THE MARGIN FOR YIELD IMPROVEMENT FOR NO. 1 COMMON 5/4 RED OAK IN A CONVENTIONAL ROUGH MILL

by

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(ABSTRACT)

This study examined the potential for improvement within a conventional (crosscut-first) rough mill. Improvement was measured in terms of volume and also value of cuttings produced. Current levels of yield were obtained from an in-plant yield study of 138 boards. The same material was then processed with a computer optimization program designed to simulate a crosscut-first operation. Tests between the two methods, actual and optimized, showed that current levels of cutting volume production were not able to be improved upon with optimization. Due to the varying costs of different length cuttings, however, a significant increase in the *value* of cuttings produced was possible. The distribution of cutting lengths produced was found to be a significant factor in these results.

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1.0 INTRODUCTION

The current level of technology in the furniture rough mill leaves it lagging far behind other highly advanced sectors of the forest products industry. Although many efforts have been made within the past two decades to improve efficiency in the rough mill, the research and development has yet to reach a point of widespread utility. Researchers are faced with the task of applying technological advancements to a system which has for centuries been very highly labor intensive. The dilemma lies in the fact that machines must be designed to perform operations normally involving very complex human decisions.

Rough mill processing is comprised of essentially three closely interrelated tasks: defect detection, cutting decisions, and cut-up. Automation attempts to replace the human operator in each of these components, thereby eliminating human error and optimizing yields. Much of the past research has been directed toward each of these processes. This work can be seen in scanning technology for automatic defect detection, computer programs to make optimum cutting solutions, and alternative methods of cutting wood. More recent attention has been given toward full rough mill automation through the interfacing of the separate components.

While several yield studies have employed some of these new technologies, the magnitude of potential improvement in the conventional[1] rough mill has yet to be determined. The full scale automation that would incorporate all of these innovations into a completely new rough mill system is still far off in the future. Because of this, it is important to consider what the presently (or soon-to-be) available advancements can do in the conventional mill used by the majority of furniture manufacturers. These advancements may or may not increase efficiency in the conventional mills; determining this will affect the direction of continuing research in this area.

Rough mill yield is traditionally thought of in the sense of volume, i.e. the recovery of cuttings from lumber processed. In another sense, yield can be considered in terms of *value*, i.e. the value of the cuttings produced regardless of volume. In this project, both *volume* and *value* yield will be examined.

For the purposes of this study, "value" will be used to describe the worth of a cutting based only on its cost. "Cost" will reflect the amount of material resource expended to produce the cutting. The logic maintained here will be that a cutting of higher cost also has a higher value.

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[1] conventional refers to a crosscut-first operation.

1.1 Hypothesis

It is hypothesized that if conventional rough mill processing can be improved, then yield can be increased. Acceptance of this hypothesis will suggest that current systems do have the potential to be improved upon, and that some form of gain can result. Rejection of this hypothesis will indicate that conventional systems are already performing at an optimum level, and that an improvement in yields would require a new system of processing.

1.2 Objectives

There are two major objectives of this study:

- to investigate the effects of cutting size on value of No. 1 Common 5/4 red oak furniture cuttings.
- to quantify both volume-based and value-based differences between actual and optimized yields of No. 1 Common 5/4 red oak in a conventional rough mill.

2.0 LITERATURE REVIEW

2.1 Defect Detection and Scanning

Because raw material costs account for a substantial portion of overall rough mill costs, improved utilization of lumber has become a key issue. The Hardwood Research Council recently placed "Automated Defect Detection" on their list of Research Priorities for Eastern Hardwoods (McLintock 1987). They stated that the "development of a system or systems for automating the identification of surface defects on lumber, and positioning the saw to cut them out, qualifies as a high-priority research objective." There were several considerations on which this decision was based: 1) existing scanning and computer technology which can be adapted from other disciplines, 2) encouraging progress made in recent years toward a working system, 3) industry interest, and 4) the large value-added element in furniture manufacturing which makes the necessary capital investments highly favorable.

Szymani and McDonald (1981) have summarized the major methods for defect detection in lumber. The various methods they describe are included in five general classifications: optical, ultrasonic, microwave, X-ray, and neutron. These methods are discussed in terms of function and potential for online application. For details on these systems, the reader is referred to the original publication.

2.2 Computer Programs for Yield Estimation and Optimization

The first system for rough mill yield estimation was developed by Thomas (1962). This computer program simulated the crosscut-first sequence but did not allow for factors such as kerf and number of operations. The results of yield studies using this program were incorporated into the first useable yield tables for hardwood lumber. Thomas' program was the forerunner of the many other yield programs, with a major contribution being the use of a weighting function to emphasize cutting length. This concept which Thomas developed is now used widely in various forms (Brunner 1984).

The computer program YIELD, developed by Wodzinski and Hahm (1966) at the U.S. Forest Products Laboratory, was the next major advancement in rough mill estimation. Unlike Thomas' program which is restricted to the crosscut-first sequence, this program chooses either the crosscut or rip operation as the first step in its cutting solution. It does, however, incorporate the same weighting factor function. YIELD's board data input also requires diagramming with a blocking concept, but it is based on Cartesian coordinates instead of the single block address used in Thomas'. The program arrives at an optimum sawing solution and sequence by locating clear areas among the defect areas while considering kerf lines and number of necessary operation changes (Brunner 1984).

Since its development, YIELD has had a far-reaching impact on rough mill research. This program has been used to develop yield estimates which are presented in graphical utility charts (nomagrams) for particular species. In FPL research paper 118, Englerth and Schumann (1969) presented the combined results of two yield estimates for 4/4 hard maple. These two studies (Schumann and Englerth 1967a and 1967b) based their yields on the program YIELD. YIELD was later used to develop yield estimates for both 4/4 black walnut (Schumann 1971) and 4/4 alder (Schumann 1972). This program has also been used as a source of theoretical yields in mill studies and as a model for later estimation and optimization programs (Brunner 1984). However, while YIELD has been an important development, it does not accurately model a true rough mill, and its use of shortcuts to save computing time leads to "less than optimal yields" (Giese and Danielson 1983).

As the need for a true crosscut-first yield program became apparent, CROMAX was developed at the U.S. Forest Products Laboratory (Giese and Danielson 1983). Like YIELD, this program uses the Cartesian coordinate system of diagramming board defects and possesses a weighting factor option. However, the weighting factor in CROMAX is variable with both length and width, unlike the earlier programs which weight only length. The greatest contribution of CROMAX is its basic algorithm of optimizing crosscut-first yields. However, due to the large number of cutting combinations it considers, the lengthy computing time limits its use and application.

There is another class of rough mill yield programs which does not model the traditional crosscut-first sequence. RIPYLD (Stern and McDonald 1978) and MULRIP

(Stern 1978) both simulate the multiple rip-first sequence. OPTYLD (Giese and McDonald 1982) extends this concept in a multiple rip-first, crosscut, and re-rip sequence (Brunner 1984). OPTYLD was also the basis for the crosscut-first CROMAX program (Giese and McDonald 1983). While these "rip-first" programs are potentially very useful, they apply to non-conventional rough mills which rip before crosscutting.

The latest rough mill yield program, CORY, was developed at Virginia Polytechnic Institute and State University (Brunner 1984). This program is designed to model either the crosscut or rip-first sequence and is largely based on the earlier program YIELD. CORY utilizes both the same board data input method of 1/4-inch blocks referenced by a Cartesian coordinate system and also the same weighting factor option. However, while YIELD analyzes the defect areas and positions clear cuttings among them, CORY uses clear area representations to determine its solution. Another major functional difference between the two programs is seen in the cutup sequence modeled. YIELD's solution models either the crosscut-first or rip-first sequence, depending on which produces greater yield; i.e. the operator has no influence over the choice of the sequence (although it is typically crosscut-first.) CORY, however, can be programmed for either a crosscut-first or a rip-first operation; i.e. the operator has the choice of which sequence will be modeled. This feature of CORY creates flexibility and allows the program to be applied toward both conventional and non-conventional systems.

2.3 ALPS

One significant move toward automated rough mill processing has been the on-going development of ALPS, an Automated Lumber Processing System. This is a concept which was jointly initiated by the U.S. Forest Service and several universities (Huber and McMillan 1987). Through the collaboration of many individuals, ALPS is being designed to include all phases of processing lumber for furniture, and the development of these various components is being done at several research facilities throughout the country. ALPS combines existing technology with some recent advances in automation to create a singular yet extensive system.

The first step in ALPS is the automated processing of logs in the sawmill. Using computer axial tomography (CAT), the logs are scanned for internal defects. They are then automatically positioned and sawn to maximize grade or value (McMillan et al. 1984). ALPS begins in the sawmill to provide control of the raw material from the earliest stage possible.

The second step in ALPS takes the system into the furniture rough mill where the seasoned lumber is processed into parts. This involves the scanning of boards by a video camera through which a computer digitizes and stores the images. These images are analyzed for tonal and textural qualities and are identified as defects or clear wood. Based on the board geometry and the location and type of defects, the system then devises an optimum cutting pattern for the board. What makes the ALPS defect detection subsystem unique is its ability to classify as well as detect and locate defects; other presently available systems do not possess this capability (McMillan et al. 1984). A more thorough treatment of the ALPS defect detector is given in (Conners et al. 1983).

The third step of ALPS incorporates laser cutting technology to process the optimized cutting pattern in the board. Using the stored information, a high powered CO_2 laser automatically makes the programmed cuts using a "punch press" concept. This punch press cutting eliminates the required extended kerf lines of traditional sawing by being able to start and stop at any location. In the final stage of ALPS, parts are automatically sorted for size, and any residue is chipped for fuel (McMillan et al. 1984).

There are a number of expected advantages of ALPS over traditional processing systems: 1) increased value of lumber from optimized log-sawing, 2) increased yield of useable parts from lumber due to automatic defect detection and optimized sawing, 3) improved yield from laser cutting due to reduced kerf and punch press cutting, 4) ability of manufacturers to specify type and extent of allowable defects in a cutting bill, 5) reduced labor costs and minimized human error due to computer controls, and 6) overall economical benefits (McMillan et al. 1984). There are still, however, obstacles to ALPS which must be overcome before the full system can be implemented. A major disadvantage lies in the inadequacy of present laser wood cutting technology: low cutting speed and char surface on the cut edge (Huber et al. 1987).

Within the realm of rough mill processing, ALPS begins with the automated defect detection subsystem. A study was conducted to evaluate the technical feasibility of such a system for identifying and locating surface defects (Conners et al. 1984). In this study, a prototype software system was designed based on algorithms that had been developed for the ALPS. There were three stages of the prototype system: 1) differentiating board from background, 2) differentiating clear wood from a potential defect, and 3) differentiating the types of defects.

The objective of this study was to determine the performance of these methods in an industrial setting. The sample consisted of seventy red oak boards which represented actual boards processed in a furniture rough mill. A scanner digitized a section of each board, and the system divided the image into a number of disjoint regions. At the first "node" of the logic system, regions containing the board were recognized, and those containing only background were eliminated. At the second node, the system examined the remaining board regions and differentiated clear wood from potential defect; the result was an approximately 95% correct classification rate. At the third node, the system classified the potential defects into ten categories: clear wood, splits and checks, knots, decay, mineral streak, wane, holes, stain, dark bark, and light bark. Six of the ten classes had classification accuracies above 68%, with only four below this level, three of which were below 30%.

The results of this study seem to indicate that the defect detection subsystem currently in development holds great potential for industrial application. The main problem is in the system's ability to classify defects correctly. The use of color information to improve the system's ability to distinguish types of defects is currently being investigated at both Louisiana State University and Virginia Polytechnic Institute and State University.

A study done in 1971 investigated the economics of punch press cutting, proposed to be made possible through laser or water jets (Huber 1971). This study was designed "to show the economic advantage which could be derived from a new processing technique, and to present the urgency of the need to engage technology in the problem." The idea behind this study, the punch press method, was a concept which was later to become a component of ALPS.

The raw material used for this study were hard maple boards of two grades, FAS and No. 1 Common, and of two cutting size groups, shorter and longer lengths. These boards were "processed" through two computer programs, one representing the conventional cutting method, and the other, the punch press method. The program used for the conventional yield was adapted from a U.S. Forest Products Laboratory program (YIELD), while the program used for the punch press yield had been written and tested for this study. The results of the comparison were that the punch press yields were on the average 10% higher than the conventional yields, and that most of the increase was in the longest sizes.

The last stage of this study incorporated another computer program that calculated total annual rough mill costs. All variable and fixed costs were included in the calculations, as were the capital costs associated with implementing the new method of cutting in the mill. The analysis showed that this new method "would produce about 10% more product from the same quantity of rough lumber than [would] the conventional cutting method." The two biggest factors responsible for this increase were 1) elimination of sawdust, and 2) elimination of extended kerf lines. Also implied by the results is the increased yield of longer sizes.

A later study was conducted "to determine the economic feasibility of using a laser cutting device under the control of an optical image analyzer to replace conventional processing methods in a furniture dimension rough mill" (Huber et al. 1982). The analysis was based on costs involved in rough mill processing. The conventional system's costs were compared to the new system's costs in several areas: raw material, machinery, energy, and labor.

Under the assumption of a 5% yield increase due to saw kerf elimination with laser cutting, a $1210 and $1198 per day savings was calculated. These savings apply to a mill cutting 32 MBF of red oak or sap gum, respectively. The initial investment on laser equipment was analyzed for internal rate of return and also found to be an excellent investment.

The actual ALPS Cutting Program for optimizing yield through punch press cutting was recently developed, and in a study was compared to conventional crosscut-and-rip yields (Huber et al. 1988). The boards used in this study were the same No. 1 Common hard maple boards in the database used to develop the FPL-118 yield tables (Englerth and Schumann 1969).

The yields for eight different cutting bills were calculated using both the ALPS Cutting Program and the FPL 118 yield tables which represented conventional processing methods. Yield increases possible with the ALPS program were obtained in the 12.6% to 22.9% range, with a mean of 15.9%. The overall conclusion was that a substantially decreased amount of lumber would be required with the ALPS program to cut the same footage of parts as conventional methods.

2.4 Yield Studies

Most of the rough mill research conducted in the past has involved the effects of different factors on yields. A large part of this has been concerned with the differences between the crosscut-first and rip-first operations.

Lucas and Araman (1975) conducted a study to determine if gang-ripping before crosscutting held advantages over the conventional crosscut-first sequence. In the first phase of the study, the yields of three different gang-rip sequences were obtained through a combination of computer simulations and physical processing. The two best gang-rip sequences were then used in the second phase of the study for comparison with a physically processed crosscut-first sequence. The results showed no significant differences in yields between the gang-rip and crosscut manufacturing sequences.

It was concluded that although the yield of parts is unaffected by method of processing, the cost per parts may be. It was further suggested that "reductions in the total cost of manufacturing can often be achieved through automation." Through increased levels of automation, the chances for operator error would be reduced, and decreased costs would be expected. One of the gang-rip sequences tested had included a mark-sensing scanner to automatically crosscut to length.

Another similar study was done by Araman (1978) to find the most efficient method of producing high-grade furniture core material from low-grade yellow-poplar lumber. Three gang-rip-first and one crosscut-first sequences were used for comparison. Yields for the gang-rip sequences were obtained through computer simulation to determine the effects of ripping width. The yields of the two best widths were then compared to the yield of the physically processed crosscut-first sequence. Different grades of material were used, and the results showed that the average yields for all methods decreased with grade, while it was suggested that 2A Common would be the most economical. As in the previous study, no significant differences between the gang-rip and crosscut-first manufacturing sequences were seen. The conclusion was that a gang-rip sequences would probably be the most efficient due to its higher level of automation.

