fashion in either orientation. One could presume that this would mean a long term 50/50 split between top and butt first. This was verified using cluster sampling for proportions. Two randomly selected monitoring periods, representing 10% of total daily production time, were selected each day for six days. Results indicated that the orientation ratio, expressed as percentage top first, was not significantly different from 50% ($\alpha = 0.05$). Appendix II contains the details of this study.

The sawlog length combinations, or bucking rules, used for each of the two bucking programs were based upon the bucking rules used by the test sawmill. As shown in Table 3, the rules followed by the bucking operators are explicitly written down. The short program is aimed at maximizing the percentage of 4.0m (13') sawlogs produced. The long bucking program follows the short guidelines for sawlogs under 18cm (7") in SED. Above this diameter, however, the objective changes to producing sawlogs greater than 4.0m in length.

The final requirement for determining theoretical sawlog distributions involved predicting the SED's and LED's of the sawlogs produced from a given log. Logs less than 6.0m in length required no bucking, and thus the log SED and LED were used. However, the majority of logs were between 6.0m and 12.6m, with occasional logs up to 17.0m in length. These logs required the prediction of the resulting sawlogs' SED's and LED's. As previously mentioned, the taper curve of trees has been studied in detail, but research has focused on developing complex taper equations which can predict tree diameter at any point along the tree length. As shown in Figure 9, these equations are required because trees are neiloid close to the ground, conical (linear taper) close to the top, and paraboloid at the middle (Kozak, 1988).

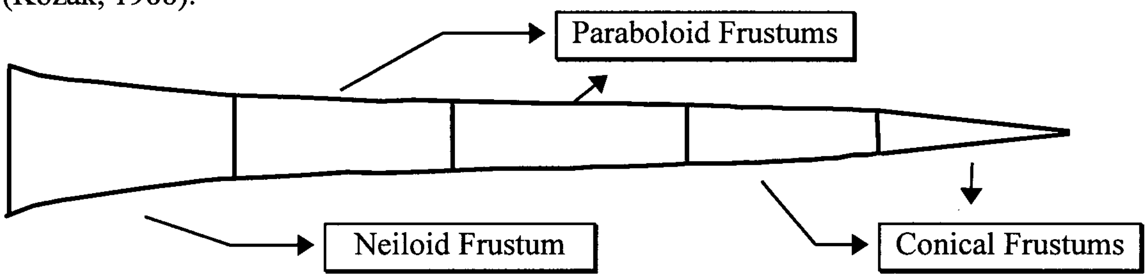
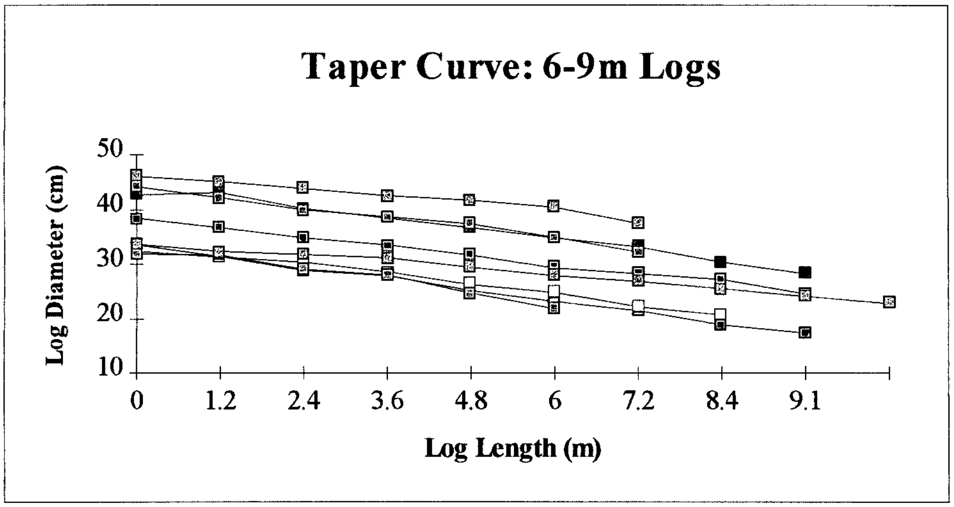
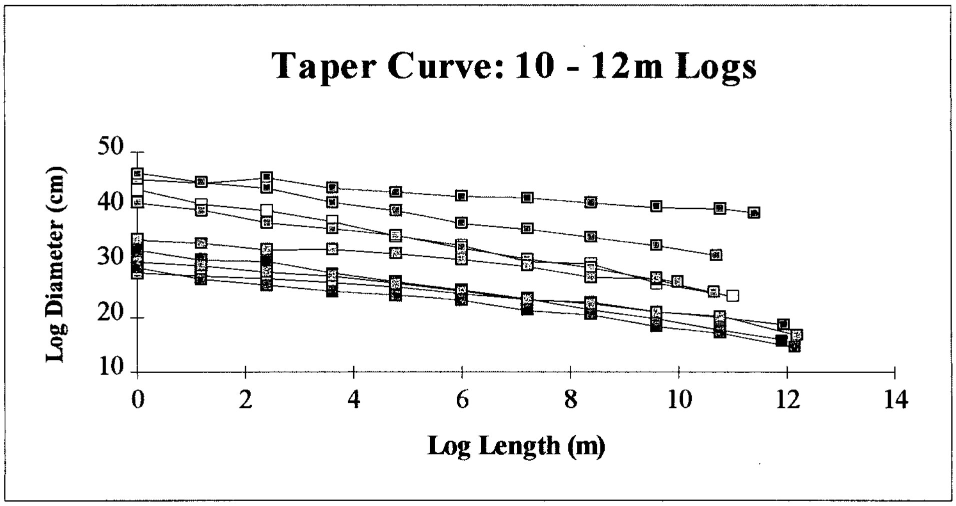


FIGURE 9 - GEOMETRIC TREE BOLE SHAPE

The merchantable grade logs consumed by the test sawmill come primarily from the tops of large old growth trees as well as from larger sections of smaller, younger trees growing beneath the main canopy of timber or in young stands. Errors in estimating the volume of logs from the lower-middle to upper bole of trees are generally small because of the greater uniformity of taper in these sections. (Patterson et al., 1993) For these reasons, the decision was made to use constant taper to predict diameter as a function of log length rather than develop a taper equation or conduct a large detailed log measurement study, two undertakings that would be substantial research projects themselves.

Further justification for this assumption, however, was gained from the analysis of the taper exhibited by a sample of Hemlock logs of similar grade to the test sawmill's log supply. These logs had diameter measurements taken at one foot intervals along their lengths. Figure 10 presents the results, which show virtually constant taper throughout the length of the log. Small "flares" in diameter at the butt were noted on some of the longer logs, but this flare is accounted for in the log scaling measurement process.





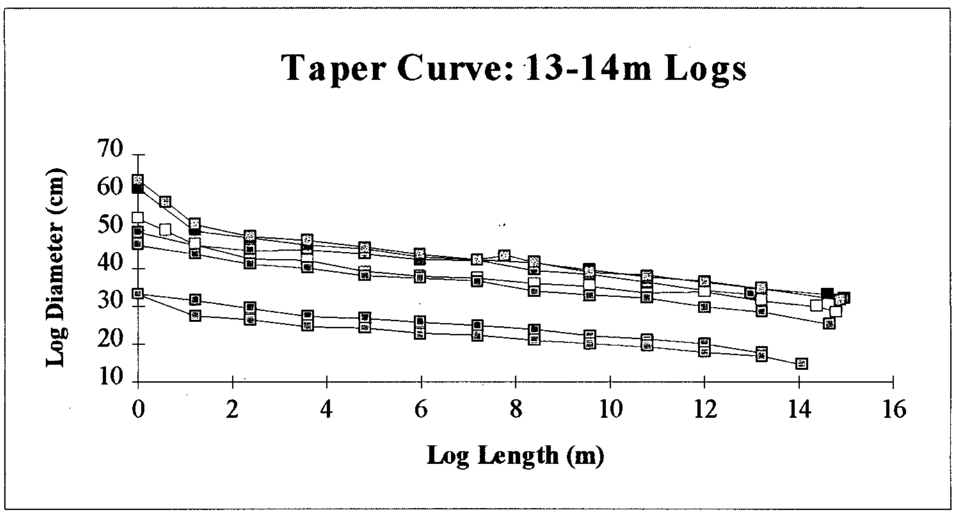


FIGURE 10 - SAMPLES OF COASTAL HEMLOCK LOG TAPER

With this information in hand, a log bucking program was written in C++ to convert a given log boom into theoretical sawlogs according to the bucking guidelines and each log's taper. The program bucks logs one after the other and tabulates both the number and volume of resulting sawlogs. During the development of this conversion process, a serious problem was detected. The problem resulted from the reclassification of diameter data from metric units (centimetres) to imperial units (inches). B.C. scaling data is recorded to a precision of 2 cm of diameter, and the sawlog diameter classes are based upon the industry standard format of 1" ranges. Because the 1" class (2.54cm) is very close to the measurement precision of 2 cm, severe bias will occur in the resulting sawlog distributions that are classified according to 1" diameter ranges. This problem is best explained by Columns 1 & 2 in Table 4, which show that when the metric diameter is reclassified into imperial units, the 18cm (7"), 28cm (11"), and 38cm (15") diameter ranges are twice as likely to be chosen over the other ranges. This would result in distributions which were incorrectly biased towards 7", 11" and 15" diameter sawlogs.

This problem was solved by assuming the scaled diameter measurements actually represent a classification of log diameters uniformly distributed throughout the range of each 2 cm class. Obviously every log in the 0.16m SED class does not have a SED of 0.16m, but rather a SED somewhere between 0.15m (7.5 rads) and 0.17m (8.5 rads). These diameter ranges are shown in columns 3 & 4 of Table 4, and are based upon the very specific rounding rules used by the Ministry of Forests (B.C. MOF, 1995). This assumption of uniform distribution was used by Husch, Miller, and Beers (1982) for stand table projection.

Random numbers were used to better reflect the true variability in log diameter measurements and eliminate the bias that occurs when the diameters are re-classified according to 1" diameter increments. As shown in Table 4, the product of a random number (between zero and one) and the diameter range was added to the minimum diameter possible in the range to produce a new diameter. This procedure was used to assign unbiased, theoretical diameters (both SED and LED) to every log. Although it can be argued that this procedure "invents" precision which isn't really there, it should be clear that the purpose was only to eliminate the bias which results from reclassifying metric units to imperial units.

Original Diam (m)	**Original Diam (in)**	**Range (radius rads)** min.	max.	**Range (inches)** min.	max.	Difference (inches)	Random Number	**New Diam (in)**
0.10	3.9	4.51	5.49	3.55	4.32	0.77	0.622	4.0
0.12	4.7	5.50	6.50	4.33	5.12	0.79	0.831	5.0
0.14	5.5	6.51	7.49	5.13	5.90	0.77	0.339	5.4
0.16	6.3	7.50	8.50	5.91	6.69	0.79	0.809	6.5
0.18	**7.1**	8.51	9.49	6.70	7.47	0.77	0.543	7.1
0.20	**7.9**	9.50	10.50	7.48	8.27	0.79	0.354	7.8
0.22	8.7	10.51	11.49	8.28	9.05	0.77	0.506	8.7
0.24	9.5	11.50	12.50	9.06	9.84	0.79	0.716	9.6
0.26	10.2	12.51	13.49	9.85	10.62	0.77	0.001	9.9
0.28	**11.0**	13.50	14.50	10.63	11.42	0.79	0.224	10.8
0.30	**11.8**	14.51	15.49	11.43	12.20	0.77	0.762	12.0
0.32	12.6	15.50	16.50	12.20	12.99	0.79	0.946	13.0
0.34	13.4	16.51	17.49	13.00	13.77	0.77	0.910	13.7
0.36	14.2	17.50	18.50	13.78	14.57	0.79	0.895	14.5
0.38	**15.0**	18.51	19.49	14.57	15.35	0.77	0.926	15.3
0.40	**15.8**	19.50	20.50	15.35	16.14	0.79	0.472	15.7
0.42	16.5	20.51	21.49	16.15	16.92	0.77	0.493	16.5
0.44	17.3	21.50	22.50	16.93	17.72	0.79	0.277	17.2

TABLE 4 - DIAMETER OFFSETTING PROCEDURE

After the new SED and LED for a log were determined, another random number decided whether the log will be bucked top or butt first. The bucking rules were then followed by accessing a lookup table, and the resulting sawlogs were classified into a diameter/length matrix consisting of thirteen 1" SED classes and 7 length classes. Sawlogs

43cm (17") and larger in SED were recorded, but were not included in this analysis, as they are diverted to other facilities by the test sawmill. Both the number and volume of sawlogs were categorized for the two bucking programs. The sum of the sawlog volumes from each log were made to equal the scaled log volume contained in the scaling data, as the scaling volume is the volume on which log costs are paid and lumber recovery is measured. Figure 11 shows graphically the results of converting a boom's log SED distribution to its predicted sawlog SED distribution.

