Feasibility study on efficient processing and use of eastern cottonwood (Populus deltoides Bartr.) for wall framing lumber

James Walter Funck
Iowa State University

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Feasibility study on efficient processing and use of eastern cottonwood (Populus deltoides Bartr.) for wall framing lumber

by

James Walter Funck

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of DOCTOR OF PHILOSOPHY

Department: Forestry
Major: Forestry (Biology - Wood Science)

Approved:

Signature was redacted for privacy.

In Charge of Major Work

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For the Major Department

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Iowa State University
Ames, Iowa

1979

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GENERAL INTRODUCTION

Present shortages of nonrenewable resources in the United States and the rest of the world have focused greater attention on wood, a renewable resource. Projections by the U.S. Forest Service indicate that this greater attention will result in a doubling of the demand in the United States for raw wood between the years 1970 and 2000 (Boyd et al., 1976). Presently, the approximate annual U.S. per capita consumption of pulp and paper products is 640 pounds (Slatin, 1975) and of timber products is 61 cubic feet (cu. ft.) (Stone, 1977). A steady rise in prices for wood-based products is predicted in response to the strong demand (Lambert, 1978). Obviously, to meet the growing demand and minimize the price rises, timber resources must be more efficiently utilized.

Because only 63 percent of the raw wood is converted into lumber and rigid panels (Boyd et al., 1976), the aforementioned factors can be expected to have an adverse effect on the price of homes. W. Dikin (1972) suggested that there are four ways to lower housing material costs: (1) lower raw material costs, (2) lower conversion costs, (3) more efficient utilization of materials, and (4) substitution of cheaper materials for those now in use. Looking specifically at wood-based products in home construction, Bulgrin (1975) suggested that long run needs could be met by improved timber management and increased utilization of the material harvested. He also felt that better use of all species and types of wood would increase their availability and help stabilize prices.
Since housing and wood construction in the United States has traditionally been a softwood-based industry, one way to lower housing material costs and improve supply is to substitute underutilized hardwoods for softwood products. Hardwoods account for 54 percent of the U.S. timberland and one-third of the cubic feet of standing timber (Saeman, 1977). However, in 1970 the hardwood timber growth to removal ratio was 1.80 while the softwood ratio was 1.10 (Stone, 1978). This overemphasis of softwood production has led to a 4 percent decrease in softwood sawtimber inventory since 1952, while the hardwood sawtimber inventory has increased by 19 percent (Saeman, 1977). Projections for the year 2000 show only a 15 percent increase in softwood sawtimber supply but a 67 percent increase in hardwood sawtimber supply (Stone, 1978). These figures indicate the need to more fully develop hardwood utilization.

Utilization of Eastern Cottonwood

One underutilized hardwood species that appears promising as a softwood substitute is eastern cottonwood (Populus deltoides Bartr.). McKnight (1976) listed five reasons why continued attention should be paid to cottonwood. They are: (1) good wood properties, (2) rapid growth rates, (3) excellence for genetic improvement, (4) ease of propagation, and (5) ability to grow in marginal land areas such as flood plains. These reasons warrant greater detail.

Cottonwood heartwood is grayish white to light brown, while the sapwood is whitish and merges gradually with the heartwood. The wood is comparatively uniform in texture and is generally straight grained.
Eastern cottonwood is moderately low in bending and compressive strength, moderately limber, moderately soft, moderately low in ability to resist shock, and has moderately large shrinkage. Primarily due to tensionwood, some cottonwood is difficult to machine because of fuzzy surfaces (U.S.D.A. Forest Products Laboratory, 1974).

Cottonwood is a fast growing species. White (1976) found that diameter growth rates of one inch per year are easily obtained in long-rotation plantations. Figure 1 shows an example of the inch per year diameter growth rate. Zsuffa (1976) reported that eastern cottonwood can easily be propagated from stem cuttings and by sprouting from stumps and from the root collar. Because cottonwood is relatively easy to cross and propagate and grows rapidly, Gordon and Promnitz (1976) felt that it offers excellent opportunities for yield improvement studies.