Hallock and Giese (1980) took another approach to compare the yields of gang-ripping to those of conventional methods. Factors examined included length of cuttings and best rip width in addition to grade. Gang-ripping was found to have higher yields (computer simulated) in all grades when a good selection of lengths was cut. This resulted from a higher recovery of medium and shorter lengths, offsetting the lower recovery in the longest lengths (90″ and 96″). An interesting point mentioned here is the fact that most furniture cuttings are not as long 90″ and 96″. If these lengths are excluded, the yields of the remaining long lengths are equal for gang-ripping and crosscutting-first, with overall gang-rip yields being higher.

While the other studies were done in a laboratory setting, one study approaching the rip-first vs. crosscut-first controversy was conducted in an actual furniture rough mill (Hall et al. 1980). This in-plant study was designed to compare one rip-first line to a chop-first (crosscut-first) line, and to identify the characteristics of each sequence. No. 1 Common 5/4 red oak was processed through each of the oppositely configured lines, and both yields were compared to estimates obtained from the FPL-118 yield tables (Englerth and Schumann 1969).

The overall yields verified the findings of Lucas and Araman (1975), that yield is unaffected by manufacturing sequence. In examining the yields of individual lengths, it was discovered that in the rip-first line extreme lengths were more frequent, and that middle lengths were predominant in the chop-first line. This yield study also provided additional support for the FPL-118 estimates, and for earlier studies that found actual overall yields to be within plus or minus three to five percent of the FPL-118 predictions (Schumann and Huber 1969). However, the FPL-118 predictions were found to be inadequate for any particular lengths.

This study was unique in that it recognized the human operator as an information processor. It was suggested that the more difficult decisions in the chop-first line create saw operator "overloading." Because this phenomenon may also apply to the rip-first saw operators, it was considered to be a major factor in the discrepancy between the actual yields and the predictions.

Another part of this study compared production costs of the two different manufacturing sequences. No significant overall differences were found; only the labor costs, when isolated, showed a savings in the rip-first line.

2.5 Human Factors

According to Sanders and McCormick (1987), "human factors focuses on human beings and their interaction with products, equipment, facilities, procedures, and environments..." A major objective of human factors is said to be "... to enhance the effectiveness and efficiency with which work and other activities are carried out."

Although the term "human factors" refers to a science of its own, it is important to consider the human element and its effects on the labor-intensive rough mill.

In a study to measure the performance of rough mill employees, lumber defect detection abilities were evaluated (Huber et al. 1985). The reasoning behind this study was to justify the need for an automatic defect detection system. Two rough mill employees from each of three furniture plants were given a board processing test as well as standard vision and intelligence tests. The board test consisted of examining a board for an allotted time and then, from memory, marking on a test sheet the location and type of defects. This test sheet contained an outline of the board divided into rectangular cells, among which the subject would place the perceived defects. The tests were scored as a percentage of perfect placement and identification of defects. The results indicated that the employees performed on the average of 68 percent of perfect, thereby prompting the conclusion that an automatic defect detection system "... holds considerable economic potential [even] if only a small yield improvement could be obtained."

Although the test controls employed in this study are sound, and the authors recommend further testing on a broader subject basis, the methodology used may be considered questionable. The memory approach to testing is not realistic enough to validate defect detection abilities of workers. In the rough mill, saw operators need to remember what the other side of a board looks like while cutting on one side, but memory is only a part of their information processing. The actual operation is much more dynamic and complex than this study seems to imply. The test was designed to evaluate subjects in terms of an automatic detector's function. However, because actual saw operators perform the complex operation of defect detection and cut-up, it would be difficult to isolate their abilities in only one of these closely interrelated tasks. The results of this study can be useful but should be viewed with these considerations in mind.

Because the human element is a considerable factor in the rough mill, it ultimately has a great impact on the efficiency and effectiveness of the system. The human operator, unlike a piece of automated machinery, is a potential source of very large variability. While it is a very important consideration, human performance is difficult to measure due to the vast array of factors influencing an individual. Along with a wide array of external stimuli, there are internal factors affecting a person's capability to perform a task.

The rough mill can be viewed as a semi-automatic system of man and machine. In this type of human/machine system, the human supplies the control while the machine supplies the power (Kemmerling 1988). In this particular combination, there is much room for human error and variability in controlling the system. Conventional rough mill employees are required to make the system's decisions, a task which greatly influences yield and efficiency. These decisions require human information processing, a function which has been often modeled but never completely understood. A basic model of the semiautomatic system depicts the human component with four basic functions: sensing, information storage, processing, and action (Kemmerling 1988). With regard to the processing function alone, one such model was developed by Wickens of Ohio University. This model is complex and includes such components as perception, memory, decision making, attention, response execution, and feedback (Sanders and McCormick 1987).

Perception is an important component in the specific case of the rough mill. Sanders and McCormick (1987) state that "the most basic form of perception is simple detection; that is, determining whether a signal or target is present." It is also suggested that "identification" and "recognition" are factors in the more complicated decisions involving classification. The rough mill employee's job of defect detection certainly fits this level of perception. He must not only have the ability to detect a defect's presence, but also be able to identify and recognize it as a certain type.

Although there are different stages or levels of memory (Sanders and McCormick 1987), the one which predominantly applies to the information processing used in the rough mill is the working, or short-term, memory. The rough mill saw operator is almost continuously fed a stream of new information to process. With each board there is a different set of information, i.e., defects and their location. Working memory essentially serves to accomplish a certain task; it is the "gateway to long-term memory" (Sanders and McCormick 1987).

For the rough mill employee, information about cutting bills, along with individual board information, is in their working memory. If the quantity of this information reaches too great a level, recall of this information will be impaired. A theoretical limit to absolute pieces of information that can be held in working memory is 7 ± 2, a concept developed by Miller in 1956 (Sanders and McCormick 1987). Although these 5 to 9 pieces of information can actually be "chunks" of items, this concept still implies that with more information to retain (e.g. cutting sizes and different defects), recall performance will decrease.

Decision making is the component which is considered to be "... at the heart of information processing." "It is a complex process by which people evaluate alternatives and select a course of action" (Sanders and McCormick 1987). In the rough mill when the operator examines a board, he will go through a series of thought processes such as weighing alternative solutions. This requires combining his visual perceptions with information stored in his memory, such as cutting bills, part quality, and defect characteristics. All of this data are together then processed into a decision.

The decision making function is probably the most complex due to the many biases inherent in the way people process information. Because it involves human psychology, it is also one of the most difficult concepts to examine or model. It is, however, a key concept in integrating automation technology with current systems. "The area of computer-aided decision making will undoubtedly become more important in the future as new technologies combine with a better understanding of the capabilities and limitations of the human decision maker" (Sanders and McCormick 1987).

3.0 METHODS AND MATERIALS

3.1 Data Collection

3.1.1 Cost Data

To investigate the effects of cutting size on value of cuttings, a survey of selected rough mills was conducted. The information obtained were manufacturers' cost estimates for different length cuttings in a hypothetical cutting bill. Their estimates were in the form of dimensionless costs per board foot of each cutting length. These costs were relative to a set-point cost of "1" for a cutting length class of 22 to 24 inches (see Appendix A).

The surveys were sent to fifteen rough mills in the area, and of those, there were five responses. Of these responses, only two were found to be useable in the analysis due to the form of the answers. The information obtained through this survey was not intended to be an average for all mills, but rather a source of some value estimates currently being used.

To obtain additional data on the cost of different length cuttings, a computer program was used to generate estimates. OPTIGRAMI is a program designed to determine the optimum grade mix to use in a rough mill (Martens and Nevel 1985). It accomplishes this by analyzing cost of raw material, lumber grades available, and the desired cutting bill, all of which are input data. The program's results are based on a large database of rough mill yields.

For cost estimates of different cutting sizes, OPTIGRAMI was run separately for each individual cutting length with all other variables kept constant. The value estimates were obtained indirectly from the changes in costs from the different outputs, and estimated costs per board foot of each cutting length were calculated.

The cost estimates from the two useable survey responses were averaged to create one set of data with which to work. The second set of cost estimates included data obtained from OPTIGRAMI. A linear regression of "cost per board foot" versus "cutting length" was obtained from each of these sets of estimates.

Both regression lines were converted such that the estimated cost per board foot of a 23.25" cutting equaled 1000. This was done to allow both sets of estimates to be compared on the same relative basis, and also for the easier handling of numbers.

Finally, the cost estimates for each actual cutting length were obtained from both regression lines. These were the estimates used in conjunction with the yield study results to generate information on the value of cuttings.

3.1.2 Yield Study

3.1.2.1 Raw Material

The raw material for this study was provided by the cooperating furniture mill at which the in-plant study was conducted. Kiln dried No. 1 Common 5/4 red oak boards of twelve-foot lengths were used. A total of 184 boards were divided into four groups of 46: one "dummy" batch and three sample batches. The dummy group was left at the furniture mill, while the remaining 138 boards were brought to Virginia Tech.

Because the boards were of random widths, and similarity was desired between the sample groups, the boards were divided into the three groups by evenly distributing the widths. This was done randomly for each width class of one inch. An analysis of variance procedure (ANOVA) was conducted on the mean widths of the boards in the three groups, and frequency distributions of the widths in each group were graphed. (See appendix B for a description of the ANOVA.) This was done prior to returning the three groups to the mill for processing to ensure that the groups had similar width distributions and, therefore, board footages.

These boards were diagrammed for use in computer optimization, and each group's board footage was recorded. They were then returned to the mill for processing along with the dummy group in the yield study.

3.1.2.2 Yield Optimization by Computer

A computer program, CORY[2] (Brunner 1984), was used to optimize yield for the 138 boards in the three sample groups. The results represented the optimized yield of a conventional rough mill. The input data for CORY required Cartesian coordinate (X-Y) locations of the defect areas on the board (see Figure 1). To obtain this data, the boards in the three sample groups were "mapped" using a clear acrylic overlay etched with a 1/4 inch grid system. The overlay was placed on each face of the board, and the coordinates of the defects and board dimensions (in 1/4" units) were recorded.

Before all of the groups were processed by CORY, one group of 46 boards was arbitrarily chosen for preliminary examinations. Since each of the three groups was designed to have the same characteristics, one group sufficed in providing the information which was necessary prior to the complete analysis.

Initially, this group was processed by CORY using the crosscut-first option and an exponential weighting factor on "length" of 2.00 (L^2 W). The purpose of this weighting factor was to emphasize the longer length cuttings. The same cutting bill of eight lengths used in the plant study was also used here (14", 15", 18.75", 21.75", 23.25", 26.75", 42.25", and 57"). CORY was programmed for cuttings of these lengths and of

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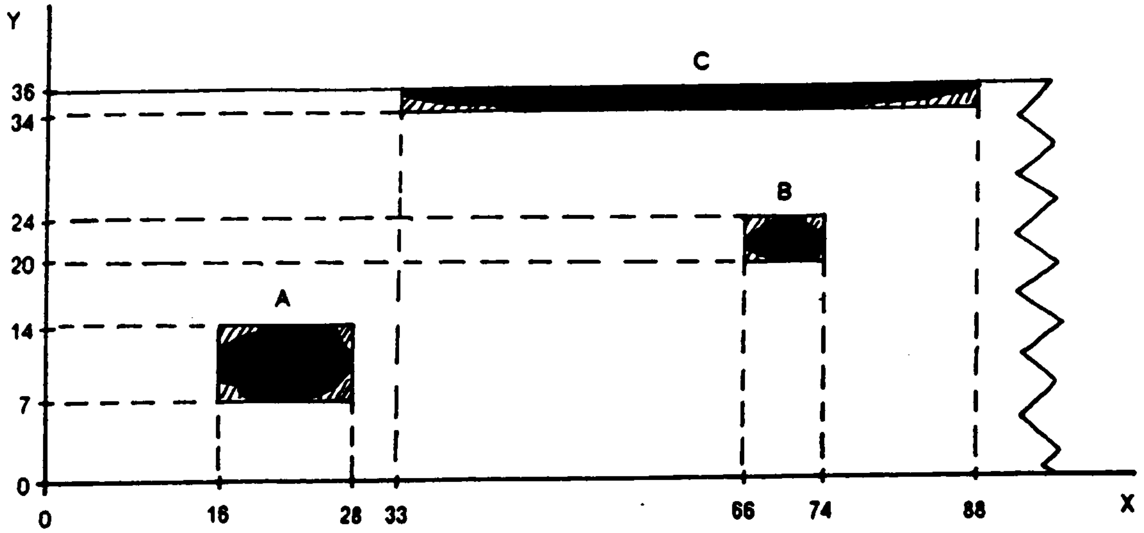
[2] An edited version of Brunner's original program CORY was used with modifications to the formatting of the input data. An input format compatible with the program was specifically developed and tested for use in this study. Because the clear-one-face option of CORY was not functioning, the data were run with the clear-two-face option of CORY, but were selectively coded to produce actual clear-one-face cuttings. This was done by manually bypassing the C1F subroutine, while the logic used in the algorithm was maintained.



DEFECT	(Y1) BOTTOM	(X1) LEFT	(Y2) TOP	(X2) RIGHT
A	7	16	14	28
B	34	33	36	88
C	20	66	24	74

Figure 1. Coordinate locations of defect areas on a board section.

random widths (for panel lay-up). CORY is designed to allow the cutting bill to "float,"[3] and as such there were no quantity or volume restrictions.

The program optimized the clear cuttings and gave outputs of the yield for each board, with cutting dimensions and locations and kerf line locations. The yield for each entire group of boards was also determined, with a frequency distribution of cutting sizes by length and width. (See appendix C for examples of the computer output.)

To test the accuracy of the program, these cutting solutions were verified by manually mapping them onto diagrams of the boards and their defects. In order to obtain information about the effects of weighting factor on yields, the same group was then processed at four additional weighting factors of 1.00, 1.50, 2.50, and 3.00. From this it was decided that a weighting factor of 2.00 would be used for the full analysis.

The remaining two groups of boards were then processed by CORY using the same program variables. These individual board results were again verified by manually mapping the optimized cuttings to check for irrational or infeasible solutions.

The data from the CORY outputs were tabulated by length and converted to board foot units. Average width of cuttings of each length and average length of all cuttings were also calculated. For reporting purposes only, recovery in terms of percent yield were also determined.

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[3] A cutting bill allowed to "float" has only length and width requirements of the cuttings. The quantity of each size cutting is assumed to be infinite such that no size cutting can be eliminated from the bill by satisfying volume requirements. This type of cutting bill is used in optimization studies to allow all boards to be independently processed under the same conditions.

All results from CORY were first examined with an ANOVA procedure to test among the mean board footages of cuttings produced in each group. A frequency distribution of cutting volumes was created for all of the boards (138), and a 95 % confidence interval of the mean was computed. This confidence interval of the mean was computed as: $\overline{X} \pm t_{.05(2),137} S_{\overline{X}}$.

For later analysis, the data from the three groups were combined.

3.1.2.3 *In-plant Yield Study*

The rough mill in which this study was conducted ("Company X") has two parallel lines, each with one crosscut saw feeding four rip saws (see Figure 2). Only one line was used, and the 184 boards were processed in four batches of 46 boards. The cutting bill used was one that was typical of the mill. It included five lengths (18.75", 23.25", 26.75", 42.25", and 57"), and had an additional three lengths in the salvage bill (14", 15", and 21.75"). As in program CORY, this cutting bill was allowed to "float" when the material was processed.

The study took place at the beginning of a Thursday morning shift, with the rough mill line cleared of any material. The first batch of 46 boards (dummy batch) was sent through the crosscut saw and each board was cut to lengths. The line was purged of material from this group, and the ends of the board sections were painted to mark the group. Each of the three sample groups were then cut and painted with a different color. With the board sections thus marked and separated, we were ensured that the boards and the resulting cuttings remained in their groups.