Despite these attempts to ensure accurate modeling, the conversion process was not without error. Log scaling data provides no information on log sweep (curve). Logs with substantial sweep are often bucked to shorter lengths in order to minimize recovery losses when the sawlog is processed. It was estimated by personnel at the test sawmill that sweep sufficient to alter bucking patterns occurred in less than 5% of logs. A very small percentage of logs may incur handling or debarking breakage en route to the bucking station at the test sawmill. This may result in these logs being bucked to different lengths. Log breakage that occurred after the point of scaling was estimated to occur in less than 0.5% of logs. Overall, the percentage of logs which may not be bucked into sawlog lengths consistent with the test sawmill's bucking rules was considered to have negligible impact on the results of this study.

The use of random numbers to better reflect the bucking process did introduce some variability, as the same boom can be bucked an infinite number of times by the computer program, and each resulting sawlog distribution would be slightly different. However, the number of logs (1000-4000) in the booms result in these distributions remaining virtually identical.

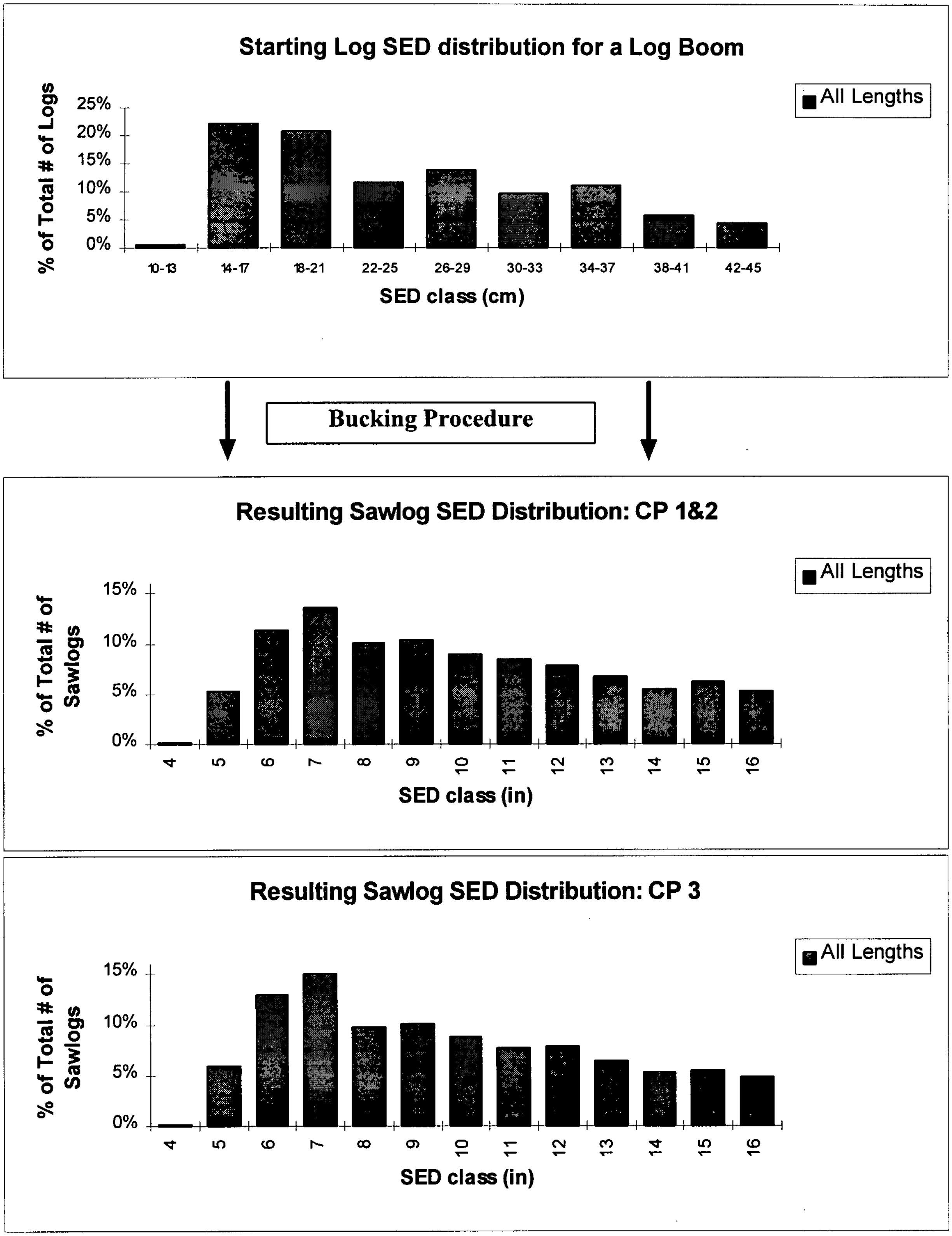


FIGURE 11 - LOG TO SAWLOG SED DISTRIBUTION CONVERSION

Sawing Simulation

The principle objective of the sawing simulation procedure was to quantify the lumber recoverable from each sawlog diameter and length class. Several steps were required to obtain this information, including the acquisition of three dimensional sawlog images, simulation of each alternative cutting program using these images, and calculation of the resulting lumber volume and value recoveries for each cutting program.

Data Acquisition

Sawlog images were obtained by randomly downloading two axis scan data from the test sawmill's computerized log breakdown system. Two axis scanning provides data points which model a sawlog as a series of elliptical cross-sections. The accuracy of the sawing simulation was greatly enhanced by using sawlog images from the test sawmill. These sawlog images account for the sweep, taper, and position of the sawlogs. Using scanned images eliminates the over-estimation of lumber recovery commonly associated with sawlog images based on perfectly shaped truncated cones. Although recently developed "true shape" scanning systems can provide more detailed three dimensional images of sawlogs, this type of scanner was not available at the test sawmill. In addition, sawing simulation programs able to utilize this data are still in their infancy.

The diameter and position of the sawlogs in the scanned images were measured to an accuracy of 0.254 cm (1/10th of an inch). These cross-sectional scans were taken every 10cm (4") along the length of each sawlog. The sawing simulation model required cross-sections every 30cm (12"), and the data needed to be converted to a different format. This conversion process was done using a Microsoft Excel© macro. The three cross-sections

10cm (4") apart were converted into one 30cm (12") cross-section using a median filter. In other words, the middle (or most common) of the three measurements was chosen to represent each 30 cm (12") section. This procedure was repeated for each diameter and position measurement. In addition, the lengths of the sawlogs were set to the standard bucking lengths, which include several inches of trim allowance.

Over 600 sawlogs were randomly downloaded via a modem from the test sawmill's computer system over a two week period. The system was programmed to ensure enough sawlogs from each SED and length class were gathered. From this sample, 364 sawlogs were stratified into 13 SED classes. These 13 SED classes were further stratified into seven length classes, resulting in four sawlogs per SED/length class. In order to better account for the influence of taper, each of the 91 SED/length classes was stratified to contain two logs with taper less than or equal to 0.254cm/ft (0.1"/ft) and two logs with taper greater than 0.1"/ft.

Table 5 shows a summary of the sawlog sample. The sample was not stratified with respect to sweep, eccentricity or position. However, sawlogs with sweep in excess of 2% (maximum deviation from centre line) were rejected. This was done to prevent biasing the recovery results for a particular diameter/length class. Since only four sawlogs were used per class, extremely crooked logs would have a large and unrealistic impact on the overall recovery for that class. If larger sample sizes were used, this would not be required. A larger sample size was not used for two reasons: downloading time and simulation time. Due to limitations in the test sawmill's hardware, data acquisition took up to two minutes per sawlog. More importantly, simulation time took up to 24 hours for the 364 sawlog sample. The tremendous time required for each run necessitated that a small sample be used.

SED Class	Criteria	3.14m	3.74m	4.11m	4.36m	4.97m	5.58m	6.19m
4.0"-4.9"	Avg. SED (in)	4.8	4.7	4.6	4.7	4.5	4.6	4.5
	Vol. (m3)	0.193	0.223	0.240	0.257	0.303	0.371	0.397
5.0-5.9"	Avg. SED (in)	5.5	5.5	5.6	5.6	5.6	5.6	5.6
	Vol. (m3)	0.256	0.291	0.316	0.378	0.404	0.510	0.595
6.0-6.9"	Avg. SED (in)	6.5	6.7	6.7	6.5	6.6	6.4	6.8
	Vol. (m3)	0.313	0.411	0.452	0.501	0.560	0.643	0.747
7.0-7.9"	Avg. SED (in)	7.6	7.5	7.4	7.6	7.3	7.4	7.6
	Vol. (m3)	0.416	0.483	0.559	0.611	0.640	0.769	0.931
8.0-8.9"	Avg. SED (in)	8.5	8.4	8.5	8.4	8.7	8.5	8.4
	Vol. (m3)	0.515	0.627	0.685	0.771	0.900	1.043	1.118
9.0-9.9"	Avg. SED (in)	9.5	9.6	9.7	9.6	9.5	9.7	9.5
	Vol. (m3)	0.668	0.798	0.890	0.973	1.048	1.278	1.385
10.0-10.9"	Avg. SED (in)	10.3	10.4	10.3	10.5	10.3	10.5	10.4
	Vol. (m3)	0.748	0.913	0.991	1.132	1.274	1.487	1.634
11.0-11.9"	Avg. SED (in)	11.4	11.5	11.3	11.6	11.5	11.1	11.2
	Vol. (m3)	0.915	1.101	1.213	1.306	1.491	1.677	1.930
12.0-12.9"	Avg. SED (in)	12.4	12.5	12.6	12.5	12.4	12.3	12.3
	Vol. (m3)	1.092	1.297	1.430	1.568	1.714	1.974	2.194
13.0-13.9"	Avg. SED (in)	13.7	13.3	13.2	13.5	13.5	13.3	13.5
	Vol. (m3)	1.278	1.493	1.649	1.793	2.076	2.293	2.662
14.0-14.9	Avg. SED (in)	14.4	14.5	14.5	14.7	14.3	14.4	14.5
	Vol. (m3)	1.397	1.761	1.920	2.150	2.356	2.688	3.099
15.0-15.9"	Avg. SED (in)	15.6	15.3	15.3	15.6	15.5	15.5	15.5
	Vol. (m3)	1.677	1.943	2.133	2.414	2.665	3.069	3.453
16.0-16.9"	Avg. SED (in)	16.3	16.5	16.6	16.4	16.5	16.3	16.4
	Vol. (m3)	1.805	2.257	2.472	2.603	3.026	3.472	3.902

TABLE 5 - SUMMARY INFORMATION ON THE 364 SAWLOG SAMPLE. (FOUR LOGS PER CLASS)

Simulation and Analysis

The simulated sawing of these scanned sawlog images was done using the True Shape Analyzer (TSA) developed by Nanoose Systems Corporation and licensed through MPM Engineering Ltd. The TSA is a sophisticated sawing simulation package which predicts the lumber produced from a given sawlog. It can replicate many different sawmill configurations and simulate a wide variety of products. Like the on-line system used by the test sawmill, the TSA finds the optimal combination of lumber products for a given log subject to operating and financial constraints. For each of the three cutting programs used by the test sawmill, the TSA was configured to replicate the decisions made by the test sawmill's on-line system.

This configuration process required a substantial amount of information to be entered into the TSA. This information was obtained from the test sawmill's computerized log breakdown system and included lumber target sizes, nominal sizes, lengths, wane requirements, cutting pattern location, and value. In addition, machine center information such as chipping depths, offset limitations, edger capacity, and kerfs was required. All of this information was required for each cutting program. The objective of the simulation process was to replicate the sawlog breakdown decisions actually made in the test sawmill. This required up to a dozen test runs per simulation run to ensure that the simulation process was occurring correctly. As a result, it took several weeks to complete each simulation run.

Three separate simulation runs were conducted on the 364 sawlog sample, one for each cutting program. For each sawlog and each cutting program the TSA predicted the amount and type (size and length) of rough lumber recovered from the test sawmill. This information is called a lumber tally. The net volume (in m^3) of this tally was then calculated using three parameters provided by the test sawmill:

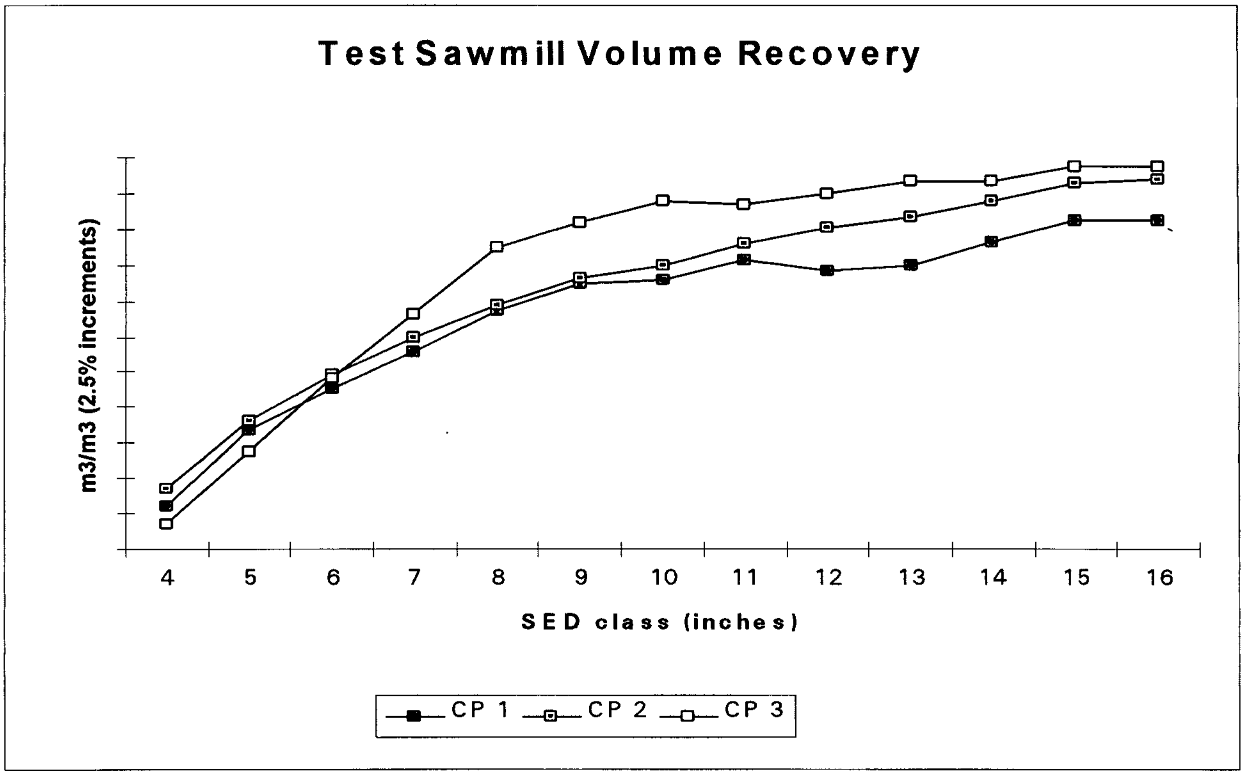
1. Production loss percentages to account for volume loss due to defect, trimming, and breakage in the sawmill.
2. Rough package percentages to account for the amount of lumber which is packaged and sold in its rough form.
3. Planer trim loss percentages to account for reductions in lumber length to meet customer grades when the rough lumber is smoothed to its finished size.

To check the accuracy of the simulation process, actual lumber tallies from the test sawmill were compared with the TSA's predictions for a group of log booms. This was done for all three cutting programs. Lumber volume recovery was always within 1-2% of the actual, and the distribution of products within the lumber tally was just as accurate.

Once the net volume of lumber recovered from each sawlog was determined, the net value (in $\$/m^3$) of this same lumber was calculated. Sales value information for the size, lengths, and customer grades of each lumber product as well as lumber grade outturns (the percentages of each lumber size which meet customer grades) were acquired from the test sawmill. This information was then applied to the lumber tally for each sawlog to determine the gross revenue it produced. In order to determine each sawlog's net revenue, or value, several costs (provided by the test sawmill) were applied against each sawlog's lumber tally:

1. Planing costs (in $\$/m^3$) for each size of lumber product.
2. Packaging costs (in $\$/m^3$) for both rough and planed packaged lumber.
3. Shipping costs (in $\$/m^3$) for both rough and planed packaged lumber.

With both volume and value recovery information calculated for each sawlog and for each cutting program, the value of particular diameters and lengths of sawlogs for each cutting program (CP) was obtained. In order to improve the accuracy of these estimates, the results from the four sawlogs in each SED/length class were grouped together and the average results used. This information indicated the degree of influence that sawlog diameter and sawlog length had in terms of percentage volume recovery (expressed as m^3 of lumber/m^3 of sawlog) and value recovery (expressed as net \$ value of lumber/m^3 of sawlog). Figure 12 shows the relationship between the SED of sawlogs processed at the test sawmill and volume and value recovery for each of the three cutting programs. Each data point on these graphs represents either the average lumber volume or average lumber value recovered from 28 sawlogs of the same diameter class at the test sawmill.



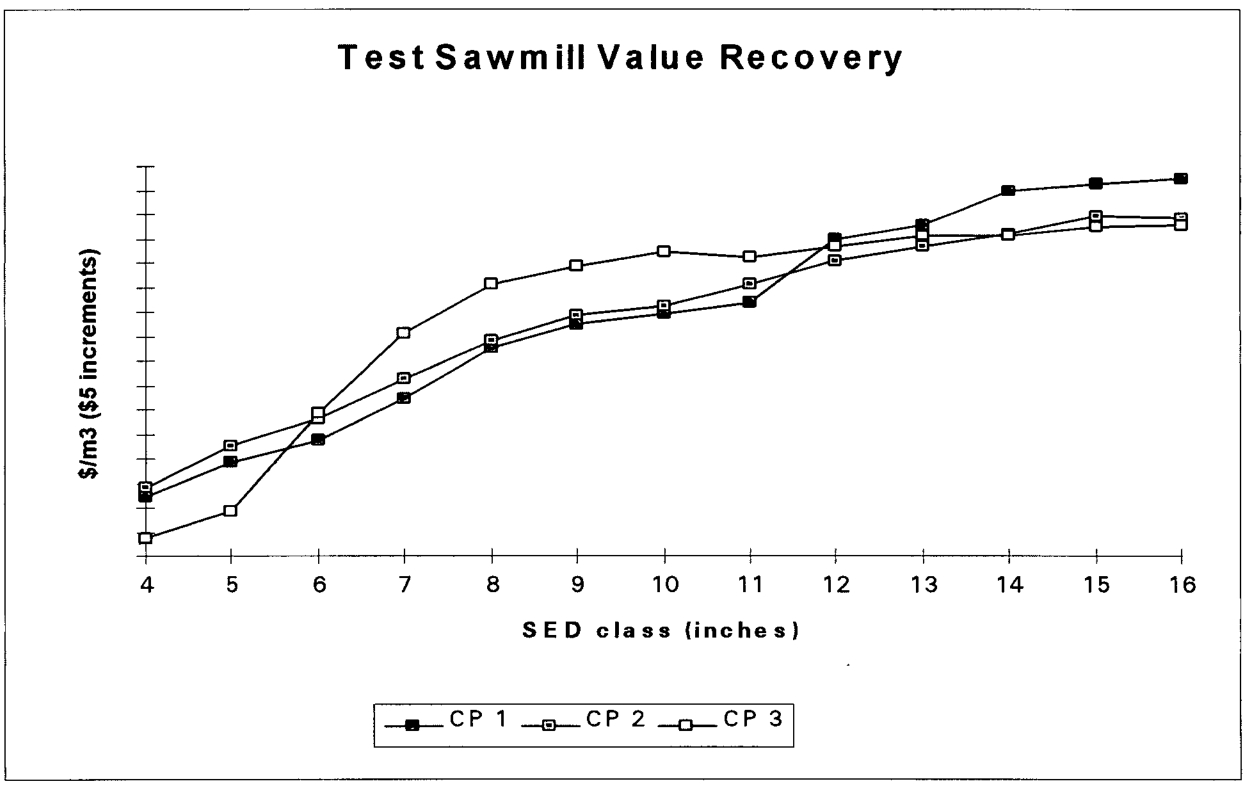


FIGURE 12 - SAWLOG SED VERSUS VOLUME AND VALUE RECOVERY AT THE TEST SAWMILL

Discussion

With respect to volume recovery, it is clear that CP 3 in virtually all instances achieved the highest volume recovery. The recovery for CP 2 was consistently greater than CP 1, with the gap increasing substantially above 30cm (12") in SED. The relative differences in lumber volume recovery are clearly shown in Figure 13 below.

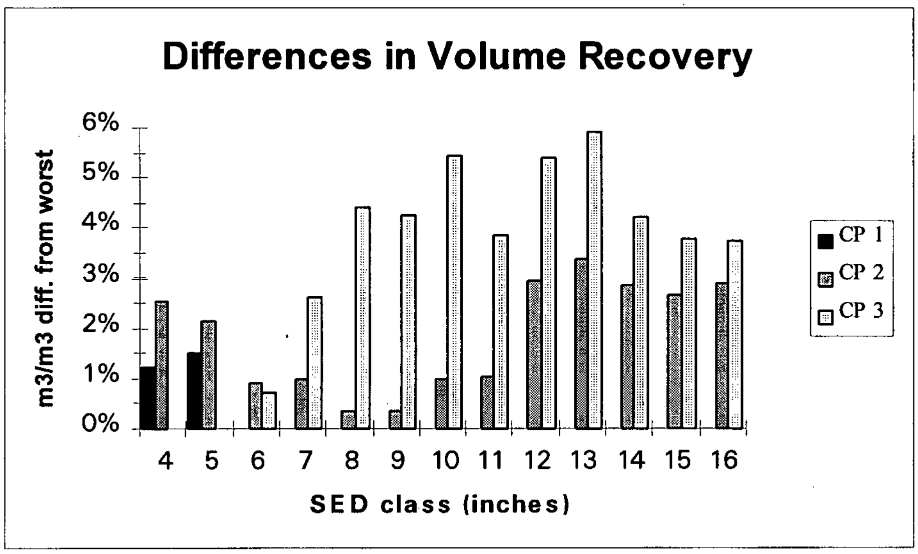


FIGURE 13 - RELATIVE DIFFERENCES IN LUMBER VOLUME RECOVERY AT THE TEST SAWMILL

The lumber recovery from CP 3 was usually two to six percent better than the other cutting programs. Differences in lumber recovery are caused by several factors, one of which is essentially straight geometry. Each cutting program produces different lumber products, and consequently has numerous different cutting patterns. For a given size of sawlog, the efficiency of the geometric fit of the products in the potential cutting patterns will be different for each cutting program. This results in lumber recovery differences among cutting programs. Another factor involves wane (roundness of the lumber edges) restrictions, which can increase or decrease geometric efficiency by making lumber fit closer or further from the outer curve of a sawlog. The major products in CP 3 are allowed more wane than similar products are in the other programs, making it easier to fit more lumber into a sawlog. The final factor is differences between the target size (the size the lumber is sawn at) and finished size (size the lumber is sold at) of lumber products. The target sizes and finished sizes are closer for some of the CP 3 products than they are for the products of the other programs. Thus, CP 3 produces a greater volume of finished lumber than the other cutting programs for the same amount of rough lumber produced at the sawmill. The wane and size difference factors were the major causes of the substantially higher lumber recoveries achieved by CP 3.

With respect to value recovery, the results of the sawmill simulation were much more interesting and important. Figure 12 clearly shows substantial interaction occurring between the cutting programs and the SED ranges. The highest value cutting program changed from CP 2 to CP 3 and then to CP 1 as the sawlog SED class increased from 10cm (4") to 41cm (16"). These changes are outlined in Figure 14 below. These results validate the second major assumption made in this study, in that the cutting program producing the highest lumber value is highly dependent upon sawlog diameter.

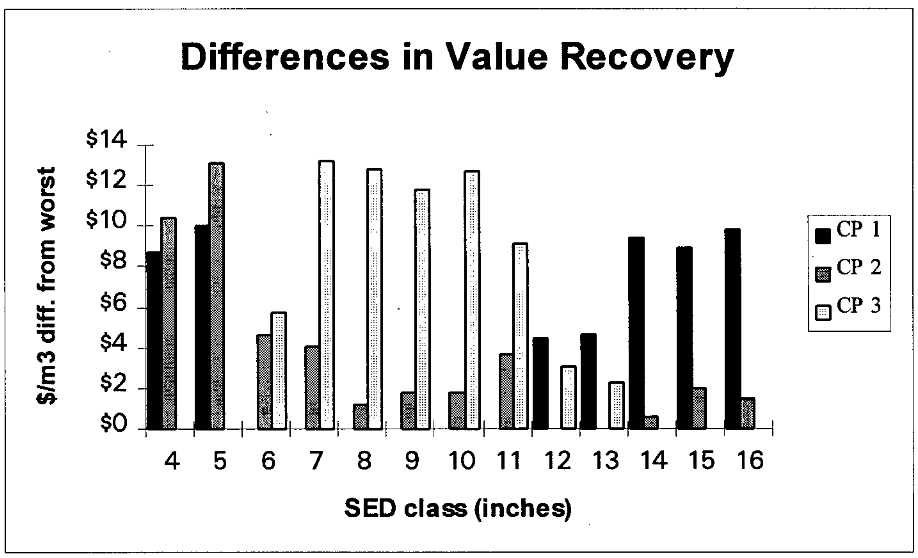


FIGURE 14 - RELATIVE DIFFERENCES IN LUMBER VALUE RECOVERY AT THE TEST SAWMILL

Log Boom Valuation

The previous steps in the method provided information on the lumber value obtainable from each sawlog SED/length class for each cutting program, as well as a prediction of the number of sawlogs produced in each of these SED/length classes. Using this information, the value of a given log boom (log valuation) and the amount and type of lumber produced (forecasting) can be predicted for each cutting program. A Microsoft Excel© interface was developed to automate the process of bucking and valuing a log boom.