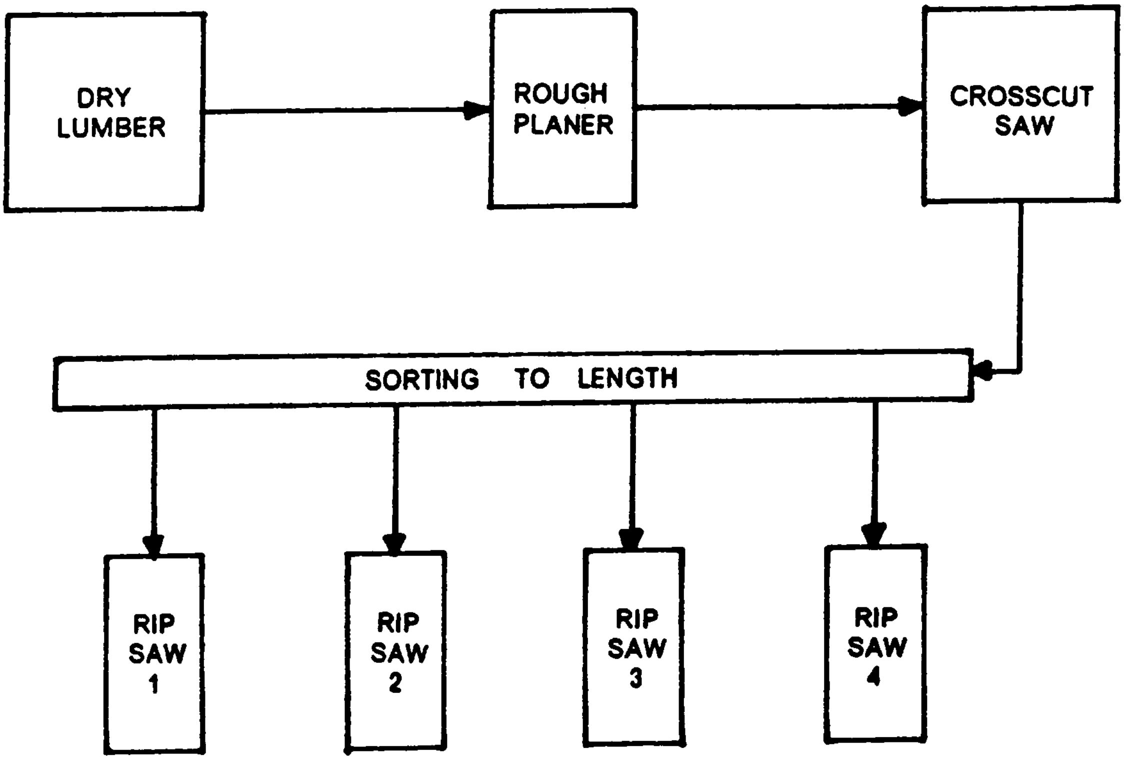


Figure 2. Schematic layout of the crosscut-first rough mill used in this study.

After the boards were crosscut, they were ripped at various stations, one length and one group at a time. They were then placed in stacks of panels (of random width cuttings) or specific width pieces. The specific width cuttings were tallied by a piece count, and their width was recorded. The random width cuttings in panels were tallied by a panel count and number of cuttings per panel. The width of the panels was also recorded.

For each group, salvage material was set aside in a bin and later cut to lengths and laid up into panels. These cuttings were tallied by a count of panels at each length, number of pieces per panel, and each panel's width. The salvage from each group was processed separately to maintain their correct grouping.

The data obtained from the study were tabulated for volumes in terms of board feet of cuttings produced in each length class. Average widths of cuttings were also computed for each cutting length, as was the average length of the cuttings. As with the computerized results, overall values combining the three groups' data were obtained, and volume in terms of percent yield was also calculated. Additionally, the percent yields were obtained for each separate stage of processing: crosscut, rip, and salvage.

Because the boards in this in-plant study were processed in groups, only aggregate information was obtainable, i.e. no individual board data exist. As such, no statistical tests could be conducted among any of these data sets.

3.2 Methods of Analysis

3.2.1 Value Data

Data from both the computerized and in-plant processing methods were transformed in the same manner to produce "value" estimates. The board footage data for each length (in each case) were combined with the cost estimate data obtained by the survey and OPTIGRAMI. The costs per board foot of each length cutting were multiplied by the corresponding board footage of cuttings produced at that length. This resulted in relative and dimensionless value estimates of the cuttings produced.

3.2.2 Computer Optimization vs. In-plant

The boards diagrammed for CORY were the same boards which were later processed at Company X. Due to mapping requirements, however, the diagrammed dimensions were sometimes not the same as the physical dimensions. This situation occurred with any boards that had crook. In such a case, the board's dimensions were defined by the outermost coordinates of the board, regardless of any warp. Within these dimensions, any areas lacking wood due to crook were recorded as wane. Because of this condition, CORY and Company X had slightly different numerical bases for their percent yield calculations. The comparisons of cutting volume between the two processing methods were, therefore, conducted on board footages rather than on percent yields.

For both overall volume and overall value, CORY and Company X were compared using one-sample t-tests of means. (See appendix B for an outline of the one-sample t-test procedure.) Similar tests were also conducted between them within each cutting length. Because no individual board data was available from Company X, paired t-tests would not have been possible. Instead, the mean value of Company X was used as the hypothesized population mean in each test.

To evaluate differences between the two processing methods in terms of cutting size, the length and width of the cuttings were examined. One sample t-tests were conducted on the overall cutting length and width. In addition, tests were also conducted on the mean cutting widths within each length.

4.0 RESULTS

4.1 Cost Data

Figure 3 shows the regression lines for both the survey and OPTIGRAMI estimates. The actual regression lines have been shifted on the y-axis to place them at the same relative point for comparison. As was mentioned earlier, these estimates are dimensionless and were designed only to be relative to one another. In other words, the information of interest lies in the *slopes* of the regression lines. The cost estimate of each length cutting was obtained from the regressions and is listed in Table 1.

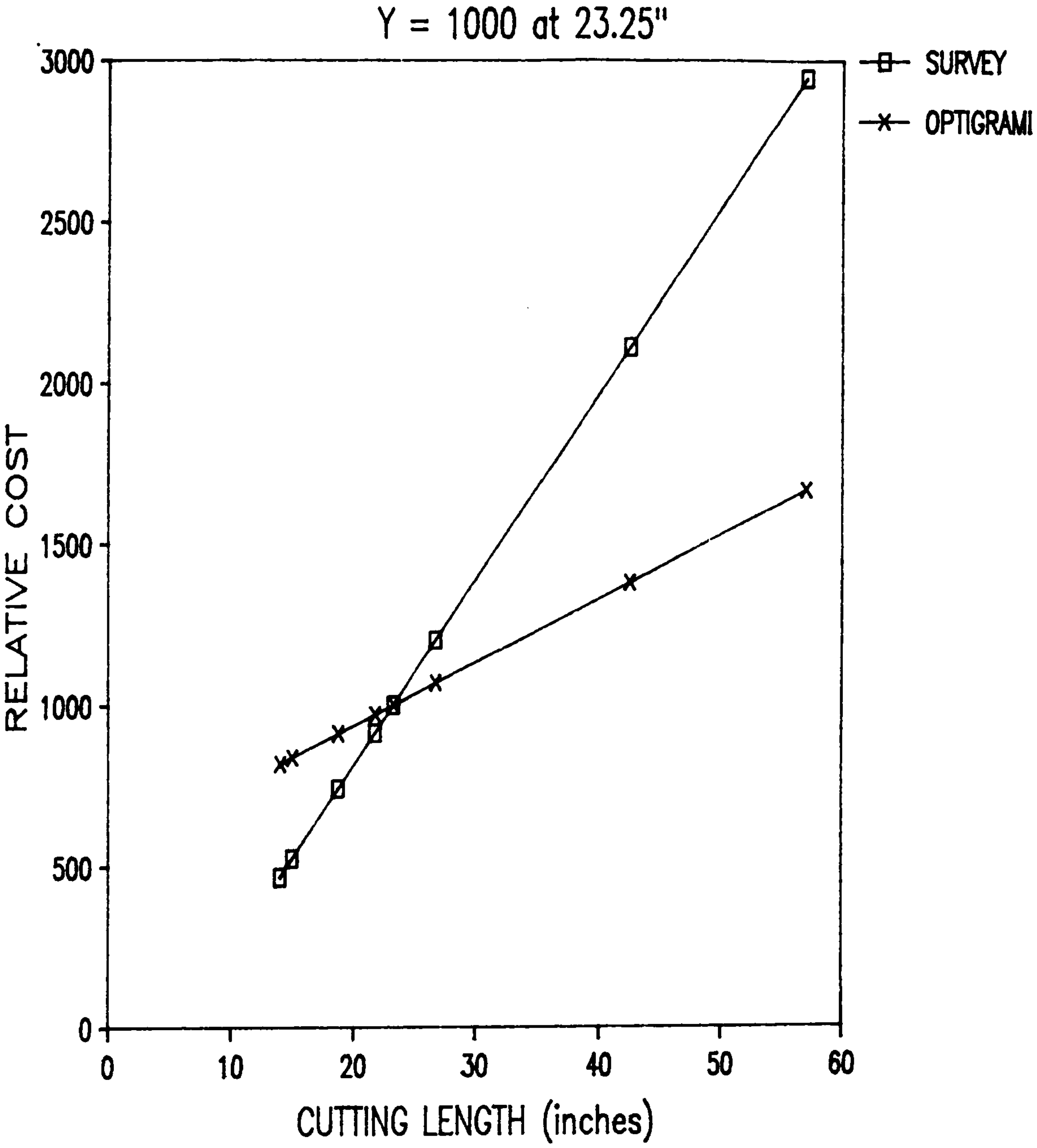


Figure 3. Cost estimate regression lines of the survey and OPTIGRAMI data.

Table 1. Estimated relative costs per board foot of each cutting length based on survey and OPTIGRAMI data.

Cutting Length (inches)	Estimated cost per board foot	
	Survey	OPTIGRAMI
14	467	818
15	524	838
18.75	741	911
21.75	914	970
23.25	1000	1000
26.75	1202	1069
42.5	2110	1379
57	2947	1665

4.2 Yield Study

4.2.1 Raw Material

The total volume of all sample boards was 938 board feet, and by group, they were 313, 315, and 310 board feet. Figure 4 depicts the frequency distribution of board widths in each sample group. This graph suggests that the widths are well distributed among the groups. The ANOVA determined statistically that there was no difference in the mean board widths of the three groups; its results are tabulated in Table 2. Because of these findings, one group (Group 1) was arbitrarily chosen for the preliminary computer analysis required before the full scale testing.

4.2.2 Computer Optimization

The initial runs of CORY on group 1 at five different weighting factors produced the average yields listed in Table 3. The graph of these values in Figure 5 illustrates that after a value of 2.00, the weighting factor has a reduced effect on the yield. Yield is only slightly decreased from 2.00 to 2.5, and actually sees an increase at 3.00.

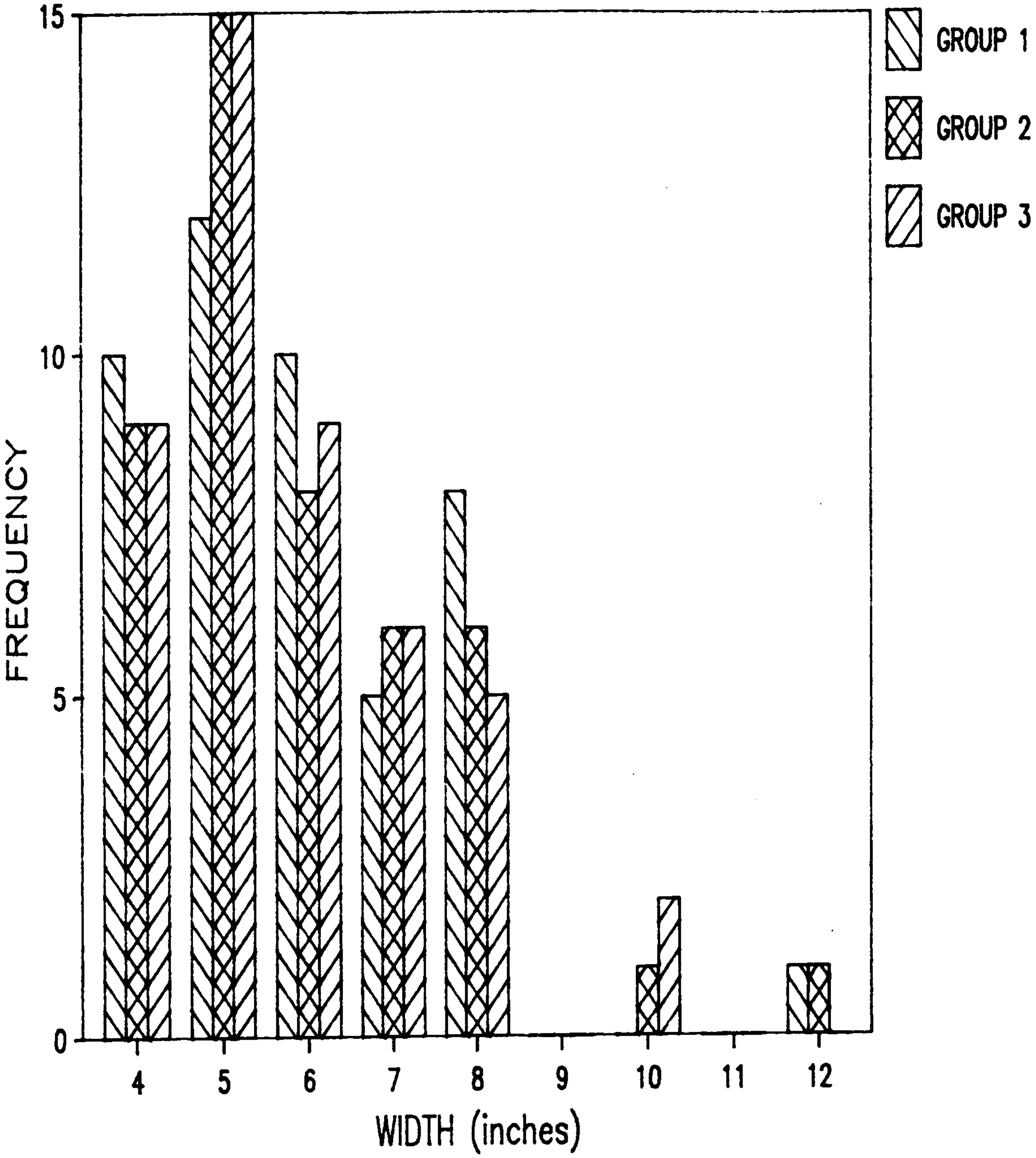


Figure 4. Frequency distributions of board widths in each sample group.

Table 2. Results of ANOVA of mean board widths among sample groups.

SOURCE OF VARIATION	DF	SS	MS	F
GROUPS	2	0.1014	0.0507	0.02
ERROR	135	347.0258	2.5706	
TOTAL	137	347.1273		

H_0 : Mean board width does not differ among the groups.

H_A : Mean board width differs among the groups.

$\alpha = 0.05$

Critical F = 3.0625

Conclusion: Do not reject H_0.

Table 3. Weighting Factor versus Yield for Group 1 CORY results.

Weighting factor, x (L^x W)	Percent Yield
1.00	74.95
1.50	72.44
2.00	71.72
2.50	71.17
3.00	71.33

Through manual verification of CORY's cutting solution for these boards at the 2.00 weighting factor, it was found that the program produced no irrational or infeasible results. (See appendix D for an example of the verification procedure.) No cuttings included defects, and no clear areas of useable size were left unused. This indicated that program CORY's performance was not only acceptable, but also very good.

CORY's solutions for groups 2 and 3 were also manually verified, and the same findings resulted: no errors in the solutions' logic.

Program CORY generated a vast amount of data on the cuttings produced. It not only produced overall yields for each group and each board, but also gave the exact dimensions and volumes of each cutting produced. The combined data is summarized in Table 4 as board footages of cuttings and average cutting widths and length. The

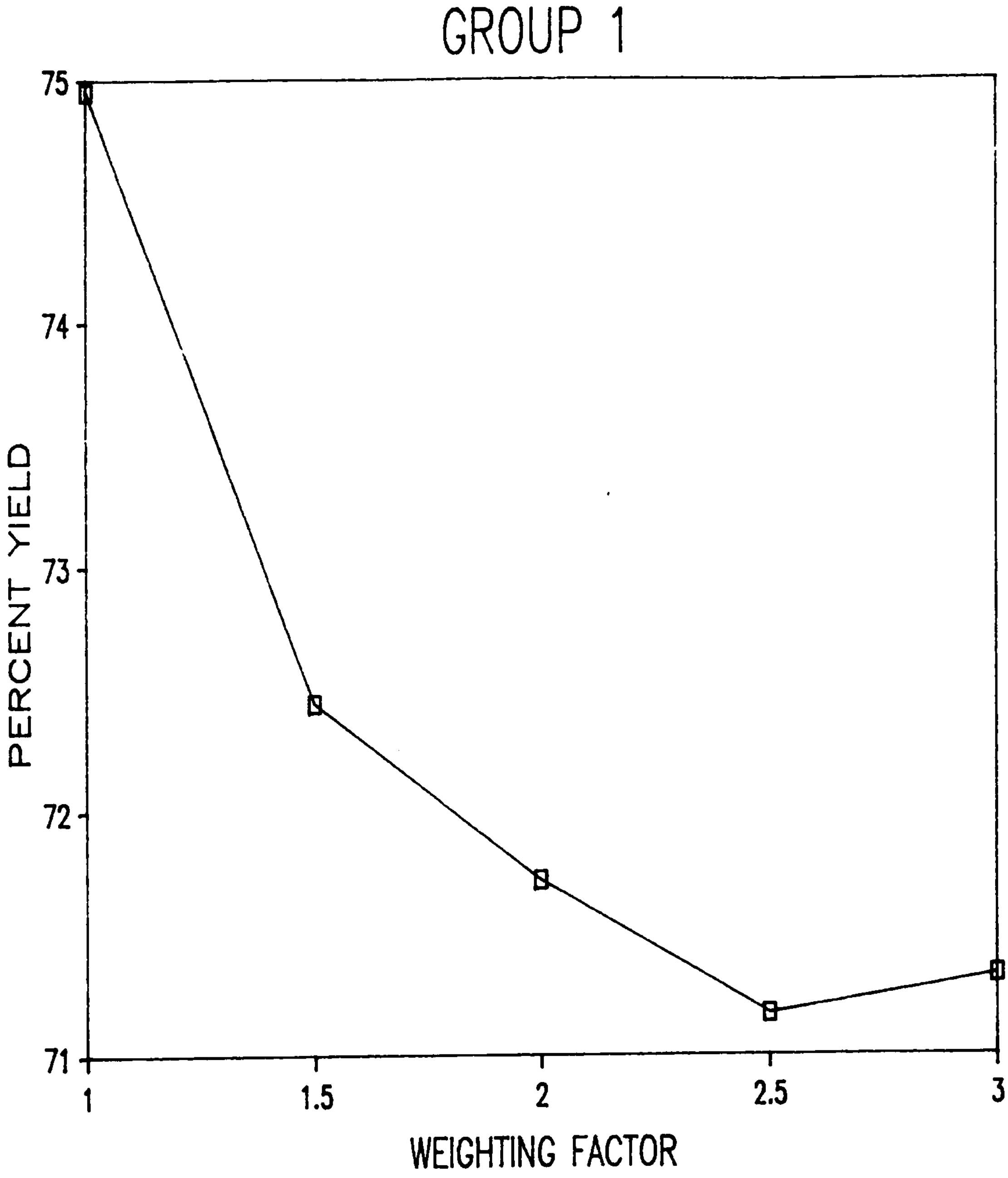


Figure 5. Weighting factor versus total yield for CORY results of Group 1.

volume information is also illustrated in Figure 6 where it is clear that the longer lengths seem to dominate the cuttings produced.

The ANOVA resulted in no significant differences among the mean board footages of the three sample groups (see Table 5). This supports the findings of the earlier board width analysis which suggested similarity among the groups.

The frequency distribution of the board footage of cuttings (for all 138 boards) is shown in Figure 7. The overall mean board footage of cuttings per board was 4.937, with a 95% confidence interval of 4.66 to 5.22. This means that one can be 95% confident that the true mean of a population of board footages of cuttings lies within this interval.

In more conventional terms, program CORY obtained an overall average yield of **72.63** percent. Although this value is not being used for analysis, it is reported here for comparison to other studies.

4.2.3 In-Plant

The in-plant yield study also produced a great deal of data for this analysis. Although no individual board yields could be obtained, data were collected on nearly every measurable variable of the processing outcome by groups. Of this gathered data, information pertinent to this study included overall yields, yields by length of cuttings, and average width of cuttings, all of which are listed in Table 6. These figures translate to an overall average yield of **75.02** percent, with the following breakdown

Table 4. CORY results summarized for volume and cutting dimensions.

Cutting Length (inches)	Volume (board feet)	Average Width (inches)	Average Length (inches)
14	8.568	1.439	
15	16.927	1.461	
18.75	13.796	1.630	
21.75	11.849	1.459	
23.25	20.891	1.418	
26.75	76.287	1.643	
42.5	72.588	1.626	
57	460.404	2.786	
Overall	681.309	1.985	36.586

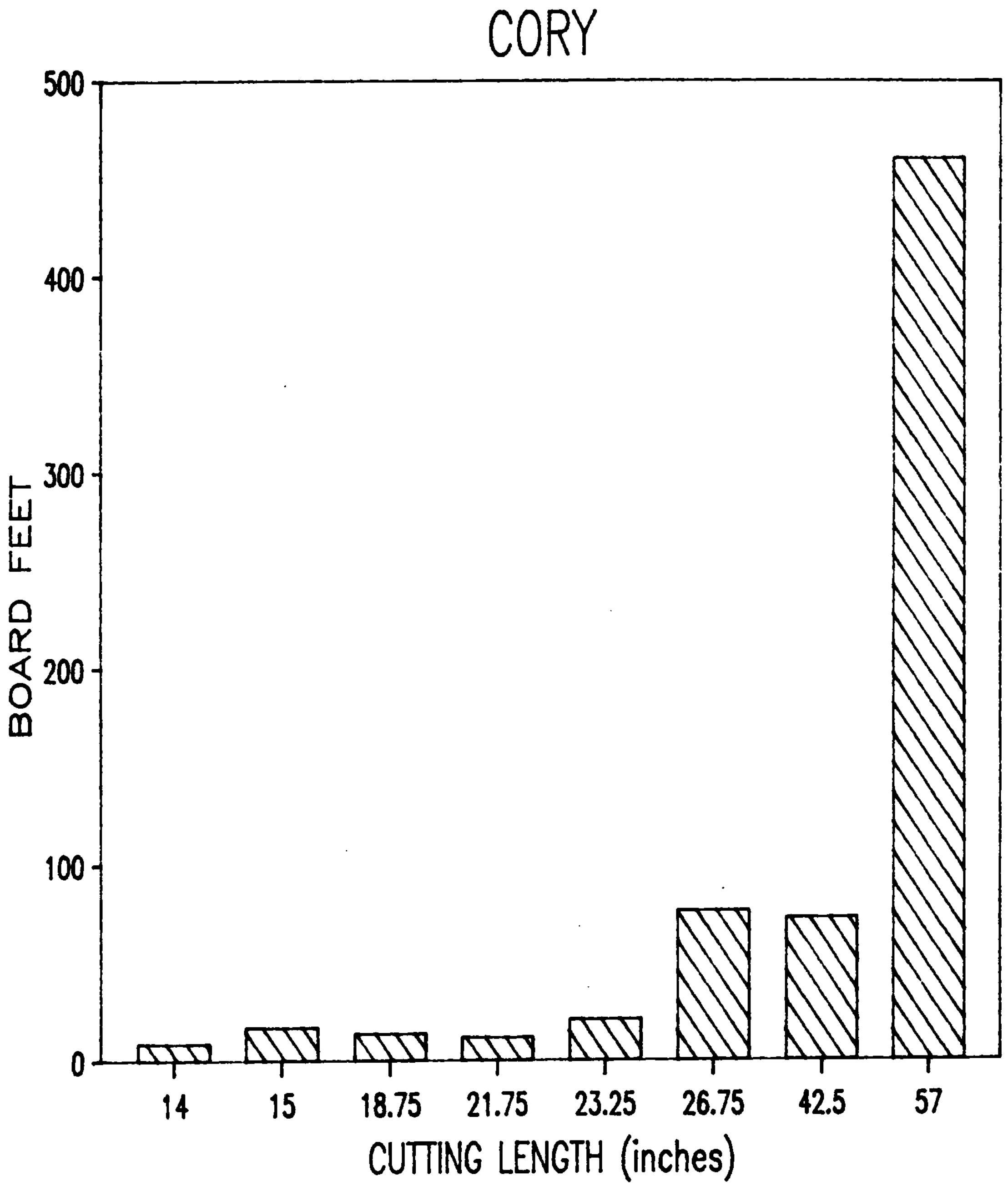


Figure 6. Total board footage of cuttings produced by CORY at each length.

Table 5. Results of ANOVA of board footage of cuttings produced by CORY per board (by group).

SOURCE OF VARIATION	DF	SS	MS	F
GROUPS	2	0.9961	0.4981	0.18
ERROR	135	381.8708	2.8287	
TOTAL	137	382.8670		

H_0 : Mean board footage of cuttings per board does not differ among groups.

H_A : Mean board footage of cuttings per board differs among groups.

$\alpha = 0.05$

Critical F = 3.0625

Conclusion: Do not reject H_0.

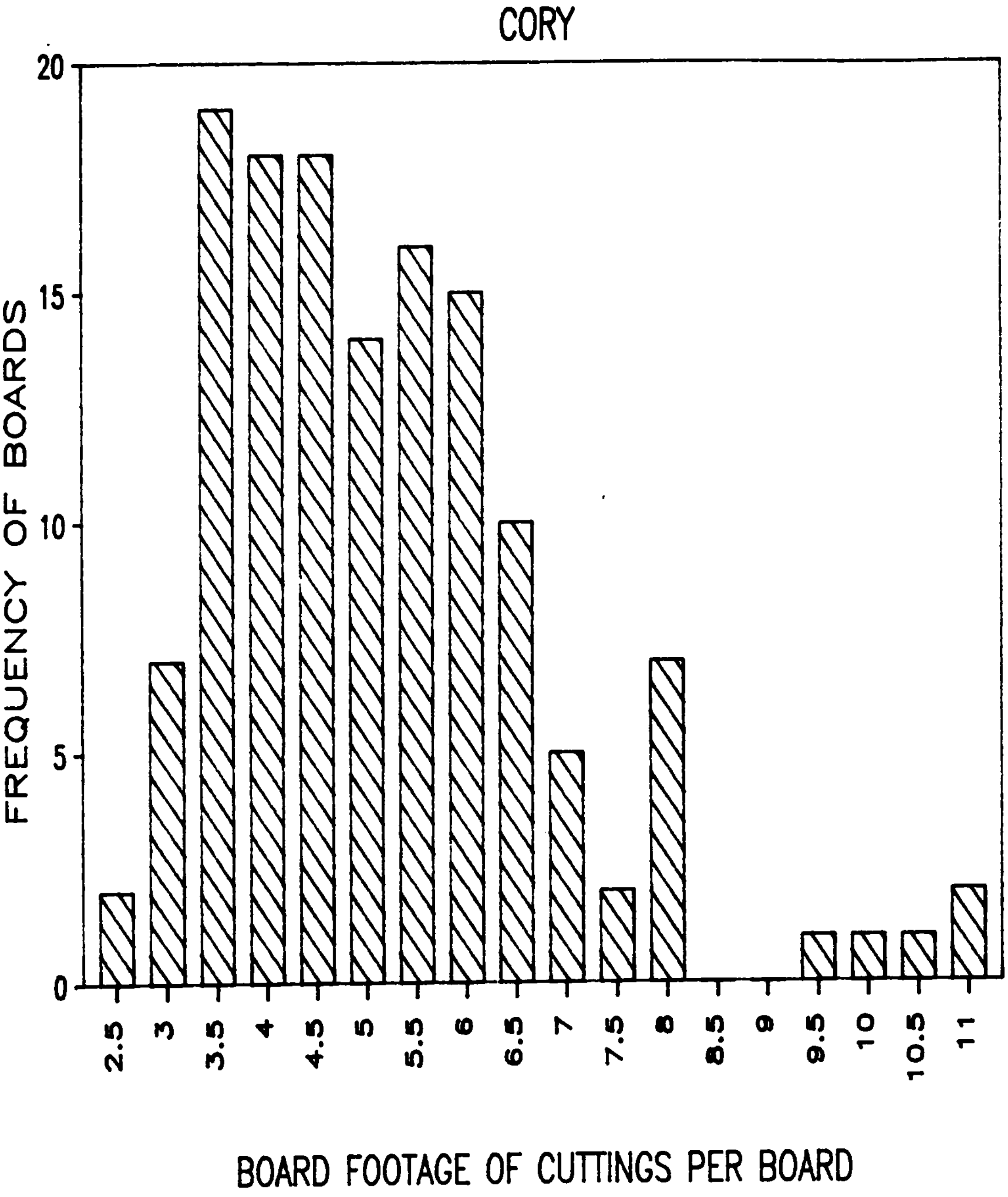


Figure 7. Frequency distribution of cutting volumes produced by CORY: board footage of cuttings per board.

of yields at the processing steps: crosscut (94.81%), rip (73.26%), and salvage (1.76%).

Figure 8 depicts the board footages of cuttings obtained at each length, showing the relative volume yields obtained. Although a 15″ cutting was included in its cutting bill, Company X produced none of this length.

4.3 VALUE ESTIMATES

The board footage data for both CORY and Company X, when combined with the cost data in Table 1 on page 33, produced the "value" estimates shown in Table 7. Due to the nature of the cost estimates, the longer cutting length cuttings were transformed into a greater proportion of the (value) yields. As expected from the cost estimates, the survey produced cuttings of greater estimated value than did OPTIGRAMI.

4.4 Computer Optimization vs. In-plant

4.4.1 Volume

The t-test between the two processing methods in overall board feet of cuttings indicated that there was no significant difference between them. Within each length of cuttings, CORY and Company X had significantly higher recoveries in alternating

Table 6. Company X results summarized for volume and cutting dimensions.