As shown in Figures 15 and 16, a financial summary can be produced for each log boom, and the results of this financial analysis will vary depending upon the log boom being analyzed. The manufactured earnings (revenue less operating costs) are predicted for each cutting program on a total and per m^3 (log) basis. For each of the three cutting programs, the boom value is derived by multiplying the appropriate sawlog distribution by the appropriate value recovery distribution. Net log costs are derived by deducting the value of the residual chips and hog fuel produced from the purchase price of the logs.

Conversion costs incorporate all costs associated with the sawmill operation other than planing, packaging, and shipping. The diameter and length distribution of each log boom is factored into this calculation, since the productivity of a sawmill is heavily impacted by the diameter and length distributions of the log supply. In other words, a log boom with a large proportion of small, short sawlogs will have higher conversion costs per m^3 than a log boom with a smaller proportion of these same sawlogs, due to much lower productivity.

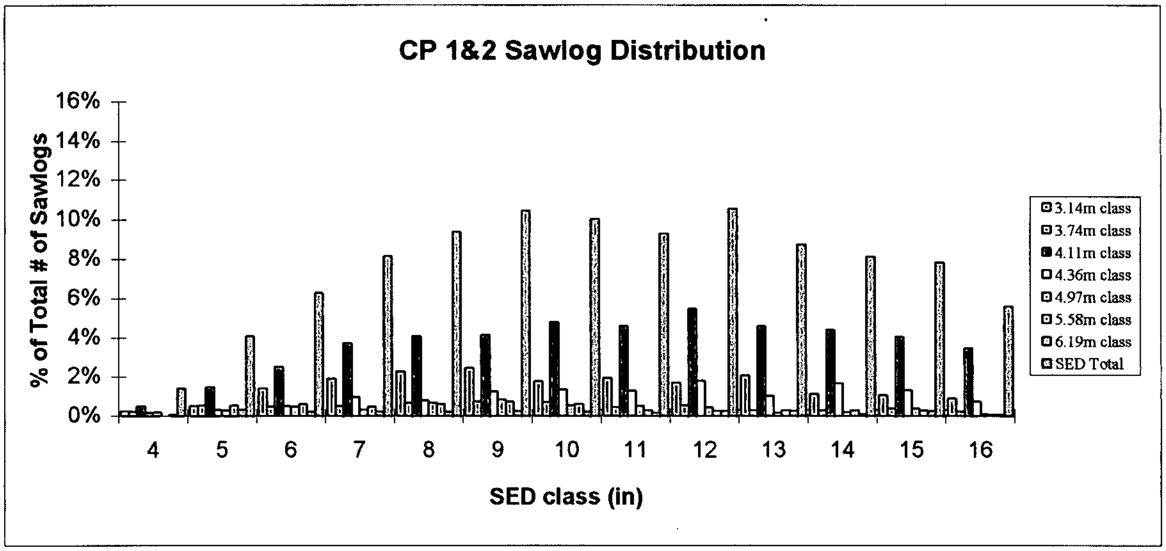
Boom: C1

Arrival date: 21-May

FINANCIAL SUMMARY

	CP1		CP2		CP3	
	Total $	$/m3 log	Total $	$/m3 log	Total $	$/m3 log
Boom Value:	$86,363.04	$100.69	$82,144.31	$95.77	$86,413.33	$98.14
(less planing, packaging, & shipping costs)						
Log Costs:						
Cost of logs	$47,174.57	$55.00	$47,174.57	$55.00	$48,427.16	$55.00
Less Chip rev.	$14,130.16	$16.47	$13,295.54	$15.50	$12,869.41	$14.62
Less Hog rev.	$218.72	$0.26	$218.72	$0.26	$224.53	$0.26
Net log costs	$32,825.69	$38.27	$33,660.31	$39.24	$35,333.22	$40.13
Conversion Costs: (sawing)	$32,165.00	$37.50	$31,446.12	$36.66	$29,969.93	$34.04
Total Manufacturing Costs	$64,990.68	$75.77	$65,106.42	$75.91	$65,303.15	$74.17
Manufacturing Earnings	$21,372.36	**$24.92**	$17,037.89	**$19.86**	$21,110.18	**$23.98**

Statistical Data	CP1	CP2	CP3
Boom Vol. (m3)	857.719	857.719	880.494
Lumber Vol produced (m3)	371.291	390.700	419.194
# shifts for this boom	1.12	1.08	1.01



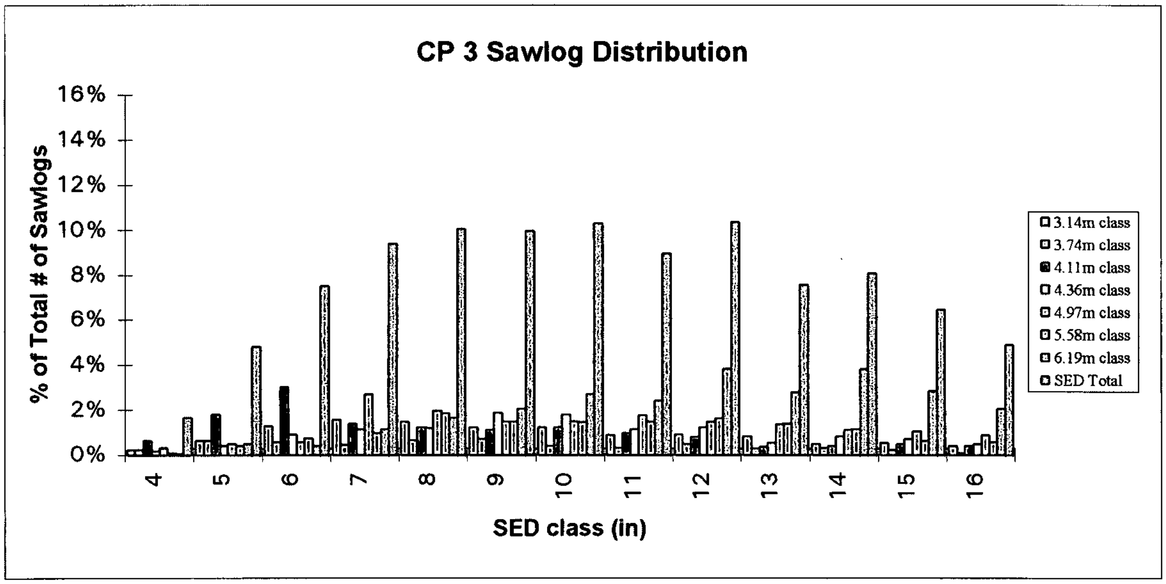


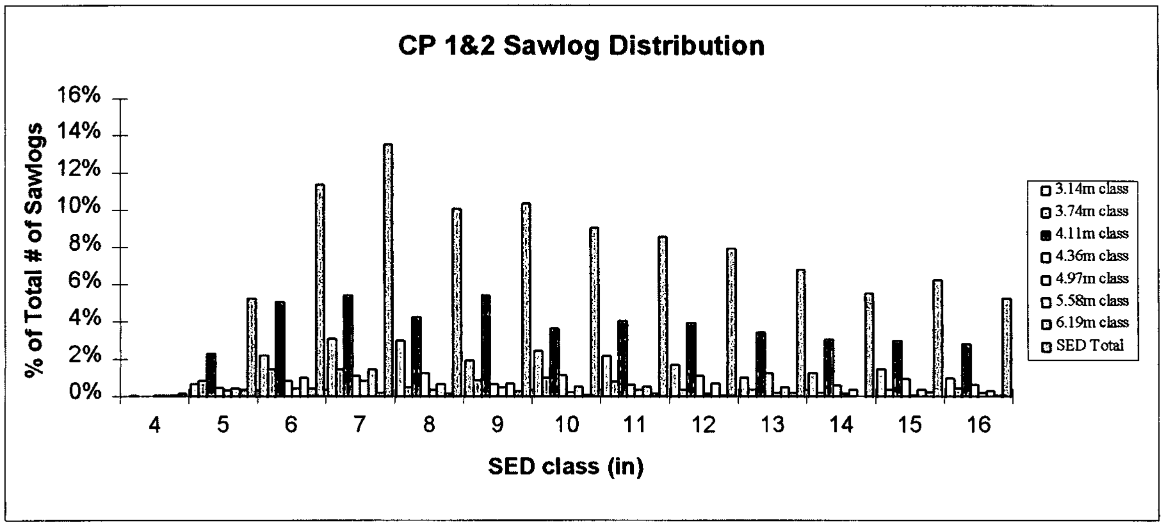
FIGURE 15 - EXAMPLE OF A TEST SAWMILL LOG BOOM VALUATION - CP 1 HAS HIGHEST VALUE

Boom: A1 — **FINANCIAL SUMMARY**

Arrival date: 17-May

	CP1		CP2		CP3	
	Total $	$/m3 log	Total $	$/m3 log	Total $	$/m3 log
Boom Value: (less planing, packaging, & shipping costs)	$75,710.09	$99.01	$73,027.97	$95.50	$77,163.87	$98.21
Log Costs:						
Cost of logs	$42,056.37	$55.00	$42,056.37	$55.00	$43,213.62	$55.00
Less Chip rev.	$12,546.12	$16.41	$11,819.75	$15.46	$11,422.76	$14.54
Less Hog rev.	$194.99	$0.26	$194.99	$0.26	$200.35	$0.26
Net log costs	$29,315.26	$38.34	$30,041.63	$39.29	$31,590.50	$40.21
Conversion Costs: (sawing)	$31,260.29	$40.88	$30,657.66	$40.09	$29,696.24	$37.80
Total Manufacturing Costs	$60,575.55	$79.22	$60,699.29	$79.38	$61,286.75	$78.00
Manufacturing Earnings	$15,134.54	**$19.79**	$12,328.68	**$16.12**	$15,877.12	**$20.21**

Statistical Data	CP1	CP2	CP3
Boom Vol. (m3)	764.661	764.661	785.702
Lumber Vol produced (m3)	332.193	349.086	375.487
# shifts for this boom	1.05	1.01	0.96



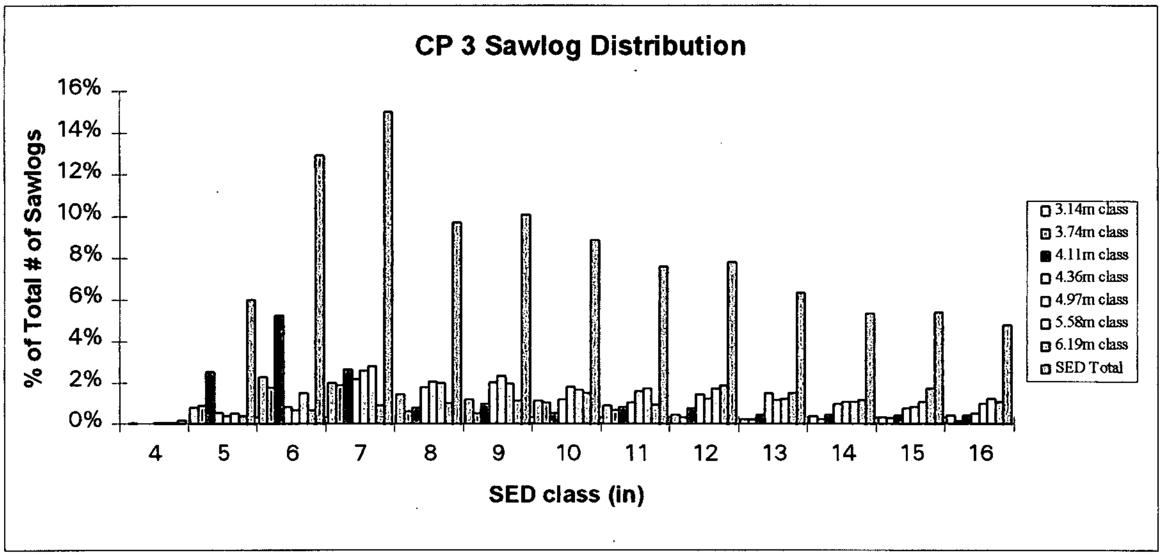


FIGURE 16 - EXAMPLE OF A TEST SAWMILL LOG BOOM VALUATION - CP 3 HAS HIGHEST VALUE

The valuing of log booms using the first four steps of the method developed by this research provides numerous benefits and opportunities. Some major examples include:

1. Knowing which cutting programs generate the highest financial return given the current log supply.
2. Knowing which log booms should be sold on the open market if they would generate a higher return.
3. Knowing what a prospective log boom would be worth if it was to be purchased by the test sawmill.
4. Knowing the volumes and types of products that would be generated by each log boom for each available cutting program before it is consumed.
5. Knowing what cutting program will generate the highest financial return for each log boom.

With this information at hand, the test sawmill would be able to make objective and informed decisions concerning its log supply, product mix, and marketing focus.

Log Boom Allocation

The first four steps of the method proposed in this research have provided the ability to predict the value of any given log boom for alternative cutting programs before it is actually processed. To test the usefulness of this method for log boom allocation, boom value information was used to drive decisions regarding which log booms each cutting program should use. In other words, log booms were allocated to cutting programs based upon their $\$/m^3$ values, and the financial impacts of these allocation decisions evaluated.

This evaluation consisted of a case study situation at the test sawmill. Three different scenarios were tried. Scenario 1 used the actual test sawmill situation, and scenario's 2 and 3 evaluated different "what if" possibilities. In each scenario, the value of the actual boom consumption schedule used by the test sawmill was compared with the value of an alternative boom consumption schedule derived using the method developed by this research. The hypothesis was that specific boom selection should increase overall manufactured earnings from a given supply of booms and a given set of cutting programs. Traditionally, at the test sawmill, little specific selection of booms is done for reasons other than practical limitations, such as length of storage time and convenience of location. Occasionally specific booms are chosen based upon visual inspection; however, selection from the available booms is essentially haphazard.

This evaluation period lasted for one month, and represented the actual operation of the test sawmill from the 25th of May, 1993 to the 25th of June, 1993. Forty-one log booms, arriving in no particular order before or during this evaluation period, were available for consumption. Thirty-four booms were consumed during the evaluation period: 15 by CP 2 and 19 by CP 3. Remaining booms were then sawn into CP 2. The test sawmill followed this cutting program schedule due to demand limitations in the market, in which no orders for CP 1 products existed, and CP 2 and 3 orders were small. The average storage time for the 34 booms was 10 days. Table 6 summarizes information for the 41 available log booms.

The three boom value columns show the large variation in log boom manufactured earnings, expressed as $\$/m^3$ of logs. For example, a CP 1 valued log boom can generate anywhere from $\$28.17/m^3$ down to $\$14.19/m^3$. This boom value variability within each cutting program is due to the variation in SED distributions of the log booms (see Figures 15 & 16). The boom value variation among the three cutting programs for each log boom is due to the value recovery differences among the three cutting programs (see Figure 12).

Case Study Log Booms

	Boom Name	Arrival Date	Run Date	Storage Days	Boom Value ($/m3)			Boom Log Volume (m3)			Boom Lumber Volume (m3)		
					CP 1	CP 2	CP 3	CP 1	CP 2	CP 3	CP 1	CP 2	CP 3
1	**A1**	17-May	25-May	8	$19.79	$16.12	$20.21	764.66	764.66	785.70	332.19	349.09	375.49
2	**C1**	21-May	25-May	4	$24.92	$19.86	$23.98	857.72	857.72	880.49	371.29	390.70	419.19
3	**H1**	10-May	26-May	16	$21.84	$17.23	$21.29	1109.14	1109.14	1124.11	480.36	504.49	533.29
4	**G1**	10-May	27-May	17	$21.79	$17.76	$21.88	1114.27	1114.27	1131.64	481.84	505.64	538.90
5	**B1**	21-May	28-May	7	$17.79	$14.41	$18.72	415.04	415.04	420.19	180.78	189.58	201.81
6	**E1**	10-May	31-May	21	$20.25	$16.31	$20.51	824.01	824.01	842.55	350.73	367.80	392.02
7	**C2**	21-May	31-May	10	$22.66	$18.15	$22.06	959.62	959.62	982.44	413.03	434.41	464.36
8	**D1**	10-May	01-Jun	22	$23.14	$18.41	$23.03	971.15	971.15	984.58	427.01	448.47	477.22
9	**C3**	27-May	01-Jun	5	$22.73	$18.40	$22.64	857.84	857.84	878.62	370.18	389.25	417.71
10	**D2**	21-May	02-Jun	12	$19.11	$15.35	$19.72	953.19	953.19	969.35	413.02	433.00	461.44
11	**D3**	27-May	03-Jun	7	$22.01	$17.86	$22.23	976.13	976.13	989.46	426.76	448.40	478.11
12	**C4**	27-May	03-Jun	7	$25.29	$20.63	$24.40	709.96	709.96	724.21	308.91	325.44	348.11
13	**E2**	01-Jun	04-Jun	3	$19.93	$15.96	$19.95	986.44	986.44	1008.89	419.48	440.36	469.50
14	**B2**	21-May	07-Jun	17	$22.68	$18.16	$21.98	378.24	378.24	387.22	162.87	171.31	183.46
15	**B3**	07-Jun	07-Jun	0	$15.69	$12.63	$16.53	349.65	349.65	354.01	147.84	155.07	164.29
16	**F1**	21-May	08-Jun	18	$25.51	$20.38	$25.03	1762.94	1762.94	1810.00	776.80	816.50	878.53
17	**C5**	01-Jun	08-Jun	7	$20.01	$15.96	$20.31	643.47	643.47	656.00	275.92	289.98	310.71
18	**J1**	04-Jun	09-Jun	5	$24.34	$19.48	$23.05	2344.44	2344.44	2382.07	1006.53	1057.75	1122.04
19	**G2**	01-Jun	11-Jun	10	$20.83	$17.12	$21.16	1403.72	1403.72	1423.14	602.53	632.39	673.39
20	**B4**	08-Jun	11-Jun	3	$19.72	$15.93	$19.88	521.01	521.01	527.01	226.39	237.43	251.36
21	**J2**	14-Jun	15-Jun	1	$22.58	$17.88	$21.83	2420.46	2420.46	2465.43	1038.62	1090.22	1161.58
22	**C6**	01-Jun	15-Jun	14	$20.95	$16.97	$20.98	604.33	604.33	613.98	260.26	273.52	291.53
23	**C7**	01-Jun	16-Jun	15	$26.51	$21.75	$25.24	691.65	691.65	705.77	301.06	317.25	338.76
24	**A2**	07-Jun	17-Jun	10	$28.17	$22.85	$26.73	818.71	818.71	838.26	362.79	381.98	409.12
25	**B5**	08-Jun	17-Jun	9	$18.48	$14.83	$18.57	402.42	402.42	411.00	170.85	179.37	191.35
26	**B6**	08-Jun	17-Jun	9	$21.86	$17.63	$20.61	423.55	423.55	430.06	182.63	192.26	203.54
27	**A3**	07-Jun	18-Jun	11	$26.50	$21.61	$25.41	823.03	823.03	851.59	363.28	382.93	413.95
28	**C8**	07-Jun	21-Jun	14	$24.14	$19.46	$23.71	808.38	808.38	826.76	350.50	368.28	395.70
29	**B7**	18-Jun	22-Jun	4	$14.19	$10.84	$15.74	567.12	567.12	575.97	243.71	254.93	271.94
30	**C9**	18-Jun	22-Jun	4	$21.46	$17.23	$21.28	1137.50	1137.50	1153.26	486.29	510.95	541.25
31	**C10**	07-Jun	23-Jun	16	$22.47	$18.25	$22.34	686.79	686.79	706.63	293.95	308.89	333.21
32	**C11**	17-Jun	23-Jun	6	$21.06	$17.00	$20.92	852.81	852.81	864.27	366.42	384.73	406.67
33	**C12**	18-Jun	24-Jun	6	$21.18	$17.21	$21.26	756.00	756.00	774.23	323.22	339.63	365.20
34	**D4**	18-Jun	25-Jun	7	$15.42	$12.00	$16.60	1083.88	1083.88	1097.28	459.88	481.40	511.69
35	**H2**	24-Jun	08-Jul		$12.44	$9.52	$13.23	1039.35	1039.35	1060.23	430.91	451.33	479.60
36	**C13**	24-Jun	09-Jul		$23.14	$18.77	$22.35	780.27	780.27	788.70	334.01	351.18	371.51
37	**C14**	24-Jun	12-Jul		$24.27	$19.88	$23.13	680.27	680.27	693.22	291.08	306.44	325.96
38	**D5**	24-Jun	14-Jul		$15.11	$11.88	$15.93	1007.98	1007.98	1027.58	426.39	446.67	476.67
39	**C15**	22-Jun	14-Jul		$22.28	$17.92	$21.95	766.36	766.36	780.04	328.93	345.67	367.94
40	**F2**	24-Jun	16-Jul		$24.12	$19.72	$23.69	1965.87	1965.87	1983.66	864.38	908.88	963.18
41	**C16**	22-Jun	16-Jul		$24.82	$20.00	$23.33	671.77	671.77	687.59	288.30	303.51	323.45

Average Storage time: 9.6 days
Stdev: 5.7 days
max: 22 days

TABLE 6 - SUMMARY OF CASE STUDY LOG BOOM VALUATIONS

The log boom volume is greater for CP 3 than for either CP 1 or 2 because of the different bucking strategy used by this cutting program. The CP 3 bucking strategy targets longer lengths (see Table 3), but the same sawlog 43cm (17") small end diameter cut-off is used for all three programs. As a result, CP 3 sawlogs near the 43cm (17") diameter limit carry more volume, due to their longer length, than sawlogs for CP's 1 and 2.

Scenario 1 (Actual)

The comparison process for scenario 1 first required that the base case (i.e. the actual allocation) be evaluated. Table 7 shows the base case allocation. The overall value was calculated to be $\$19.59/m^3$. To further assess whether the base case allocation was actually better than random allocation, four additional allocations, using random numbers to select the order of log booms to process, were evaluated. The four random allocations averaged an overall value of $\$19.55/m^3$, 4 cents less than the base case. Although this amount initially appears to be an insignificant difference, when compared with the other results it actually suggests that the current allocation strategy used by the test sawmill performs slightly better than purely random consumption.

To ensure realism and that the comparisons between base case, random, and the specific allocations were equitable, several criteria were set up and followed for all scenarios:

1. Log inventory on May 25th from previous log booms was considered to be 0.
2. The actual daily m^3 consumption of the sawmill was used for each day, regardless of the booms being used.
3. The maximum storage time allowed for any log boom was 22 days, at which time the boom had to be consumed.
4. A boom could not be considered for allocation until it had actually arrived at the sawmill.
5. Unused volume from a previous day was carried forward to the next day
6. When cutting programs were changed, any unused log volume was assumed to be in log (unbucked) form, and was carried forward to the next day.
7. Any unprocessed log volume remaining on June 25th was assumed to be in log form, and was carried forward and valued for CP 2.
8. All of the unselected log booms from the group of 41 available were valued for CP 2.

Scenario 1 (Actual) - Base Case

Date	Selected Booms		CP	Available Volume (m3)	Daily Usage (m3)	Volume in Queue (m3)	Boom Value				Vol.	Value
25-May	A1 C1		2	1622.4	1238.4	384.0	$ 12,329	$ 17,038				
26-May	H1		2	1109.1	802.8	690.3	$ 19,111					
27-May	G1		2	1114.3	916.2	888.4	$ 19,794					
28-May	B1		2	415.0	1278.0	25.4	$ 5,981					
29-May												
30-May												
31-May	E1 C2		2	1783.6	1217.7	591.4	$ 13,437	$ 17,419				
01-Jun	D1 C3		2	1829.0	1222.2	1198.1	$ 17,877	$ 15,783				
02-Jun	D2		2	953.2	1358.1	793.2	$ 14,631					
03-Jun	D3 C4		2	1686.1	1310.4	1168.9	$ 17,436	$ 14,646				
04-Jun	E2		2	986.4	1435.5	719.9	$ 15,740					
05-Jun												
06-Jun											Vol.	Value
07-Jun	B2	B3	2	727.9	1357.2	90.6	$ 6,868		$ 4,417	Out	90.6	$ 1,144
08-Jun	F1		3	1810.0	1221.3	680.4	$ 45,300			In	91.7	$ 1,515
09-Jun	C5 J1		3	3038.1	1165.5	2553.0	$ 13,324	$ 54,901				
10-Jun			3	0.0	1598.4	954.6						
11-Jun	G2 B4		3	1950.2	1101.6	1803.1	$ 30,118	$ 10,479				
12-Jun												
13-Jun												
14-Jun			3	0.0	1591.2	211.9						
15-Jun	J2 C6		3	3079.4	1632.6	1658.7	$ 53,815	$ 12,879				
16-Jun	C7		3	705.8	1261.8	1102.7	$ 17,812					
17-Jun	A2 B5 B6		3	1679.3	1424.7	1357.3	$ 22,409	$ 7,633	$ 8,862			
18-Jun	A3		3	851.6	1539.0	669.9	$ 21,638					
19-Jun												
20-Jun												
21-Jun	C8		3	826.8	1337.4	159.3	$ 19,603					
22-Jun	B7 C9		3	1729.2	1220.4	668.1	$ 9,065	$ 24,537				
23-Jun	C1 C11		3	1570.9	1477.8	761.2	$ 15,785	$ 18,085				
24-Jun	C12		3	774.2	1205.1	330.3	$ 16,459				Vol.	Value
25-Jun		D4	3	1097.3	1370.7	56.9			$ 18,210	Out	56.9	$ 944
				31339.8	**31284.0**					In	56.2	$ 674
										2		

	Value/m3	m3	m3/day
CP2	**$ 17.42**	**12136.5**	**1213.7**
CP3	**$ 22.01**	**19147.5**	**1367.7**
Excess (CP2)	**$ 16.74**	**6968.1**	
		38252.1	

Overall Value: $ 19.59 per m3

TABLE 7 - BASE CASE ALLOCATION (SCENARIO 1 - ACTUAL)

A Microsoft Excel© model was developed which facilitated the easy selection and evaluation of alternative allocation strategies. Once the rules for selection were entered, the system selected the best suited boom from those currently available. When a selected boom name was entered into the model, the log volume and dollar value were incorporated automatically. Table 8 shows the results of allocating the test sawmill log booms during the evaluation period.