Cutting Length (inches)	Volume (board feet)	Average Width (inches)	Average Length (inches)
14	10.55	1.443	
15	0	0	
18.75	99.40	2.461	
21.75	1.97	0.790	
23.25	191.80	3.127	
26.75	32.02	1.498	
42.5	192.25	2.993	
57	175.62	3.113	
Overall	703.619	2.645	28.078

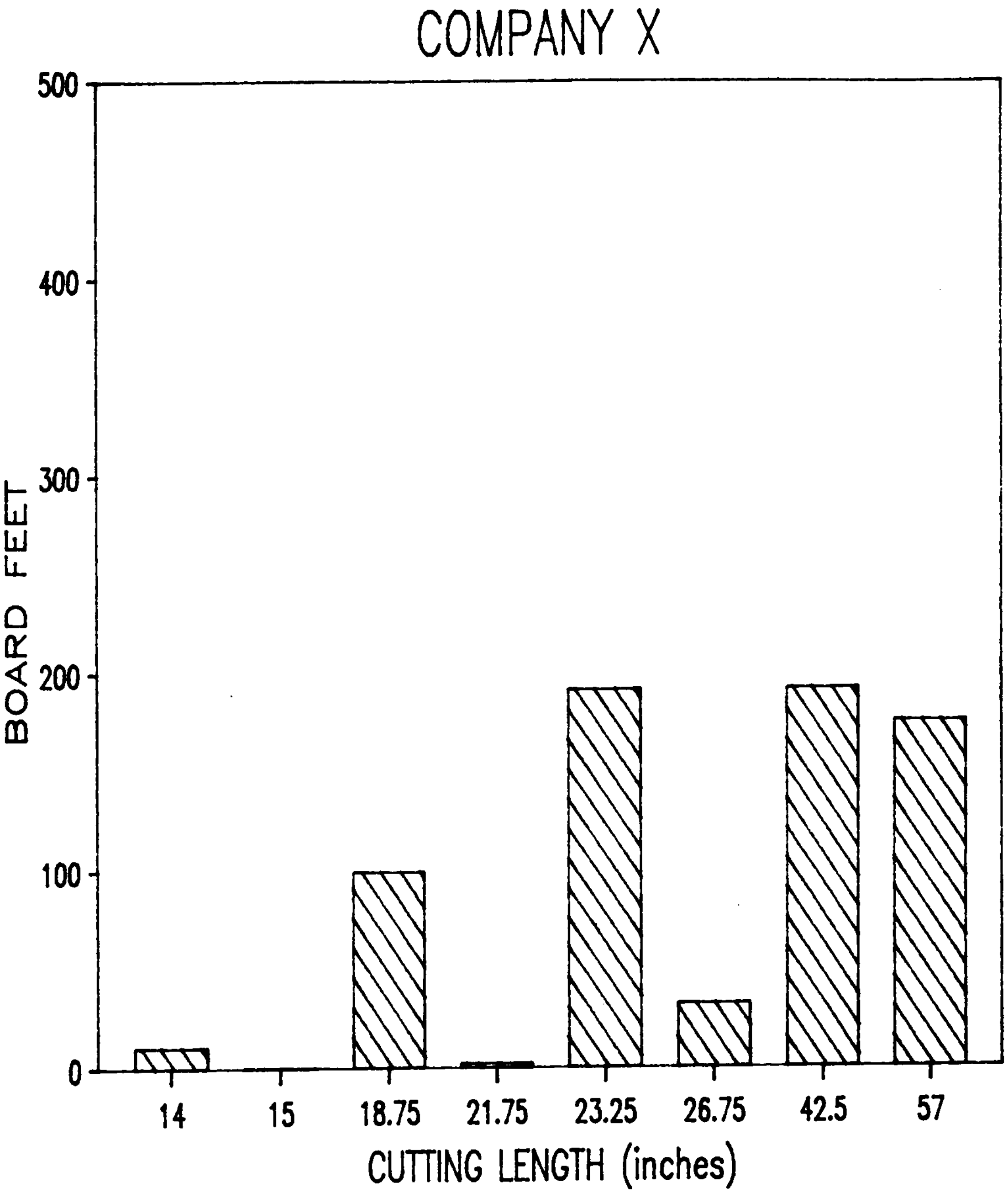


Figure 8. Total board footage of cuttings produced by Company X at each length.

Table 7. Value estimates of CORY and Company X cuttings at each length.

Cutting Length (inches)	Survey		OPTIGRAMI	
	CORY	Company X	CORY	Company X
14	3,998	4,923	7,007	8,628
15	8,875	0	14,177	0
18.75	10,216	73,608	12,573	90,591
21.75	10,824	1,800	11,499	1,912
23.25	20,891	191,800	20,891	191,800
26.75	91,683	38,482	81,545	34,227
42.5	153,160	405,645	100,107	265,134
57	1,356,386	517,390	766,422	292,350
Overall	1,656,032	1,233,648	1,014,221	884,642

lengths (see Table 8). CORY exceeded Company X in recovery of 15″, 21.75″, 26.75″, and 57″ cuttings; Company X obtained the greater volumes in the 18.75″, 23.25″, and 42.5″ cuttings. The only length in which there was no significant difference was the shortest, 14″.

The results from the two are shown together in Figure 9. Figure 10 better illustrates the relative proportions of board footages of cuttings obtained by the two methods. Company X produced an average of 5.10 board feet of cuttings per board; this volume was within the 95% confidence interval of the mean footage per board obtained by CORY.

4.4.2 Value

The t-test between the two methods in *overall value* of the cuttings indicated that CORY was significantly higher than Company X for both the survey and OPTIGRAMI. The tests within each individual length were the exact same tests which were done for volume, and so, as expected, the same results were achieved (see Table 9). Figure 11 shows the results of the two methods for both the survey and the OPTIGRAMI estimates. In Figure 12 the same information is illustrated to show the relative proportions of the total value.

Table 8. Results of one-sample t-tests between CORY and Company X for board footage of cuttings produced at each length and overall.

Cutting Length (inches)	Mean Board Footage		T value	Decision on H_0
	CORY	Company X		
14	0.062	0.076	-1.14	Do Not Reject
* 15	0.123	0.000	7.63	Reject
18.75	0.100	0.720	-34.88	Reject
* 21.75	0.086	0.014	4.33	Reject
23.25	0.151	1.390	-53.47	Reject
* 26.75	0.553	0.232	7.69	Reject
42.5	0.526	1.393	-11.95	Reject
* 57	3.336	1.273	17.85	Reject
Overall	4.937	5.10	-1.14	Do Not Reject

H_0 : Mean BF of cuttings from CORY = Mean BF of cuttings from Company X.

H_A : Mean BF of cuttings from CORY ≠ Mean BF of cuttings from Company X.

n = 138

df = 137

$\alpha = 0.05$

Critical T = 1.9776

* indicates CORY mean > Company X mean.

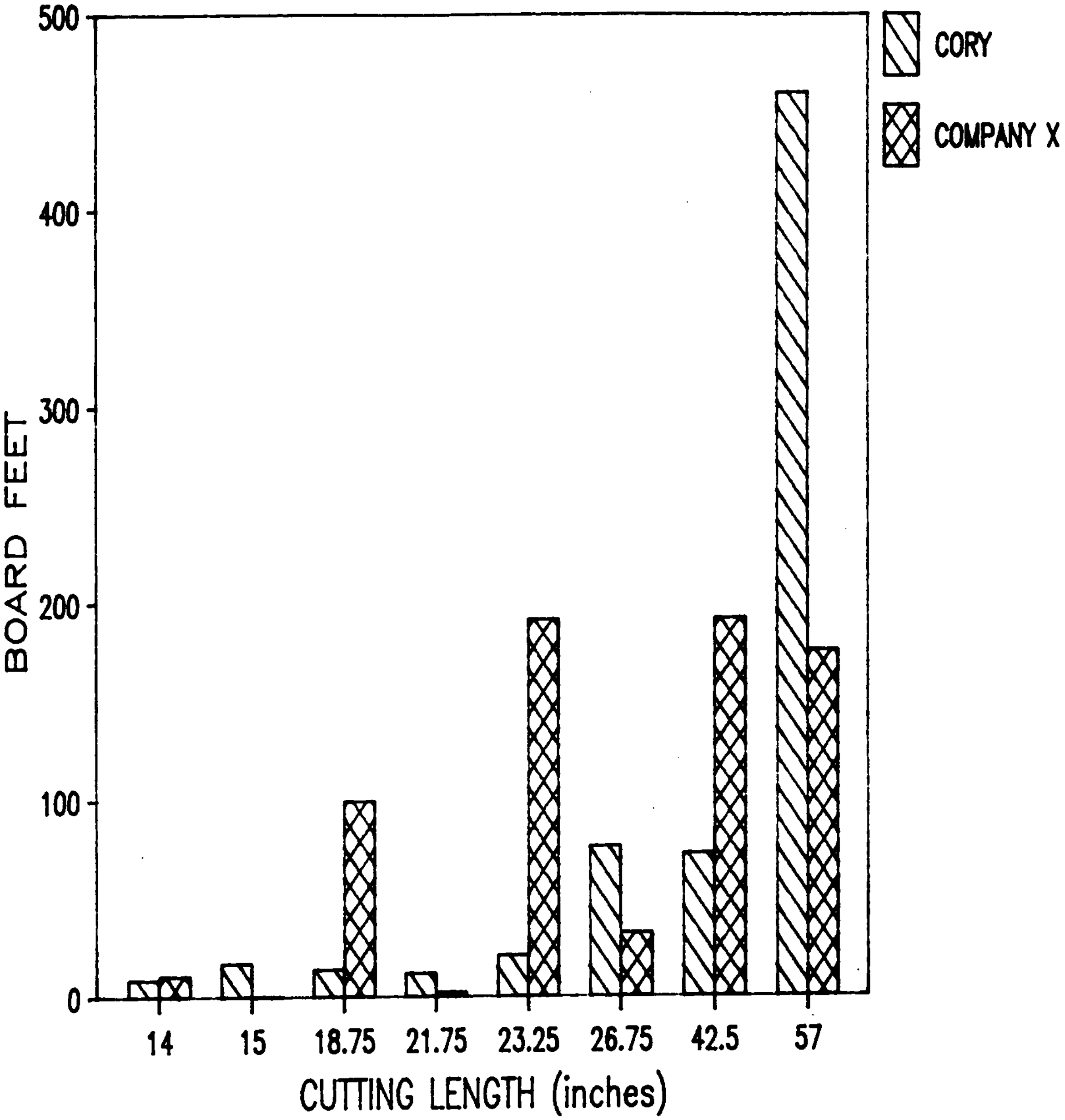


Figure 9. Total board footage of cuttings produced by CORY and Company X at each length.

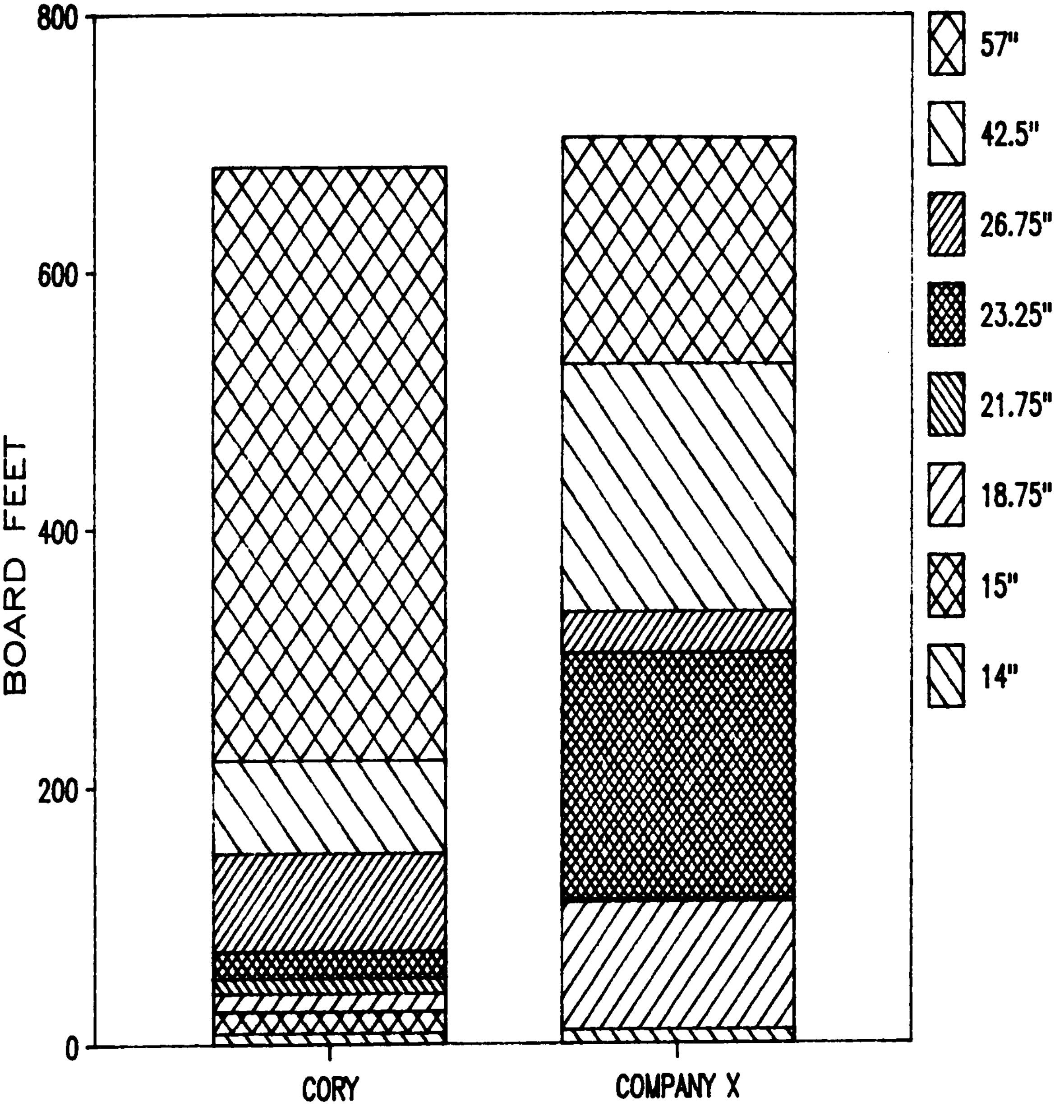


Figure 10. Relative board footages of cuttings produced by CORY and Company X at each length.

Table 9. Results of one-sample t-tests between CORY and Company X for value of cuttings based on survey and OPTIGRAMI.

A. Survey

Cutting Length (inches)	Mean Value		T value	Decision on H_0
	CORY	Company X		
14	29	36	-1.14	Do Not Reject
* 15	64	0	7.63	Reject
18.75	74	533	-34.88	Reject
* 21.75	78	13	4.33	Reject
23.25	151	1390	-53.47	Reject
* 26.75	664	1279	7.69	Reject
42.5	1110	2939	-11.95	Reject
* 57	9829	3749	17.85	Reject
Overall	12000	8939	8.80	Reject

B. OPTIGRAMI

Cutting Length (inches)	Mean Value		T value	Decision on H_0
	CORY	Company X		
14	51	63	-1.14	Do Not Reject
* 15	103	0	7.63	Reject
18.75	91	656	-34.88	Reject
* 21.75	83	14	4.33	Reject
23.25	151	1390	-53.47	Reject
* 26.75	591	248	7.69	Reject
42.5	725	1921	-11.95	Reject
* 57	5554	2118	17.85	Reject
Overall	7249	6410	4.47	Reject

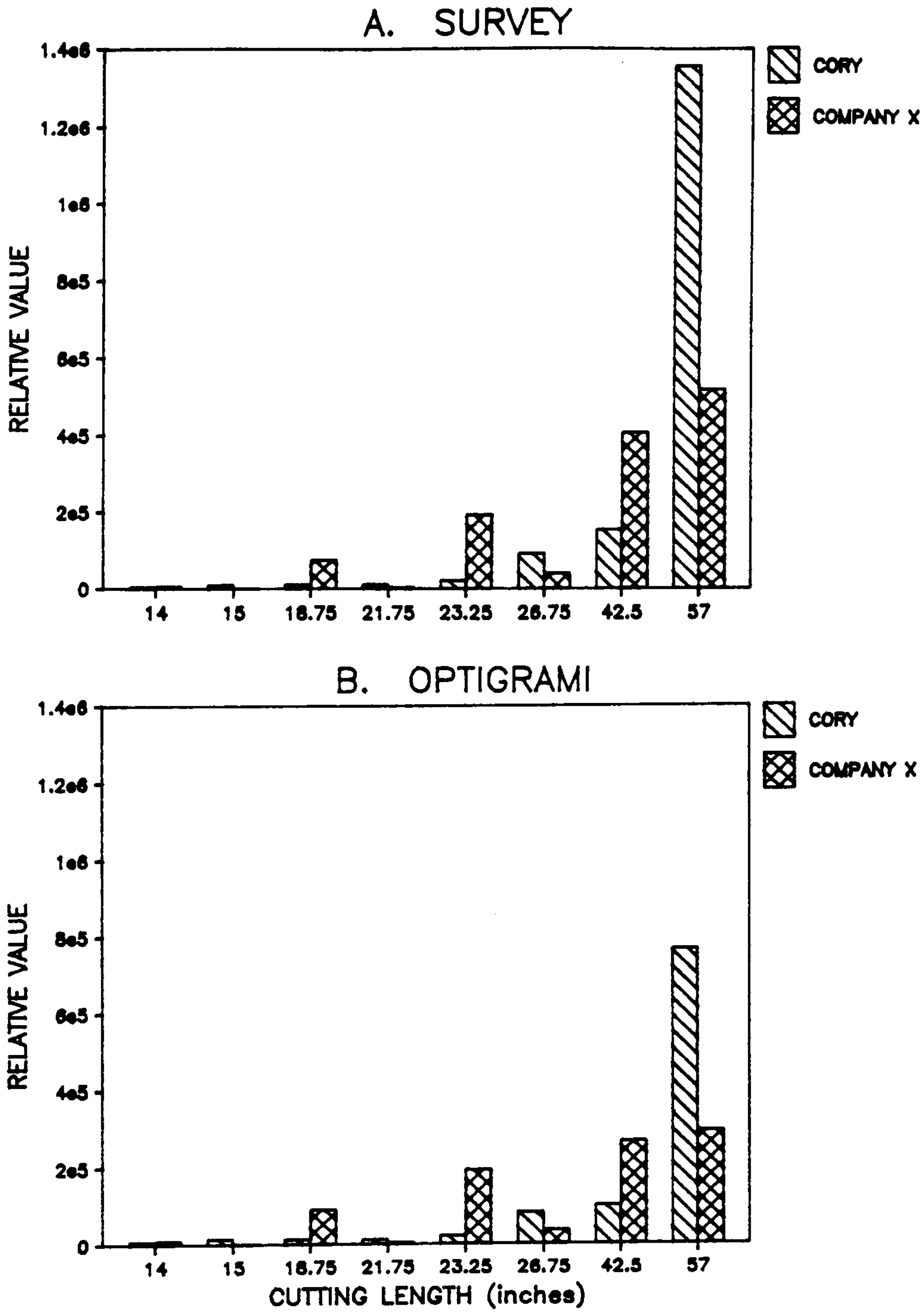
H_0 : Mean BF of cuttings from CORY = Mean BF of cuttings from Company X.

H_A : Mean BF of cuttings from CORY $\neq$ Mean BF of cuttings from Company X.

$n = 138$ $\qquad$ $df = 1337$

$\alpha = 0.05$ $\qquad$ Critical $T = 1.9776$

* indicates CORY mean > Company X mean.


A. SURVEY

B. OPTIGRAMI

Figure 11. Value of cuttings produced by CORY and Company X: a) based on survey, b) based on OPTIGRAMI.

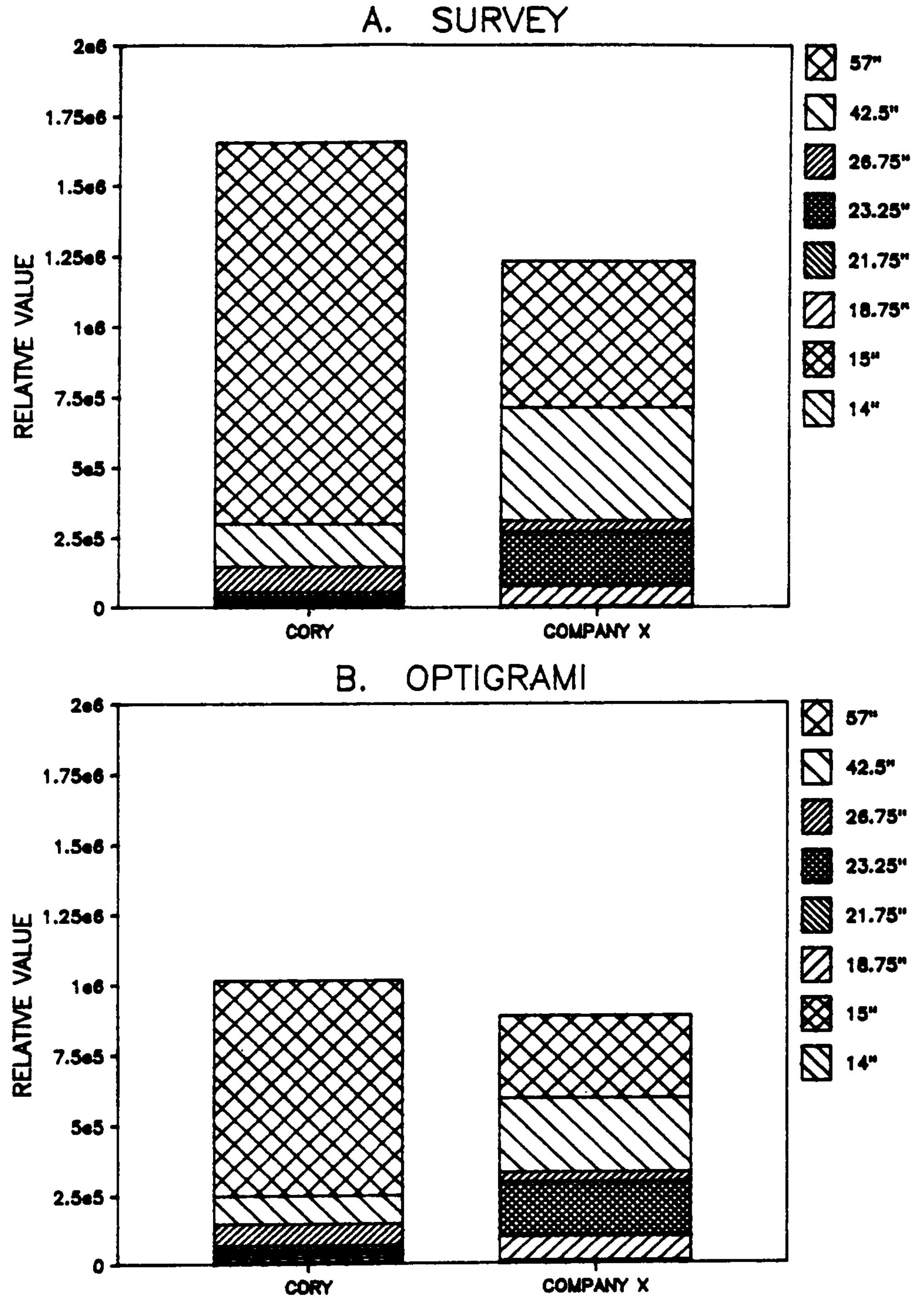


Figure 12. **Relative value of cuttings produced by CORY and Company X at each length:** a) based on survey b) based on OPTIGRAMI.

4.4.3 Size

T-tests indicated that Company X produced an overall *wider* cutting than did CORY. Within each length, however, the two each had significantly wider cuttings in different lengths (see Table 10). It was found that the only length in which the widths did not significantly differ was the 14″ class. Also, with the exception of the longest length of 57″, CORY exceeded Company X in the same lengths as it had in terms of volume (see Figure 13).

CORY's overall average length of all cuttings was found to be significantly *higher* than that of Company X (see Table 11).

The average dimensions CORY and Company X cuttings are depicted in Figure 14 where they are drawn relative to one another.

Table 10. Results of one-sample t-tests between CORY and Company X for width of cuttings produced at each length and overall.

	Mean Width (inches)					
Cutting Length (inches)	CORY	Co. X	df	T value	Critical T	Decision on H_0
14	1.4388	1.4433	48	-0.0335	2.0110	Do Not Reject
* 15	1.4607	0	88	14.1642	1.9870	Reject
18.75	1.6298	2.4605	51	-5.2122	2.0080	Reject
* 21.75	1.4593	0.7900	42	4.3894	2.0180	Reject
23.25	1.4178	3.1267	72	-13.6819	1.9930	Reject
* 26.75	1.6425	1.4982	199	1.9807	1.9729	Reject
42.5	1.6260	2.9933	120	-13.8162	1.9800	Reject
57	2.7859	3.1133	333	-4.9104	1.9677	Reject
Overall	1.9847	2.6445	960	-16.3218	1.9626	Reject

H_0 : Mean width of cuttings from CORY = Mean width of cuttings from Company X.

H_A : Mean width BF of cuttings from CORY $\neq$ Mean width of cuttings from Company X.

$\alpha = 0.05$

* indicates CORY mean > Company X mean.

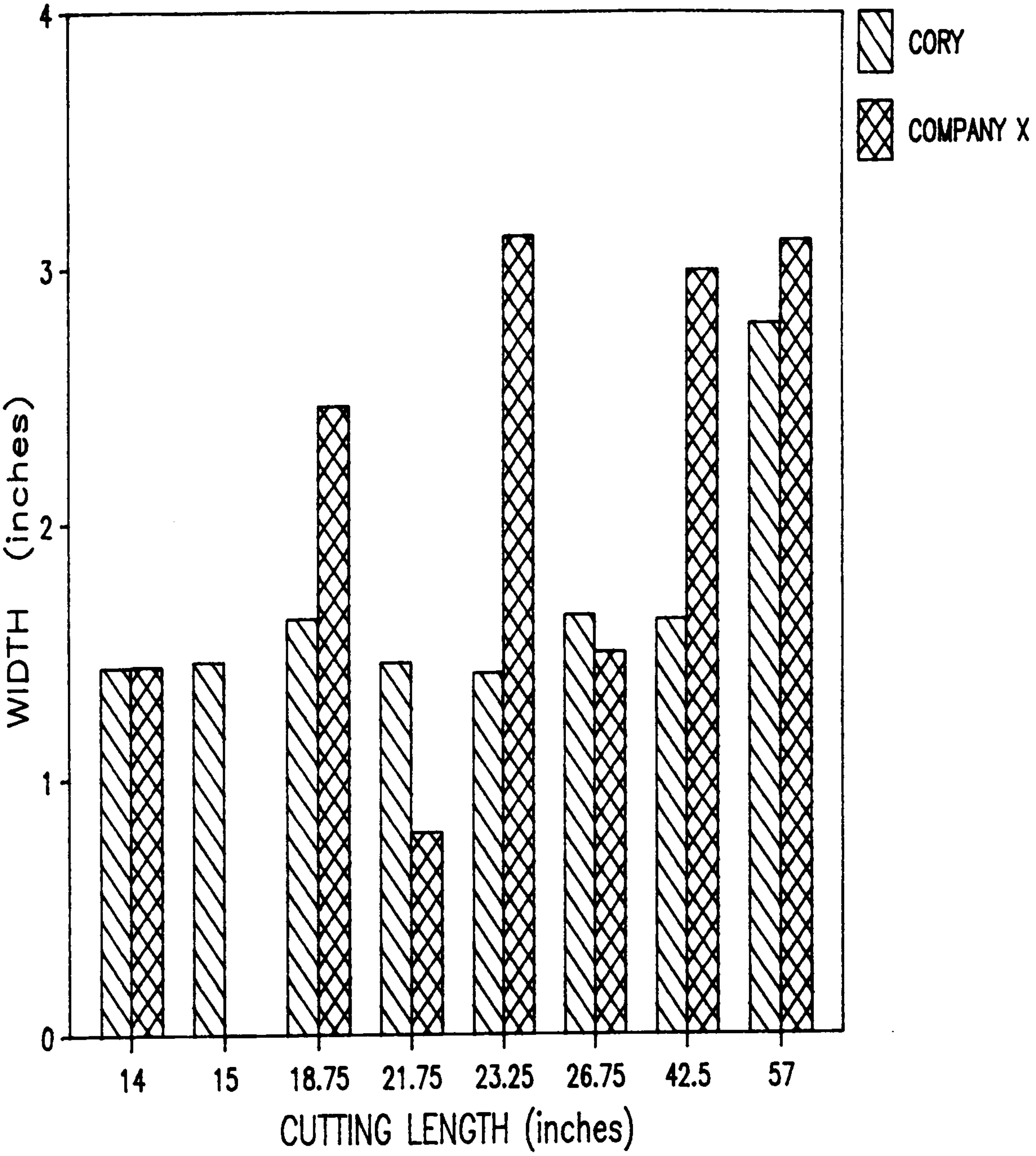


Figure 13. Average widths of cuttings produced by CORY and Company X at each length.

Table 11. Results of one-sample t-test between CORY and Company X for mean length of all cuttings produced.

	Mean Length (inches)			
	CORY	Company X	T value	Decision on H_0
All Cuttings:	36.5858	28.0777	15.7873	Reject *

H_0 : Mean length of cuttings from CORY = Mean length of cuttings from Company X.

H_A : Mean length of cuttings from CORY ≠ Mean length of cuttings from Company X.

n = 961

df = 960

$\alpha = 0.05$

Critical T = 1.9626

* indicates CORY mean > Company X mean.

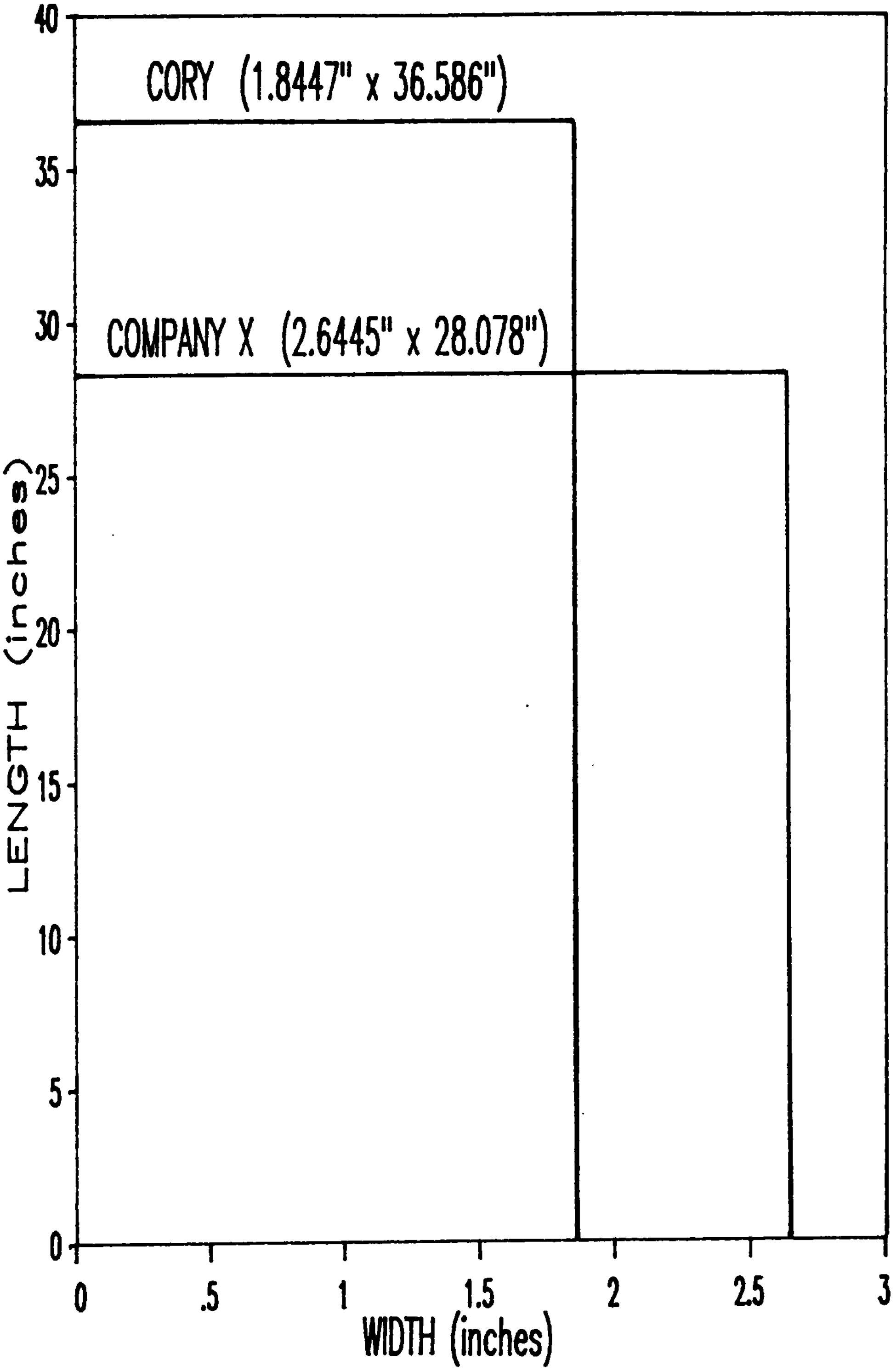


Figure 14. Relative average dimensions of cuttings produced by CORY and Company X.