Scenario 1 (Actual) - Allocation

Boom	m3 Diff	CP2	CP3
A1			
C1			
H1			
G1			
B1			
E1			
C2			
D1			
C3			
D2			
D3			
C4			
E2			
B2			
B3			
F1			
C5			
J1			
G2			
B4			
J2			
C6			
C7			
A2			
B5	$ 3.74		
B6	$ 2.97	Use	
A3	$ 3.80		
C8			
B7			
C9			
C10			
C11			
C12			
D4			
H2	$ 3.71		
C13	$ 3.57		
C14	$ 3.25		
D5			
C15			
F2	$ 3.97		Use
C16	$ 3.33		

Date	Selected Booms	CP	Available Volume (m3)	Daily Usage (m3)	Volume in Queue (m3)	Boom Value		
25-May	b2 c2	2	1337.9	1238.4	99.5	$ 6,868	$17,419	
26-May	h1	2	1109.1	802.8	405.8	$19,111		
27-May	a1	2	764.7	916.2	254.3	$12,329		
28-May	c4 g1	2	1824.2	1278.0	800.5	$14,646	$19,794	
29-May								
30-May								
31-May	c1	2	857.7	1217.7	440.5	$17,038		
01-Jun	e1	2	824.0	1222.2	42.3	$13,437		
02-Jun	c7 e2	2	1678.1	1358.1	362.3	$15,044	$15,740	
03-Jun	d1	2	971.2	1310.4	23.1	$17,877		
04-Jun	c6 g2	2	2008.1	1435.5	595.6	$10,256	$24,026	
05-Jun								
06-Jun								
07-Jun	j1	2	2344.4	1357.2	1582.9			$45,677
08-Jun		3	0.0	1221.3	387.0			
09-Jun	f1	3	1810.0	1165.5	1031.5	$45,300		
10-Jun	d3	3	989.5	1598.4	422.5	$21,997		
11-Jun	d2	3	969.4	1101.6	290.3	$19,113		
12-Jun								
13-Jun								
14-Jun	b1 c5 c8	3	1902.9	1591.2	602.0	$ 7,864	$13,324	$19,603
15-Jun	c3 c10	3	1585.3	1632.6	554.7	$19,891	$15,785	
16-Jun	b4 j2	3	2992.4	1261.8	2285.3	$10,479	$53,815	
17-Jun		3	0.0	1424.7	860.6			
18-Jun	c11	3	864.3	1539.0	185.9	$18,085		
19-Jun								
20-Jun								
21-Jun	b7 d4	3	1673.2	1337.4	521.7	$ 9,065	$18,210	
22-Jun	c12	3	774.2	1220.4	75.6	$16,459		
23-Jun	c9 c15	3	1933.3	1477.8	531.1	$24,537	$17,122	
24-Jun	b3 a2	3	1192.3	1205.1	518.2	$ 5,851	$22,409	
25-Jun	d5	3	1027.6	1370.7	175.1			$16,374
			31433.7	31284.0				

	Vol.	Value
Out	1582.9	$30,839
In	1608.3	$37,067

	Vol.	Value
Out	175.1	$ 2,791
In	171.8	$ 2,041

2

	Value/m3	m3	m3/day
CP2	$ 18.00	12136.5	1213.7
CP3	$ 21.39	19147.5	1367.7
Excess (CP2)	$ 17.75	6958.3	
		38242.3	

Overall Value:	$ 19.65 per m3		
	$ 0.06	$ 2,203.63	
Annual Difference:		$ 19,015.55	from Actual Allocation
	$ 0.10	$ 3,978.49	
Annual Difference:		$ 34,331.09	from Random1
	$ 0.09	$ 3,567.21	
Annual Difference:		$ 30,782.12	from Random2
	$ 0.11	$ 4,097.43	
Annual Difference:		$ 35,357.45	from Random3
	$ 0.10	$ 3,889.66	
Annual Difference:		$ 33,564.59	from Random4

TABLE 8 - RESULTS OF METHOD ALLOCATION (SCENARIO 1 - ACTUAL)

The results show a six cent/m^3 improvement over the base case in overall boom value. This represents a $2,203.63 dollar increase in manufactured earnings (profit) for this 1 month period, and when annualized against a years log consumption of 330,000 m^3, this represents a $19,015.55 increase. When compared with the four random allocations, the annual improvement increases to $33,508.82. Table 9 summarizes the results of scenario 1.

	\$/m^3 Value	\$/m^3 Uplift	Annualized $ Uplift
Method Allocation	19.65	---	---
Actual Allocation	19.59	0.06	$19,015.55
Random 1 Allocation	19.55	0.10	$34,331.09
Random 2 Allocation	19.56	0.09	$30,782.12
Random 3 Allocation	19.54	0.11	$35,357.45
Random 4 Allocation	19.55	0.10	$33,564.59
Random Average	19.55	0.10	$33,508.82

TABLE 9 - SUMMARY OF SCENARIO 1 RESULTS

Determining the most effective criteria for making boom selections involved both logical analysis and trial and error. Two different heuristic strategies were attempted.

1. Allocate based upon highest boom dollar value for the applicable cutting program.
2. Allocate based upon the minimum or maximum \$/m^3 differential between the competing cutting programs.

The first approach was essentially to always pick the highest valued boom available for whatever the current cutting program was. This approach ensured that each cutting program was always using the best (highest value) boom available, because it only considered the value applicable to the currently used cutting program. However, because it never considered relative differences in value between the competing cutting programs, it resulted in very little, if any improvement in overall boom value.

The second approach was based upon the relative value differences between competing cutting programs. Since CP 3 was always worth more than CP 2, the minimum positive difference was the boom chosen for CP 2 and the maximum positive difference was the boom chosen for CP 3. This is illustrated in Table 8, where the next recommended booms are B6 for CP 2 and F2 for CP 3. Boom B6 had a difference of $2.97/m^3 whereas boom F2 has a differential of $3.97/m^3. This strategy consistently generated the best results and was used as the heuristic for this research.

It should be noted that there are probably numerous other heuristic strategies which may increase the benefits of this method. A linear programming model may be the best at selecting the log allocation strategy with the highest overall value. Subsequent research should explore this alternative. The disadvantage of the heuristic approach is that the optimal selection combination will never be reached (unless by chance), only approximated. The benefit of the heuristic approach is that the heuristic will be sufficiently uncomplicated to allow a low cost, small scale, fast and practical system to be used.

Scenario 2

The scenario 1 comparison was a test between CP's 2 and 3. Table 6 shows that CP 3 generated a higher return than CP 2 on every boom in the case study. On the other hand, a comparison between CP 1 and CP 3 shows that the cutting program generating the highest boom value often changed. Another scenario was created to see if greater increases in overall value could be achieved if the test sawmill had been sawing CP 1 products in the place of CP 2 products during the first two weeks of the evaluation period. All other parameters were kept the same as the original base case in scenario 1. Table 10 shows the base case of this scenario (scenario 2). The overall value of the base case for scenario 2 was \$20.94/m^3, representing an increase of \$1.35/m^3 from scenario 1. Thus, the market driven decision to cut CP 2 instead of CP 1 during the one month evaluation period cost the test sawmill nearly \$52,000 in lost opportunity.

Scenario 2 - Base Case

Date	Selected Booms	CP	Available Volume (m3)	Daily Usage (m3)	Volume in Queue (m3)	Boom Value		
25-May	A1 C1	1	1622.4	1238.4	384.0	$ 15,135	$ 21,372	
26-May	H1	1	1109.1	802.8	690.3	$ 24,220		
27-May	G1	1	1114.3	916.2	888.4	$ 24,274		
28-May	B1	1	415.0	1278.0	25.4	$ 7,382		
29-May								
30-May								
31-May	E1 C2	1	1783.6	1217.7	591.4	$ 16,690	$ 21,747	
01-Jun	D1 C3	1	1829.0	1222.2	1198.1	$ 22,470	$ 19,502	
02-Jun	D2	1	953.2	1358.1	793.2	$ 18,212		
03-Jun	D3 C4	1	1686.1	1310.4	1168.9	$ 21,489	$ 17,954	
04-Jun	E2	1	986.4	1435.5	719.9	$ 19,661		
05-Jun								
06-Jun								
07-Jun	B2 B3	1	727.9	1357.2	90.6	$ 8,577		$ 5,486
08-Jun	F1	3	1810.0	1221.3	680.4	$ 45,300		
09-Jun	C5 J1	3	3038.1	1165.5	2553.0	$ 13,324	$ 54,901	
10-Jun		3	0.0	1598.4	954.6			
11-Jun	G2 B4	3	1950.2	1101.6	1803.1	$ 30,118	$ 10,479	
12-Jun								
13-Jun								
14-Jun		3	0.0	1591.2	211.9			
15-Jun	J2 C6	3	3079.4	1632.6	1658.7	$ 53,815	$ 12,879	
16-Jun	C7	3	705.8	1261.8	1102.7	$ 17,812		
17-Jun	A2 B5 B6	3	1679.3	1424.7	1357.3	$ 22,409	$ 7,633	$ 8,862
18-Jun	A3	3	851.6	1539.0	669.9	$ 21,638		
19-Jun								
20-Jun								
21-Jun	C8	3	826.8	1337.4	159.3	$ 19,603		
22-Jun	B7 C9	3	1729.2	1220.4	668.1	$ 9,065	$ 24,537	
23-Jun	C1 C11	3	1570.9	1477.8	761.2	$ 15,785	$ 18,085	
24-Jun	C12	3	774.2	1205.1	330.3	$ 16,459		
25-Jun	D4	3	1097.3	1370.7	56.9			$ 18,210
			31339.8	31284.0				

	Vol.	Value
Out	90.6	$ 1,421
In	91.7	$ 1,515

	Vol.	Value
Out	56.9	$ 944
In	56.2	$ 674

2

	Value/m3	m3	m3/day
CP1	$ 21.65	12136.5	1213.7
CP3	$ 22.01	19147.5	1367.7
Excess (CP2)	$ 16.74	6968.1	
		38252.1	

Overall Value: $ 20.94 per m3

TABLE 10 - BASE CASE ALLOCATION (SCENARIO 2)

The same allocation model developed for the base case of scenario 1 was used to allocate booms for scenario 2. This time, however, the model would recommend for CP 1 instead of for CP 2. The results of this allocation (Table 11) indicated a $21.06/m^3 overall value, 13 cents per m^3 greater than the base case for scenario 2. This would result in an annualized profit increase of $41,732.53.

Scenario 2 - Allocation

Boom	m3 Diff	CP1	CP3
A1			
C1			
H1			
G1			
B1			
E1			
C2			
D1			
C3			
D2			
D3			
C4			
E2			
B2			
B3			
F1			
C5			
J1			
G2			
B4			
J2			
C6			
C7			
A2	-$ 1.43		
B5			
B6	-$ 1.26		
A3			
C8			
B7			
C9			
C10			
C11			
C12			
D4			
H2	$ 0.80		Use
C13	-$ 0.79		
C14	-$ 1.14		
D5			
C15			
F2	-$ 0.43		
C16	-$ 1.49	Use	

Date	Selected Booms	CP	Available Volume (m3)	Daily Usage (m3)	Volume In Queue (m3)	Boom Value		
25-May	c1 b2 c2	1	2195.6	1238.4	957.2	$21,372	$ 8,577	$21,747
26-May		1	0.0	802.8	154.4			
27-May	h1	1	1109.1	916.2	347.3	$24,220		
28-May	c4 f1	1	2472.9	1278.0	1542.2	$17,954	$44,967	
29-May								
30-May								
31-May		1	0.0	1217.7	324.5			
01-Jun	d1	1	971.2	1222.2	73.5	$22,470		
02-Jun	c7 c3	1	1549.5	1358.1	264.9	$18,339	$19,502	
03-Jun	g1	1	1114.3	1310.4	68.7	$24,274		
04-Jun	e1 e2	1	1810.5	1435.5	443.7	$16,690	$19,661	
05-Jun								
06-Jun								
07-Jun	j1	1	2344.4	1357.2	1430.9			$57,061
08-Jun		3	0.0	1221.3	232.6			
09-Jun	b1 b3 d2	3	1743.6	1165.5	810.6	$ 7,864	$ 5,851	$19,113
10-Jun	a1 g2	3	2208.8	1598.4	1421.1	$15,877	$30,118	
11-Jun		3	0.0	1101.6	319.5			
12-Jun								
13-Jun								
14-Jun	c5 d3	3	1645.5	1591.2	373.7	$13,324	$21,997	
15-Jun	b4 b5 c6	3	1552.0	1632.6	293.1	$10,479	$ 7,633	$12,879
16-Jun	c10 c8	3	1533.4	1261.8	564.7	$15,785	$19,603	
17-Jun	j2	3	2465.4	1424.7	1605.5	$53,815		
18-Jun		3	0.0	1539.0	66.5			
19-Jun								
20-Jun								
21-Jun	b7 d4	3	1673.2	1337.4	402.3	$ 9,065	$18,210	
22-Jun	c12 c11	3	1638.5	1220.4	820.4	$16,459	$18,085	
23-Jun	c9	3	1153.3	1477.8	495.9	$24,537		
24-Jun	c15	3	780.0	1205.1	70.8	$17,122		
25-Jun	a3 d5	3	1879.2	1370.7	579.3	$21,638		$16,374
			31840.3	31284.0				

	Value/m3	m3	m3/day
CP1	$ 23.24	12136.5	1213.7
CP3	$ 20.90	19147.5	1367.7
Excess (CP2)	$ 17.73	6948.0	
		38232.0	

	Vol.	Value
ut	1430.9	$34,827
In	1453.9	$33,509

	Vol.	Value
ut	579.3	$ 9,230
In	568.2	$ 6,750
2		

Overall Value: $ 21.06 per m3

$ 0.13 $ 4,834.90

Annual Difference: $ 41,732.53 from Actual Allocation

TABLE 11 - RESULTS OF METHOD ALLOCATION (SCENARIO 2)

Scenario 3

During these first two allocation scenarios, it was noted that although the order of booms often changed, only a few booms were actually allocated to different cutting programs. For example, in scenario 2 only five booms (A1, B1, D2, D3, B3) were allocated forward to CP 3 from CP 1, and only three booms (F1, J1, C7) were allocated back to CP 1 from CP 3. It appeared that the two week interval was limiting the allocations, as several booms were always force allocated (due to storage time limits) rather than being scheduled according to the model's instructions.