5.0 DISCUSSION

5.1 Cost Data

The cost estimates from the survey and from OPTIGRAMI have been maintained separately throughout this study. Because these estimates are from two very different sources, it would not have been valid to combine them. The survey estimates serve as an example of what manufacturers may consider to be variations in cost of cuttings as their lengths vary. OPTIGRAMI provides another estimate which is not based on any actual situations, but rather on inferences from an optimization routine.

The regression line of the cost estimates from the survey response was found to be steeper than that of the OPTIGRAMI results (Figure 3 on page 32). This implies that, over the same range of cutting engths, the survey estimates vary more dramatically, covering a wider range of values. These two data sets could be considered as defining a hypothetical range of costs. Due to the highly subjective nature of this data, it is difficult to obtain what can actually be claimed to be true costs.

It is generally believed that cost of cuttings increases with length, and these data support that hypothesis. It is difficult to demonstrate the accuracy of either set of estimates, but for the purposes of this study, general estimates will serve. The linear regressions of each data set had, however, resulted in R-square values of .998 for the survey and .957 for OPTIGRAMI. (See appendix E for original data sets and regressions.)

These cost estimates are not meant to include processing and other costs. Instead, they represent the relative variations in costs arising from the greater degree of difficulty in obtaining the longer lengths. This is a phenomenon which is based on the distribution of defects throughout any given board. The smaller the cuttings, the greater the chance of utilizing more clear areas of the board, i.e. obtain higher yields. It is more difficult to fit larger cuttings into the same clear areas, and less board footage is recoverable. Given a board of certain initial cost, these larger cuttings actually cost more to produce than do the smaller cuttings. Likewise, to obtain the same board footage of longer cuttings, more volume of lumber must be used.

5.2 Yield Study

5.2.1 Computer Optimization

Brunner (1984) found in the initial developmental studies of program CORY that an increase in the weighting factor from 1.00 to 2.00 resulted in a 3 percent decrease in yield. It was seen in the analysis of group 1 that similar results were obtained

(Table 3 on page 37 and Figure 5 on page 38). With group 1, increasing the weighting factor from 1.00 to 2.00 resulted in a 3.23 percent decrease in yield.

A review of literature indicates that in nearly every study involving computer optimization of yields, a weighting factor of 2.00 has been used. Although there is no actual numerical basis for the use of this value, it has become accepted as the convention. That fact alone justified using the same weighting factor in this study. The preliminary analysis done here, however, tends to also provide some additional support for the use of 2.00 as a realistic estimate. A considerable amount of further research on this issue of weighting factors will be required in order to obtain sufficient verification of the values.

The weighting factor option in program CORY allowed for systematic control over cutting length priorities. The results showed that the cutting solutions were, in fact, dominated by the longer lengths. This is the key factor in the analysis of cutting value.

5.2.2 In-plant

Although rough mill yields are generally believed to be at or about the fifty percent level, the mill in this study exceeded expectations. Company X is not believed to be highly representative of all rough mills, and its level of recovery places them at the upper end of a range of yields. Since there are many factors which affect the yield of a rough mill, it is difficult to fully characterize its performance. In particular, however, it was noticed that the cutting grades of Company X were rather liberal in allowing defects.

The purpose of this yield study was not to evaluate the factors contributing to yield nor to compare this mill's performance to others which exist. It was used strictly as a case study.

The results from Company X indicate that there was no systematic variation in volume of cuttings of different lengths. From this we can infer that the saw operators have little control in emphasizing particular lengths of cuttings. Because the cutting bill had been allowed to float, the task of the saw operator was to essentially optimize each board for useable cuttings of appropriate size.

5.3 Computer Optimization vs. In-plant

5.3.1 Volume

On the basis of volume alone, Company X recovered cuttings at a rate which could not be exceeded by computer optimization. The length distribution of cuttings varies dramatically between the two methods, but the differences disappear on the overall level. This trend is similar to the results of Hall's study (Hall et al. 1980) which had compared the yields of crosscut-first and rip-first sequences to FPL-118 predictions (Englerth and Schumann 1969). Their results had shown that overall predictions were accurate, while those for the individual cutting lengths were not. This similarity in the results suggests that overall yield is not an all-inclusive indicator of rough mill performance.

Each board's defects had been mapped and entered into program CORY according to Company X's specific grading rules. This means that CORY and Company X had the exact same raw material to process. Therefore, any difference between the two outcomes must be the result of cutting solution development.

The lengths in which CORY exceeded Company X in cutting volume production are evident in the graph of Figure 9 on page 50. From the t-test results in Table 8 on page 49, it is quite clear that there is a trend among the lengths in which CORY exceeds Company X. It would appear that, in every pair of two consecutive lengths, CORY was able to produce more cutting volume in the longer one.

One may speculate that this phenomenon results from the computer's ability to more accurately discriminate between similar lengths. Whereas a human decision-maker would tend to have a much more subjective response, the computer can quickly determine the maximum length that will fit into a clear area. In other words, CORY requires no guesswork as might the saw operator.

The stacked bar graph (Figure 10 on page 51) shows clearly that CORY produced a greater proportion of longer length cuttings. These results are largely due to the fact that with the computer optimization, there is a systematic control over the weighting factor. In Company X (or any other mill), this same role is left to the subjective interpretation of the saw operator. Although the saw operators are capable of producing the same level of volume, they have less control over the size distribution.

5.3.2 Value

In both cases of estimates (survey and OPTIGRAMI), CORY was found to have produced total cuttings of higher value than Company X had. This results from CORY's volume distribution which is skewed toward the longer lengths, unlike that of Company X. Whereas the volume yields were the same between CORY and Company X, the value yields significantly differ.

5.3.3 Size

While it had been found that overall *volumes* were not significantly different between the two processing methods, this overall *width* test indicated that one (Company X) had a greater cutting width. This means that CORY would have had to compensate for their volume in the length of its cuttings. The test for cutting length showed that this was, in fact, true. This result was not surprising since CORY had been shown to produce a greater proportion of it cuttings in the longer lengths.

In the analysis of cutting width of each length, the results showed a trend similar to the volume tests. With the exception of the 57″ length class, the lengths in which CORY had wider cuttings were the same lengths in which it also had produced more volume. This general correlation seems logical since, in a given length, the only remaining variable is width.

6.0 CONCLUSIONS

- The cost estimates alone indicated that the value of cuttings increases with increasing length. However, the total value of cuttings produced was governed by the distribution of cutting sizes resulting from the cut-up.

- Computer optimization was not able to produce a volume of cuttings which exceeded that of the conventional rough mill. It was, however, able to produce cuttings of greater value than could the conventional rough mill.

7.0 IMPLICATIONS AND FUTURE RESEARCH

This study is perhaps most valuable in its implications to this area of research. It has quantified, through the use of a case study, several concepts which had previously only been assumed or generally held without investigation.

The continuing research in the area of rough mill automation had been driven under the assumption that conventional processing methods could easily be improved upon. The present systems have often been looked upon as inadequate and inefficient, and that computerization and automation were the solutions.

This study has shown that, although there are benefits to be gained through computer optimization, these advantages are not necessarily in the expected forms. Computer optimization was not able to improve on the volume yield of the mill in this study. Volume recovery has been the traditional measure of rough mill efficiency or performance. If one were to examine this situation in that manner, then the conclusion would be that computerization has no value to the system.

Examination of the length distributions and value components of this study has made it possible to see the potential benefits of automation. The level of consistency and control over processing variables makes computerization highly desirable. It is because of these factors that an improvement in the value of cuttings can result.

The automated system is not superior simply in its ability to make cutting decisions, for this, in fact, has yet to be proved. Its merit, rather, lies in its ability to make systematic decisions based on input variables.

This situation clearly indicates a need for new measures of rough mill performance. The physical volume of cuttings produced in a system may indicate only general levels of efficiency. The true indicator is the value of the cuttings produced. It is, after all, the value and not volume which reflects an object's worth. A rough mill could recover cuttings based only on volume, but unless those cuttings fit its requirements, they are of no use.

In addressing the more general issue of rough mill automation, this study shows that a conventional rough mill has potential for improvement. It implies that alternative cutting systems are not necessarily required to achieve these improvements. This finding provides a optimistic outlook toward rough mill automation. It has shown that there is potential to automate the rough mill in stages, without completely overturning the current system. It is most likely that the successful and acceptable automation of the rough mill will occur in this gradual fashion.

However, before even this stepwise merging of automation with conventional systems can occur, more research will be required. Although progress continues, the prospect for full rough mill automation in the near future is quite low. Therefore, in addition to continuing efforts on that level, it may definitely be worthwhile to redirect some emphasis on interfacing systems which would enable the industry to utilize currently available technologies.

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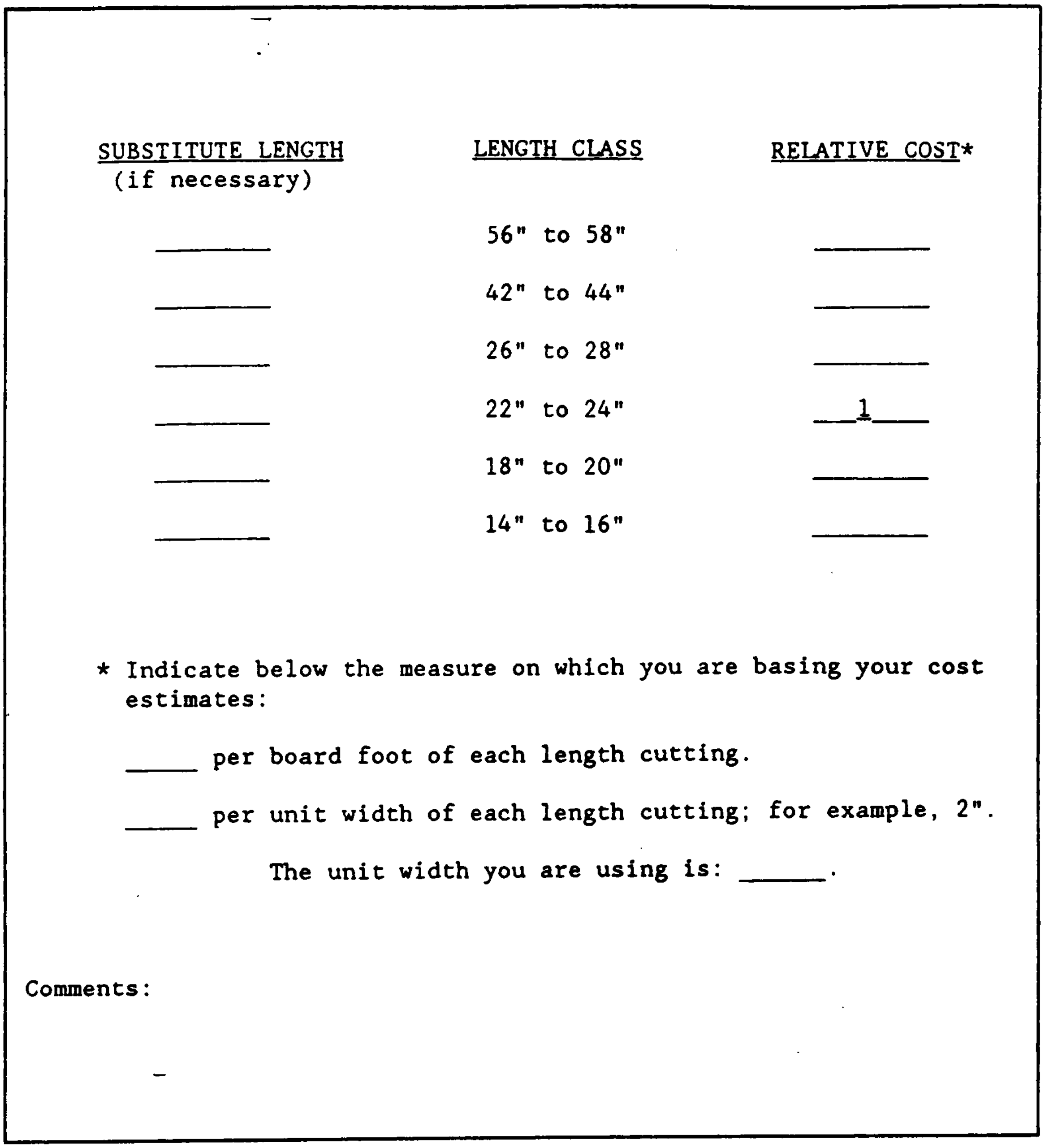
Appendix A. Cost Data Survey



SUBSTITUTE LENGTH (if necessary)	LENGTH CLASS	RELATIVE COST*
________	56" to 58"	________
________	42" to 44"	________
________	26" to 28"	________
________	22" to 24"	___1____
________	18" to 20"	________
________	14" to 16"	________

* Indicate below the measure on which you are basing your cost estimates:

_____ per board foot of each length cutting.

_____ per unit width of each length cutting; for example, 2".

The unit width you are using is: ______.

Comments:

Figure A. Survey sent to selected rough mills for obtaining cost estimates of different length cuttings.

Appendix B. Statistical Procedures

The statistical methods employed throughout this study are very basic procedures commonly used. Zar (1984) was used as a reference.

B.1 Analysis of Variance (ANOVA)

[4]

SOURCE OF VARIATION	DF	SS	MS	F
GROUPS	K - 1	$\frac{\sum_{i=1}^{k}\left(\sum_{j=1}^{n_i} X_{ij}\right)^2}{N} - C$	$\frac{\text{GROUP SS}}{\text{GROUP DF}}$	$\frac{\text{GROUP MS}}{\text{ERROR MS}}$
ERROR	N - K	$\text{TOTAL}_{SS} - \text{GROUP}_{SS}$	$\frac{\text{ERROR SS}}{\text{ERROR DF}}$	
TOTAL	N - 1	$\sum_{i=1}^{k}\sum_{j=1}^{n_i} X_{ij}^2 - C$		

$H_0 : \mu_1 = \mu_2 = \mu_3$

H_A : Not all μ_i are equal.

df = degrees of freedom

N = sample size = $\sum_{i=1}^{k}\sum_{j=1}^{n_i}$

SS = sum of squares

MS = mean squares

$$C = \frac{\left(\sum_{i=1}^{k}\sum_{j=1}^{n_i} X_{ij}\right)^2}{N}$$

At α level, reject H_0 if $F > F_{k-1,N-k}$

---

[4] Adapted from (Zar 1984), Table 11.2.

B.2 One sample t-test of means procedure.