In order to explore this factor, a third scenario (scenario 3) was created in which the production order in the evaluation period was changed from 10 days of CP 1 and then 14 days of CP 3, to four days of CP 1, five days of CP 3, six days of CP 1, and finally nine days of CP 3. The excess booms were again valued for CP 2. Cutting program 1 was used instead of CP 2 because the maximum potential benefit of this method was being sought. Since scenario 2 had a higher overall profit improvement than scenario 1, it was felt that CP 1 would again show better results if used in scenario 3. The base case of scenario 3 is shown in Table 12. When compared with the base case of scenario 2, an overall value improvement of six cents/m^3 was achieved just from switching to a shorter, more varied production schedule.

When this third scenario was allocated (see Table 13), improvements of 16 cents/m^3 from the scenario 3 base case and 22 cents/m^3 from the scenario 2 base case were realized. This resulted in annualized profit increases of $51,758.83 and $73,887.92, respectively.

Scenario 3 - Base Case

Date	Selected Booms	CP	Available Volume (m3)	Volume in Queue (m3)	Daily Usage (m3)	Boom Value		
25-May	A1 C1	1	1622.4	1238.4	384.0	$ 15,135	$ 21,372	
26-May	H1	1	1109.1	802.8	690.3	$ 24,220		
27-May	G1	1	1114.3	916.2	888.4	$ 24,274		
28-May	b1	1	415.0	1278.0	25.4			$ 7,382
29-May								
30-May								
31-May	E1 C2	3	1825.0	1221.3	629.4	$ 17,279	$ 21,677	
01-Jun	D1 C3	3	1863.2	1165.5	1327.1	$ 22,674	$ 19,891	
02-Jun	D2	3	969.4	1598.4	698.1	$ 19,113		
03-Jun	D3 C4	3	1713.7	1101.6	1310.2	$ 21,997	$ 17,669	
04-Jun	e2	3	1008.9	1591.2	727.8			$ 20,131
05-Jun								
06-Jun								
07-Jun	B2 B3	1	727.9	1357.2	82.3	$ 8,577	$ 5,486	
08-Jun	F1	1	1762.9	1217.7	627.6	$ 44,967		
09-Jun	C5 J1	1	2987.9	1222.2	2393.3	$ 12,875	$ 57,061	
10-Jun		1	0.0	1358.1	1035.2			
11-Jun	G2 B4	1	1924.7	1310.4	1649.5	$ 29,242	$ 10,274	
12-Jun								
13-Jun								
14-Jun		1	0.0	1435.5	214.0			
15-Jun	J2 C6	3	3079.4	1632.6	1663.3	$ 53,815	$ 12,879	
16-Jun	C7	3	705.8	1261.8	1107.3	$ 17,812		
17-Jun	A2 B5 B6	3	1679.3	1424.7	1361.9	$ 22,409	$ 7,633	$ 8,862
18-Jun	A3	3	851.6	1539.0	674.5	$ 21,638		
19-Jun								
20-Jun								
21-Jun	C8	3	826.8	1337.4	163.8	$ 19,603		
22-Jun	B7 C9	3	1729.2	1220.4	672.7	$ 9,065	$ 24,537	
23-Jun	C1 C11	3	1570.9	1477.8	765.8	$ 15,785	$ 18,085	
24-Jun	C12	3	774.2	1205.1	334.9	$ 16,459		
25-Jun	D4	3	1097.3	1370.7	61.5			$ 18,210
			31358.9	31284.0				

	Vol.	Value
Out	25.4	$ 452
In	25.7	$ 482

	Vol.	Value
Out	727.8	$ 14,523
In	711.6	$ 14,184

	Vol.	Value
Out	214.0	$ 4,220
In	216.5	$ 4,305

	Vol.	Value
Out	61.5	$ 1,020
In	60.7	$ 728

2

	Value/m3	m3	m3/day
CP1	$ 22.28	12136.5	1213.7
CP3	$ 21.75	19147.5	1367.7
Excess (CP2)	$ 16.74	6972.6	
		38256.6	

Overall Value: $ 21.00 per m3

TABLE 12 - BASE CASE ALLOCATION (SCENARIO 3)

Discussion

Based upon the results from the three scenarios evaluated at the test sawmill (see Table 14), financial benefits are achievable from the log allocation step of the method developed by this research. Thus, the hypothesis that specific boom selection should increase overall manufactured earnings from a given supply of booms and a given set of cutting programs is correct.

Scenario 3 - Allocation

Boom	m3 Diff	CP1	CP3
A1			
C1			
H1			
G1			
B1			
E1			
C2			
D1			
C3			
D2			
D3			
C4			
E2			
B2			
B3			
F1			
C5			
J1			
G2			
B4			
J2			
C6			
C7			
A2			
B5			
B6			
A3			
C8			
B7			
C9			
C10			
C11			
C12			
D4			
H2	$ 0.80		
C13	-$ 0.79		
C14	-$ 1.14		
D5	$ 0.83		Use
C15			
F2	-$ 0.43		
C16	-$ 1.49	Use	

Date	Selected Booms	CP	Available Volume (m3)	Daily Usage (m3)	Volume In Queue (m3)	Boom Value					
25-May	c1 b2 c2	1	2195.6	1238.4	957.2	$ 21,372	$ 8,577	$ 21,747			
26-May		1	0.0	802.8	154.4						
27-May	h1	1	1109.1	916.2	347.3	$ 24,220				Vol.	Value
28-May	c4 f1	1	2472.9	1278.0	1542.2	$ 17,954		$ 44,967	Out	1542.2	$ 39,336.74
29-May									In	1583.4	$ 39,628.48
30-May											
31-May		3	0.0	1221.3	362.1						
01-Jun	b1 d2	3	1389.5	1165.5	586.1	$ 7,864	$ 19,113				
02-Jun	a1 g2	3	2208.8	1598.4	1196.6	$ 15,877	$ 30,118				
03-Jun		3	0.0	1101.6	95.0					Vol.	Value
04-Jun	g1 e1	3	1974.2	1591.2	478.0	$ 24,755		$ 17,279	Out	478.0	$ 9,802.03
05-Jun									In	467.4	$ 9,467.88
06-Jun											
07-Jun	d1	1	971.2	1357.2	81.4	$ 22,470					
08-Jun	a2 j1	1	3163.1	1217.7	2026.8	$ 23,060	$ 57,061				
09-Jun		1	0.0	1222.2	804.6						
10-Jun	c7	1	691.7	1358.1	138.2	$ 18,339					
11-Jun	b6 a3	1	1246.6	1310.4	74.4	$ 9,260	$ 21,814				
12-Jun											
13-Jun										Vol.	Value
14-Jun	c8 c10	1	1495.2	1435.5	134.1	$ 19,512		$ 15,431	Out	134.1	$ 3,011.88
15-Jun	b3 c5 d3	3	1999.5	1632.6	504.8	$ 5,851	$ 13,324	$ 21,997	In	137.9	$ 3,080.93
16-Jun	b4 b5	3	938.0	1261.8	181.0	$ 10,479	$ 7,633				
17-Jun	c6 e2	3	1622.9	1424.7	379.2	$ 12,879	$ 20,131				
18-Jun	c3 c11	3	1742.9	1539.0	583.1	$ 19,891	$ 18,085				
19-Jun											
20-Jun											
21-Jun	b7 d4	3	1673.2	1337.4	918.9	$ 9,065	$ 18,210				
22-Jun	c12	3	774.2	1220.4	472.7	$ 16,459					
23-Jun	c9	3	1153.3	1477.8	148.2	$ 24,537					
24-Jun	c15 j2	3	3245.5	1205.1	2188.6	$ 17,122	$ 53,815			Vol.	Value
25-Jun		3	0.0	1370.7	817.9				Out	817.9	$ 17,852.53
			32067.4	31284.0					In	803.0	$ 14,355.57
			Value/m3	m3	m3/day				2		
	CP1		$ 24.13	12136.5	1213.7						
	CP3		$ 20.87	19147.5	1367.7						
	Excess (CP2)		$ 16.78	6948.5							
				38232.5							

Overall Value: $ 21.16 per m3

$ 0.16 $ 5,996.57

Annual Difference: $ 51,758.83 From Weekly Base Case

$ 0.22 $ 8,560.36

Annual Difference: $ 73,887.92 From Original Base Case

TABLE 13 - RESULTS OF METHOD ALLOCATION (SCENARIO 3)

	$/m³ Value	$/m³ Uplift	Annualized $ Uplift
Scenario 1 Actual Allocation	19.59	---	---
Scenario 1 Method Allocation	19.65	0.06	$19,015.55
Scenario 2 Base Allocation	20.94	---	---
Scenario 2 Method Allocation	21.06	0.13	$41,732.53
Scenario 3 Base Allocation	21.00	---	---
Scenario 3 Method Allocation	21.16	0.16	$51,758.83

TABLE 14 - SUMMARY OF RESULTS FROM CASE STUDY ALLOCATION SCENARIOS

However, the financial benefits of improved log boom allocation at the test sawmill were less than expected. Although certain situations (i.e., scenario 3) produced reasonable value increases, it is unlikely that on average the profit uplift at the test sawmill would cover the costs of implementing an extensive log allocation system at this operation. These operational costs would fall into two categories: logistics and maintenance. Logistical costs would involve extra work by test sawmill personnel responsible for storing and retrieving the log booms. Maintenance work would consist of the costs of a person to continuously download, buck, value, and allocate log booms as they arrived at the test sawmill. Although the system developed by this method is almost fully automated by computer, it would still require at least a half hour's work per day to maintain. Additional time would also be required to update the sawlog simulations when cutting programs were changed and/or when product prices changed substantially. Total time required would probably average at least one day per week.

The relatively small value increases could be attributed to several factors. While it is unlikely the primary cause, the heuristic used to allocate the booms may not be very effective. A more likely explanation stems from the lack of relative differences among cutting programs for each log boom. As previously mentioned, there is substantial variability among log boom values for each individual cutting program. However, all three cutting programs examined in this research respond reasonably the same to this variability. For example a boom may be valued at $24/m^3$ for CP 3 and $22/m^3$ for CP 2, and another boom valued at $16/m^3$ for CP 3 will be valued at $14.25/m^3$ for CP 2. While the absolute value difference between the log booms is approximately $8/m^3, the relative value difference between the cutting programs is only 25 cents/m^3.

Another factor could be that all log booms must ultimately be consumed by the test sawmill. If the test sawmill was able to sell or trade the lowest value log booms, this may improve the opportunity of increasing overall value, as the results would not be negatively impacted by the low valued log booms. The final reason, and probably the most important, is the constraint that, at the test sawmill, the entire sawlog supply generated by each log boom must be utilized by the current cutting program. There is no way of storing particular sizes and lengths of sawlogs for use by other cutting programs. Whether or not a particular sawlog segment has the highest value for the current cutting program (see Figures 12 & 14), it must be sawn as soon as it is produced.

V CONCLUSION

With the rapid changes occurring in the Forest Products Industry's operational environment, a forest company's ability to compete is contingent upon the effective utilization of their fibre supply. Numerous methods have been developed over the years to ensure that the right logs are processed by the right facility and into the right products.

Advances in computer technology have made possible the detailed analysis of vast amounts of electronically recorded data (such as log scaling data) and the effective and accurate prediction of lumber recovery from sawlogs using sawing simulation.

A method of improving log boom utilization was developed in this research which capitalizes on this new technology. The method seeks to overcome diameter sorting limitations on merchantable quality log booms to quantify and value individual booms for different product lines, and then allocate them specifically to these product lines in order to improve overall profitability. A five step procedure was used.