H_0 : Sample mean = Hypothesized population mean.
H_A : Sample mean $\neq$ Hypothesized population mean.

$$T = \frac{\bar{X} - \mu_0}{S_{\bar{X}}}$$

$$S_{\bar{X}} = \frac{S}{\sqrt{N}}$$

$\bar{X}$ = sample mean
N = sample size
S = sample standard deviation
μ_0 = hypothesized population mean

For a two-tailed test, reject H_0 if: $|T| > T_{\alpha(2),df}$

Appendix C. CORY Output

```
 ______________________________________________________________________________
|                                                                              |
|                  DIMENSION STOCK YIELD FOR BOARD ONE                         |
|______________________________________________________________________________|
|                                                                              |
|                        PROGRAM INPUT SPECIFICATIONS                          |
| ------PROCESSING OPTIONS------          ---CUTTING BILL SIZES IN INCHES---   |
| FIRST OPERATION=CROSSCUT           [5]  ROUGH THICKNESS= 1.25                |
| CUTTING QUALITY=CLEAR TWO FACE          WIDTH:  MIN.=0.50   MAX.= 5.00      |
| WEIGHTING FACTOR=2.00                    8 CUTTING LENGTH CLASSES:           |
|                                          14.00  15.00  18.75  21.75  23.25   |
|                                          26.75  42.50  57.00                 |
|______________________________________________________________________________|

-------------------------BOARD AND YIELD INFORMATION-------------------------

       BOARD WIDTH :   0.50 FT.               CUTTING  AREA :   3.89 SQ.FT.
       BOARD LENGTH:  12.10 FT.               CUTTING VOLUME:   4.86 BD.FT.
       BOARD AREA  :   6.06 SQ.FT.            AREA  YIELD   :  64.13 PERCENT
       BOARD VOLUME:   7.57 BD.FT.            WEIGHTED YIELD:  19.06 PERCENT

-------------------------CUTTING STOCK INFORMATION-------------------------

                         NUMBER OF CUTTINGS: 10
  AVG. CUTTING  WIDTH:  1.53 IN.        AVG. CUTTING  AREA:    55.89 SQ.IN.
  AVG. CUTTING LENGTH: 39.38 IN.        AVG. WEIGHTED AREA:  2412.23 SQ.IN.-IN.

   NUMBER     --------DIMENSIONS--------        --------COORDINATES--------
               WIDTH     LENGTH     AREA        (LOWER  LEFT) (UPPER  RIGHT)
               (IN.)      (IN.)   (SQ.IN.)      Y-COOR X-COOR Y-COOR X-COOR

     1         3.00      57.00    171.00           2     97     14     325

     2         4.50      23.25    104.63           4      1     22      94

     3         1.00      57.00     57.00           1    326      5     554

     4         1.00      23.25     23.25          15     97     19     190

     5         0.75      57.00     42.75          19    326     22     554

     6         1.00      42.50     42.50          12    337     16     507

     7         1.25      23.25     29.07           6    337     11     430

     8         0.50      57.00     28.50          20     97     22     325

     9         1.00      26.75     26.75          15    218     19     325

    10         1.25      26.75     33.44           6    447     11     554
```

Figure C.1. Individual board yield, cutting dimensions, and locations.

---

[5] The cutting quality produced was actually clear-one-face. (See footnote 2.)

```
-------------------------KERF LINE INFORMATION-------------------------

 NUMBER OF OPERATIONS:22   NUMBER OF CROSSCUTS:11   NUMBER OF RIP CUTS:11

    -----CROSSCUT LINES-----                --------RIP LINES--------
     KERF   STARTING  ENDING                 KERF   STARTING  ENDING
    X-COOR.  Y-COOR.  Y-COOR.               Y-COOR.  X-COOR.  X-COOR.

      97       1        25                     4        1        94

      95       1        25                     2       97       325

     326       1        25                    15       97       325

     555       1        25                    23        1        94

     218      15        19                    23      326       554

     191      15        19                    19      326       554

     337      12        18                    12      326       554

     508      12        18                     6      326       554

     447       6        11                    20       97       325

     337       6        11                    17      337       507

     431       6        11                    23       97       325
```

Figure C.2. Individual board kerf line locations.

```
 ____________________________________________________________________________
|                                                                            |
|               AGGREGATE DIMENSION STOCK YIELD FOR                          |
|                   GROUP 1                                                  |
|                                                                            |
| -----NUMBER TALLY-----                            --------VOLUMES*-------  |
| BOARDS   ANALYZED:  46                            BOARD  : 223.22(BD.FT.)  |
| CUTTINGS PRODUCED: 332                            CUTTING: 312.23(BD.FT.)  |
|____________________________________________________________________________|
|                                                                            |
|                     PROGRAM INPUT SPECIFICATIONS                           |
| ------PROCESSING OPTIONS------         ---CUTTING BILL SIZES IN INCHES---  |
| FIRST OPERATION=CROSSCUT               ROUGH THICKNESS= 1.25               |
| CUTTING QUALITY=CLEAR TWO FACE         WIDTH:  MIN.=0.50   MAX.= 5.00      |
| WEIGHTING FACTOR=2.00                   8 CUTTING LENGTH CLASSES:          |
|                                         14.00  15.00  18.75  21.75  23.25  |
|                                         26.75  42.50  57.00                |
|____________________________________________________________________________|


------------------------------YIELD VARIABLES-------------------------------

     VARIABLE             MEAN     STANDARD    C.V.      MINIMUM    MAXIMUM
  (BOARD AVERAGES)        VALUE    DEVIATION (PERCENT)    VALUE      VALUE

BOARD WIDTH (FT.)          0.45      0.139     30.68        0.25       0.94

BOARD LENGTH (FT.)        12.16      0.300      2.47       10.98      12.69

BOARD VOL. (BD.FT.)        6.79      2.065     30.41        3.76      14.04

NUMBER OF CUTTINGS         7.22      3.483     48.23        3         15

CUTTING WIDTH (IN.)        2.10      0.832     39.60        1.05       4.84

CUTTING LENGTH (IN.)      38.25      4.686     12.26       28.80      46.92

CUTTING VOL. (BD.FT.)      4.86      1.577     32.47        2.28      10.63

PERCENT AREA YIELD        71.72      9.756     13.61       52.70      89.86

PERCENT WEIGHTED YIELD    23.73      4.088     17.23       16.12      31.89

----------------------------OPERATION VARIABLES-----------------------------

     VARIABLE             MEAN     STANDARD    C.V.      MINIMUM    MAXIMUM
  (BOARD AVERAGES)        VALUE    DEVIATION (PERCENT)    VALUE      VALUE

NUMBER OF OPERATIONS      14.81      6.246     42.18        5         28

NUMBER OF RIP CUTS         6.66      2.931     44.03        1         12

NUMBER OF CROSSCUTS        8.16      3.893     47.73        3         17
```

Figure C.3. Yield of the entire group of boards.

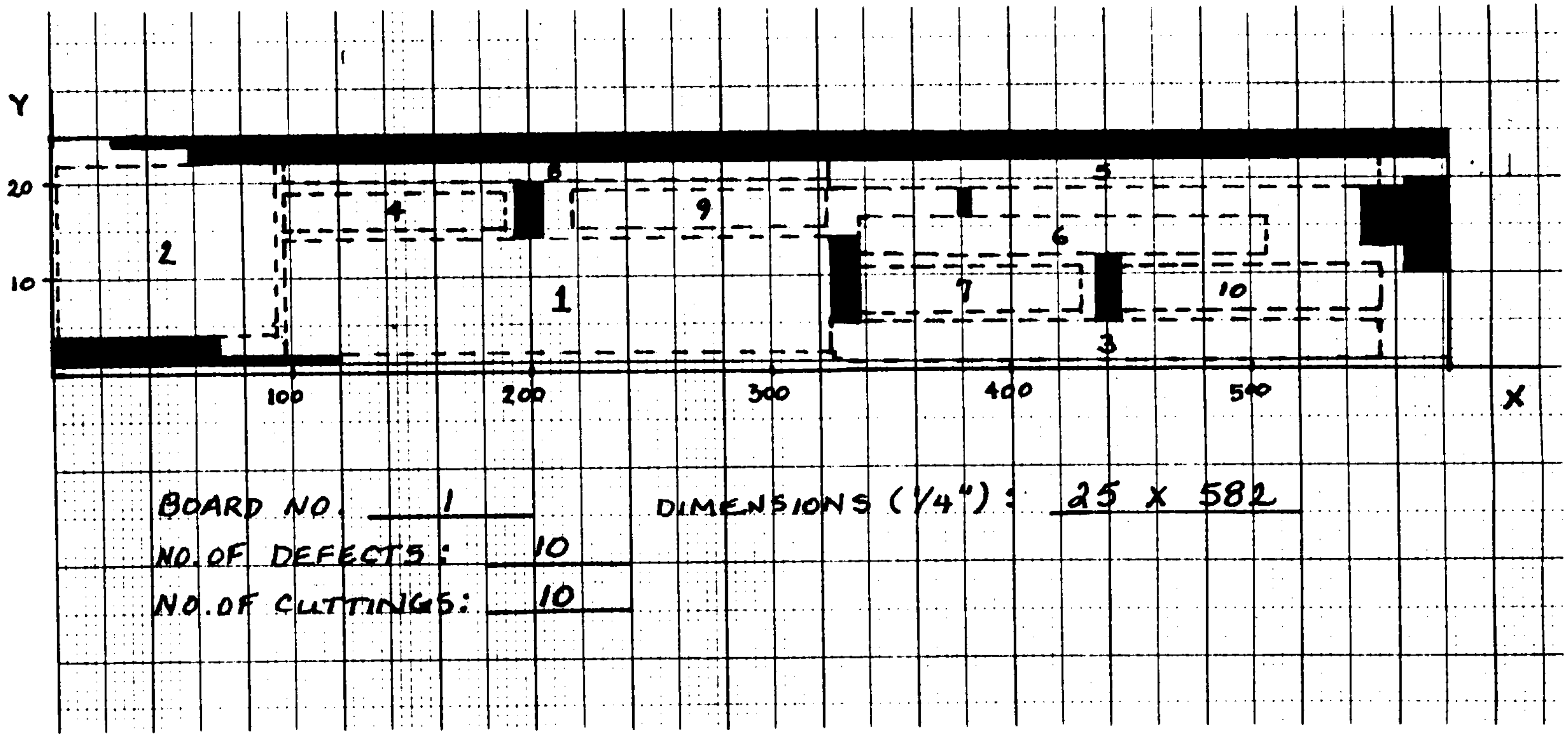
---

* The 'BOARD' and 'CUTTING' volume labels are reversed. This resulted from previous manipulations of CORY's formatting statements.

CUTTING WIDTH (IN)	<-CUTTING LENGTH (IN)--------							
	14.00	15.00	18.75	21.75	23.25	26.75	42.50	57.00
0.50	3	6	3	6	8	18	7	5
0.75	0	7	2	4	3	9	7	7
1.00	2	0	3	1	6	9	8	3
1.25	0	4	1	2	2	3	2	4
1.50	2	3	3	2	0	7	3	11
1.75	0	0	1	0	2	3	3	2
2.00	0	0	0	0	1	4	1	6
2.25	0	1	0	0	0	2	2	4
2.50	0	2	1	2	1	3	4	13
2.75	0	1	0	0	0	7	2	12
3.00	1	1	0	1	0	6	1	10
3.25	0	1	1	0	0	1	1	14
3.50	0	1	0	0	2	1	0	8
3.75	0	0	1	0	0	0	0	2
4.00	0	0	1	0	0	1	0	5
4.25	0	0	0	0	0	0	0	2
4.50	0	0	0	0	1	0	1	2
4.75	0	0	0	0	1	1	0	3
5.00	0	0	1	0	0	0	1	3
TOTAL NUMBER	8	27	18	18	27	75	43	**
TOTAL WIDTH (IN)	9.5	37.5	32.0	20.5	39.0	117.0	66.8	300.0
PERCENT RECOVERY	0.52	2.19	2.34	1.74	3.53	12.18	11.04	66.50

Figure C.4. Frequency distribution of cutting sizes in the group of boards.

Appendix D. CORY Verification



BOARD NO. 1

DIMENSIONS (1/4"): 25 X 582

NO. OF DEFECTS: 10

NO. OF CUTTINGS: 10

Figure D. Example of the procedure used for verifying CORY's cutting solutions.

Appendix E. Original Cost Estimates and Regressions.

Table E. Original cost estimates: 1)Survey 2)OPTIGRAMI

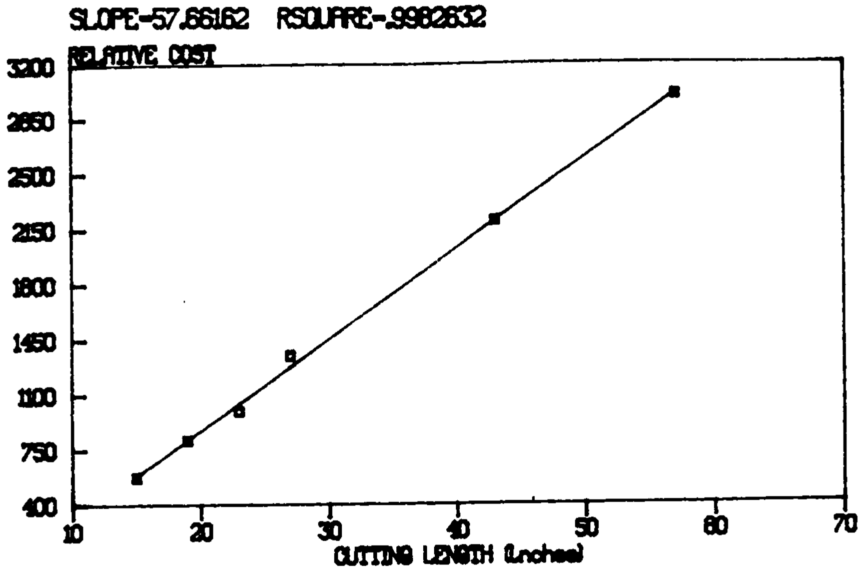
1. Survey

Length (inches)	Survey Cost Estimates		
	Mill 1	Mill 2	Average
14 - 16	0.76	0.4	0.58
18 - 20	0.83	0.8	0.815
22 - 24	1	1	1
26 - 28	1.2	1.5	1.35
42 - 44	2	2.4	2.2
56 - 58	3	3	3

2. OPTIGRAMI

Length (inches)	Calculated OPTIGRAMI Estimates
14	0.12
15	0.15
18.75	0.15
21.75	0.16
23.25	0.15
26.75	0.17
42.5	0.22
57	0.26

1. SURVEY



2. OPTIGRAMI

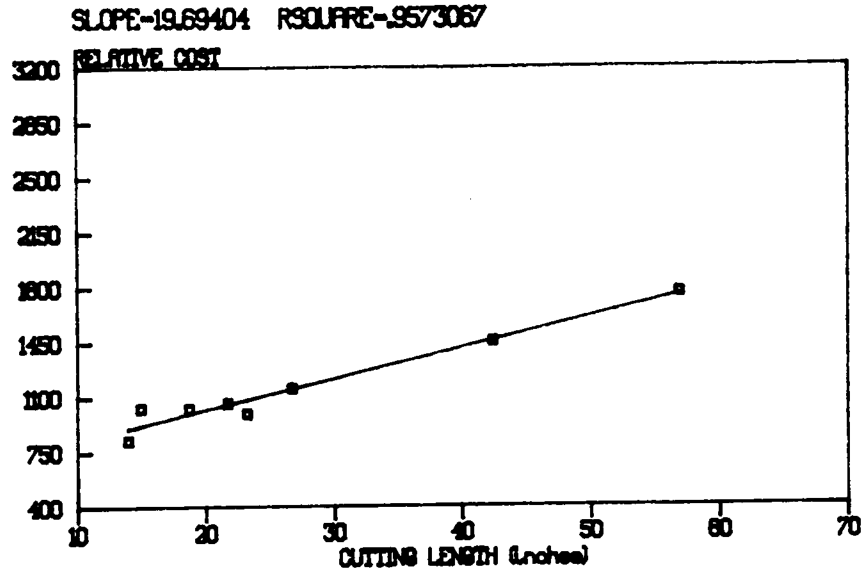


Figure E. Linear regressions of original cost data: 1)Survey 2)OPTIGRAMI