1. Acquisition and analysis of log scaling data.
2. Log bucking simulation.
3. Cutting program simulation.
4. Log boom valuation.
5. Log boom allocation.

Several computer programs were written to acquire and convert log boom scaling data into sawlog diameter and length distributions. Statistical tests clearly showed the presence of significant variability in small end diameter distributions among log booms which were originally classified based upon the same coastal log sort. The sawing simulation of 364 actual sawlogs gathered from the case study test sawmill for three different cutting programs (product lines) clearly showed how lumber volume and value recovery can change with respect to sawlog small end diameter. When the information from these two analyses was applied to a given log boom and the associated processing costs were deducted, a prediction of the profitability of the boom was derived. This procedure was completed for three different cutting programs. A total of 41 log booms from the test sawmill were valued using this method. The results showed substantial variability in the $/m^3 values of the log booms.

A heuristic based allocation was conducted and the overall value compared with the actual allocation strategy of the test sawmill during a one month evaluation period in which sales were fixed. The results showed that changes in allocation strategy improved value recovery from the same log supply at the test sawmill, but the dollar value uplift was most likely insufficient to cover the costs of maintaining a comprehensive allocation strategy at the test sawmill. A linear programming based allocation procedure may be able to find significantly greater benefits. Further research should explore this alternative. The test sawmill could still benefit from log boom allocation by developing simple rules of thumb. The fact that the actual allocation used by the test sawmill performed better than four random allocations suggests that this process is already occurring to a small degree.

The method developed by this research provides numerous tools of significant value to an operation. The method can predict the volumes and sizes of lumber contained in the currently inventoried log supply. Such information would be invaluable to sales departments for production forecasting. The method can calculate the value of a log boom to an operation, facilitating the accurate purchasing and selling of log booms on the open market.

The research also suggests that variability in cutting program value recovery by small end diameter may best be exploited by a short log (sawlog) sorting and storage concept. Further research into the area of short log (sawlog) based allocation amongst alternative product lines (cutting programs) is needed to fully explore this opportunity. Unless a sawmill has the lumber manufacturing and sorting capability in their sawmill to handle several product lines at once, the ability to sort and store sawlogs for their highest potential return is the only way to fully maximize value extraction from a log supply.

Based upon the results of the case study, the allocation of log booms containing a broad diameter range of sawlogs cannot achieve substantial increases in profitability. This is primarily due to the limitation of having to consume the entire distribution of a log boom at once. An interesting future analysis could be done using the method developed by this research to determine whether sorting log booms to tighter diameter ranges and allocating these smaller "mini-booms" amongst alternative cutting programs would achieve substantially better results.

Currently many lumber producing facilities treat their log supply as a consistent entity. The log supply of a sawmill is usually described by only one statistic, the average sawlog diameter. Variations in sawlog diameter distributions are only noticed at the end of a production shift. This "reactive" approach to log supply utilization severely limits the ability of a company to maximize the revenue from its operation. Technological advances in data acquisition and analysis now allow the use of "proactive" methods, such as the one developed in this research, to capture and exploit opportunities contained within what is often considered to be a homogeneous supply of fibre.

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APPENDICES

Appendix I - Evaluation of Log Boom Diameter Distribution Variability

The following is a description of the statistical testing done to determine the presence or absence of significant small end diameter (SED) distribution variability among the 72 log booms gathered as data from the test sawmill used in this study.

Data

The number of log booms from each of the logging camps is as follows:

Camp Code	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
# Booms	5	13	20	6	5	4	3	4	6	6

There are r populations in all, with one random sample (boom) drawn from each population. Let n_i represent the number of observations (logs) in the ith boom (from the ith population). Each log is classified into one of c different categories (in this case eight 4 cm SED classes). Let O_{ij} be the number of logs from the ith boom that fall into SED class j.

Therefore: $n_i = O_{i1} + O_{i2} + \ldots + O_{ic}$ for all i

The data for each test to be conducted is arranged in a contingency table like the following:

	SED class 1	SED class 2	. . .	SED class c	Totals
Boom 1	O_{11}	O_{12}	. . .	O_{1c}	n_1
Boom 2	O_{21}	O_{22}	. . .	O_{2c}	n_2
. . .	. . .	. . .	. . .	. . .	. . .
Boom r	O_{r1}	O_{r2}	. . .	O_{rc}	n_r
Totals	C_1	C_2	. . .	C_c	N

where: $N = n_1 + n_2 + \ldots + n_r$ $C_j = O_{1j} + O_{2j} + \ldots + O_{rj}$, for j = 1,2, ..., c

Assumptions

1. Each sample is a random sample from a population.
2. The outcomes of the various samples are all mutually independent. (Each boom comes from a different stand of timber at different locations. Thus an observation in boom x can be considered independent of an observation in boom y.)
3. Each observation may be categorized into exactly one of the c categories. (Each SED is a specific number which can only be placed in one of the diameter classes.)

Hypothesis

The hypothesis discussed in the case study section can be restated as:

Let p_{ij} (i = 1...r, j = 1...c) be the probability of a randomly selected observation from the ith population being classified in the jth class.

H_o: All of the probabilities in the same column are equal to each other.
($p_{1j} = p_{2j} = \ldots = p_{rj}$ for all j)

H_1: At least two of the probabilities in the same column are not equal to each other.
($p_{ij} \neq p_{kj}$ for some j, and for some pair i and k)

Test Statistic (χ^2)

$$\chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}, \quad \text{where} \quad E_{ij} = \frac{n_i C_i}{N}$$

where: O_{ij} = observed number of logs in cell i,j
E_{ij} = expected number of logs in cell i,j

Decision Rule

The χ^2 distribution is used to approximate the exact distribution of the test statistic. This is conditional on the E_{ij}'s being greater than five. Due to the large (1000-4000) sample sizes in this analysis, this criteria is easily met in every test. The critical region of size α corresponds to χ^2 values larger than the χ^2_α variable with (r-1)(c-1) degrees of freedom.

Therefore: *Reject Ho only if χ^2 is greater than χ^2_α.*

Results

The results of the contingency tests are listed below. For all tests $\alpha = 0.01$

Test of:	All	A	B	C	D	E	F	G	H	I	J
r (# booms)	72	5	13	20	6	5	4	3	4	6	6
χ^2	4441.5	164.9	299.8	300.2	649.8	54.3	50.9	25.1	192.0	98.9	170.4
χ^2_{crit}	573.3	48.3	117.1	173.9	57.3.	48.3	38.9	29.1	38.9	57.3	57.3
Decision	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Accept	Reject	Reject	Reject

The results of the tests clearly show that significant small end diameter distribution differences (with 99% confidence) exist among the booms in this analysis. Only the three booms from camp G are considered to all have the same distribution. In any of the tests, in order to determine exactly which booms (or boom) have different distributions, a series of contingency tests must be done using one of three methods: elimination, stepwise, or combination. These three methods follow the same idea as the variable elimination techniques in multiple regression. An example of the stepwise technique for the boom A test is shown below. Graphs of the 5 boom's distributions could be used to aid selection, and $\alpha = 0.01$ for all tests.

1. Booms 2& 3 are selected. Results: $\chi^2 = 5.9$, $\chi^2_{crit} = 18.5$
   Therefore Accept Ho, their distributions are not significantly different.

2. Boom 5 is added to the test. Results: $\chi^2 = 9.1$, $\chi^2_{crit} = 29.1$
   Therefore Accept Ho, their distributions are not significantly different.

3. Boom 1 is added to the test. Results: $\chi^2 = 155.5$, $\chi^2_{crit} = 38.9$
   Therefore Reject Ho, at least one distribution (that of boom 1) is significantly different.

This test could continue by removing boom 1 and adding boom 4 instead. The point, however, is to show that although it is a time consuming process, booms can be tested against each other to determine exactly which booms are significantly different from others.

Discussion

Several Nonparametric, or "distribution free" tests were considered but rejected for this analysis, including the two-sided k-sample Smirnov test (equal sized samples required) and the Birnbaum-Hall test (only 3 equal sized samples allowed). The Kruskal-Wallis test for several independent samples was tried on several booms. Walpole (1982) describes this test as an alternative to the parametric Ftest in a one-factor Analysis of Variance on the equality of several means. Conover (1980) states that this test is sensitive to differences in means & medians, but little else. Since this project is trying to identify distribution differences, not mean SED differences, the Kruskal-Wallis test was not used, although several tests were conducted on the data, producing (accept, reject) results identical to the r x c contingency tables.

It can be seen from the above discussion that the lack of a multiple range type test, such a Duncan's or Bonferroni's, to easily classify booms according to their distribution severely hinders ones ability to test specific booms. It would be extremely beneficial to have a test which could quickly discern distributions among booms. However, the aim of this evaluation is not to identify exactly how many and which booms were different, it is to show that significant differences in small end diameters can exist among booms of the same sort. The results of the statistical analyses have clearly satisfied this objective.

Appendix II - Sampling Procedure used for Test Sawmill Log Bucking

Logs can be bucked either top first or butt first. The test sawmill does not have the ability to purposely orient logs in a particular direction, thus logs arrive in a random fashion in either orientation. In order to determine whether the actual orientation proportion was significantly different from a 50/50 split between top and butt first, a sampling plan using cluster sampling for proportions was conducted over 6 days.

Population definition

The population being sampled consisted of all logs which pass through the bucking station at the test sawmill.

Data to be measured

The only data requirement was the determination of a given log's orientation to the bucking station. Logs are either oriented top first (end with smaller diameter) or butt first (end with larger diameter). In virtually every instance this required only a visual inspection of the log. In the cases where the diameter appeared equal at both ends (only once in this study), the number of growth rings were counted at either end. The end with the fewest growth rings was considered to represent the top of the log.

Efficiency

For this particular plan, cost was represented by time, and was considered the dominant factor in determining sample size. Total sampling time was restricted to a maximum of one hour per day for six days, including travel time to the sampling location. It was decided to sample at least 10% of a production shift's duration, which equates to 46 minutes (460 min. x 0.10). This time was split into two equal 23 minute sample times.

Each log measured was recorded as either a 1 (top first) or a 2 (butt first). Since the measurement was based upon visual inspection, precision was dependent upon the attention span and abilities of the person sampling (the author). Measurement precision was assumed to be 100% accurate due to the short sample times and the importance of this work.

Sampling procedure

Allocation of the 23 minute sampling periods during the six day period was done with practical limitations in mind. Each day was divided into eight possible sampling start times beginning at 7:45 a.m. and continuing once each hour until 2:45 p.m., and only two sampling times were allowed per day. This reduced the effect of lunch and coffee breaks and increased the ease of scheduling other work. For each of the six days, the two 23 minute sample times were randomly allocated without replacement to the eight possible sampling start times. The results of this modified simple random sampling procedure are shown below.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Random #'s	8,3	1,7	3,5	6,1	2,7	3,4
	Resulting start times					
Sample a	9:45am	7:45am	9:45am	7:45am	8:45am	9:45am
Sample b	2:45pm	1:45pm	11:45am	12:45pm	1:45pm	10:45am

Results of the sampling procedure are given below.

Sample (Day,time)	# Top First	# Observed	Proportion Top First
1a	25	45	0.56
1b	30	62	0.48
2a	24	59	0.41
2b	30	55	0.55
3a	39	75	0.52
3b	24	39	0.62
4a	34	65	0.52
4b	13	38	0.34
5a	25	50	0.50
5b	5	8	0.63
6a	35	63	0.56
6b	23	48	0.48

Equations

The average and standard deviation for the proportion top first were calculated using:

$$\bar{y} = \frac{\sum_{i=1}^{n} a_i}{\sum_{i=1}^{n} m_i} \qquad S\bar{y} = \sqrt{\frac{1}{n\bar{m}^2}\left(\frac{\sum a_i^2 - 2\bar{y}\sum a_i m_i + \bar{y}^2 \sum m_i^2}{n-1}\right)\left(\frac{N-n}{N}\right)}$$

where:

N = number of possible sample times = 48.
n = number of cluster samples = 12.
a_i = number of top first logs in sample i.
m_i = number of logs in sample i.
$\bar{m}$ = average number of logs in n samples.

Results

The average proportion of top first stems ($\bar{y}$)was determined to be 0.506, very close to 50%, with a standard deviation ($S\bar{y}$)of 0.016 (1.6%).

Hypothesis test

A simple hypothesis test was conducted to determined whether the average is significantly different from 50%.

H_o: *The average proportion equals 0.50* $\bar{y} = 0.50$

H_1: *The average proportion does not equal 0.50.* $\bar{y} \neq 0.50$

Decision Rule

Reject H_o *only if* t_{obs} *is greater than* t_{crit}.

Test statistic: ($\alpha = 0.05$) $$t_{obs} = \frac{\bar{y} - 0.50}{S\bar{y}}$$

$t_{crit} = t_{value\ (n-1,1-\alpha/2)} = 2.201$

$t_{obs} = (0.506-0.5)/0.016 = 0.375$

Since $t_{obs} < t_{crit}$, accept H_o and conclude with 95% confidence that ($\bar{y}$),the proportion of logs fed top first at the test sawmill, is equal to 0.50.