Eastern cottonwood grows in every state from the Great Plains to the Atlantic Coast and is found mainly on alluvial soils of river bottoms. The total U.S. sawtimber volume is 1 3/4 billion board feet (bd. ft.). It is presently a valuable species for various lumber products, veneer, and pulpwood. While the demand for cottonwood as pulpwood appears to be rising, cottonwood lumber and veneer production are declining (Anderson, 1976).

Many states, such as Colorado, have recognized the need to more fully utilize their cottonwood resources (Wilcox, 1976). In the South, almost 50,000 acres of cottonwood plantations have been established (Anderson, 1976), and this number is expected to increase (Canonge, 1979).
Figure 1. One inch per year diameter growth rate in eastern cottonwood
Thirty-one percent of this material is intended for sawlog and veneer production (Burkhardt and Krinard, 1976).

Iowa has 436.4 million bd. ft. of sawtimber size cottonwood. The annual growth of sawtimber cottonwood is 18.25 million bd. ft. The annual growth of all cottonwood growing stock in Iowa is 4.5 million cu. ft., while only 1.9 million cu. ft. is converted to timber products (Ostrom, 1976).

This underutilization of cottonwood, combined with the aforementioned information regarding wood shortages, indicated to the Iowa State University Forestry Department, in cooperation with the U.S. Forest Service and Iowa Conservation Commission, that new product markets needed to be investigated for eastern cottonwood. A promising market is wall framing lumber, specifically 2 x 4's. As mentioned before, only 63 percent of the raw wood is converted to lumber and rigid panels. Forty-three percent of the lumber produced is used in residential construction (Boyd et al., 1976). The average three-bedroom house requires about 300 2 x 4's or about 1,600 bd. ft. of material. This represents approximately 10 to 12 percent of the lumber used in an average single-family dwelling (Hendricks et al., 1969). This provides a market of considerable size for cottonwood 2 x 4 production.

Project Scope and Flow Diagram

The feasibility study on efficient processing and use of eastern cottonwood for wall framing lumber involved three stages; determining the most efficient processing methods, developing and gaining official approval of eastern cottonwood working stress values, and determining
the economics of 2 x 4 production by Iowa sawmills. Each of these stages will be discussed separately in this dissertation. Figure 2 is a flow diagram illustrating the relationships between the various stages of this project. The previous discussion has already indicated that there is sufficient demand for and a sufficient supply of eastern cottonwood.
Figure 2. Project flow diagram
Sufficient demand?

Can demand be increased?

Sufficient supply?

Can supply be increased?

Can Cottonwood 2 x 4's be efficiently produced?

Yes

Development of working instructions

Yes

Approval obtained from grading agency?

Yes

Approval obtained from American Lumber Standards Committee?

Yes

Market and Product Promotion and Communication of Results

Feedback Loop

FHA and HUD Approval

Yes

Are there new procedures?

Yes
PART I.

DETERMINATION OF EFFICIENT PROCESSING METHODS
INTRODUCTION

As shown in Figure 2 in the general introduction, the first stage of this project was to determine the most efficient processing methods for the production of 2 x 4's from eastern cottonwood logs. Production of 2 x 4's involves sawing, seasoning, machining, and grading. Little previous research has been done involving cottonwood 2 x 4 production, but sawing and seasoning problems were expected to be similar to those encountered by researchers working with several other species.

General Sawing Problems

Work done with aspen and yellow poplar indicated that a sawing pattern was needed that would minimize crook in the 2 x 4's. Crook, illustrated in Figure 3, is a deviation edgewise from a straight line drawn from end to end of a board. Stud grade rules only allow 1/4 inch deviation. Any crook greater than 1/4 inch will reduce the grade and thus, the value of the piece.

Figure 3. Crook, bow, and twist in lumber
In working with aspen, Hendricks et al. (1969) only removed 2 x 4's from the outside portion of each log (Figure 4). This produces 2 x 4's that are mainly flatsawn sapwood, resulting in more bow than crook or twist. More bow is allowable, as stud grade rules allow 3/4 inch deviation. While this technique appears applicable to small diameter logs such as aspen, it does not permit enough 2 x 4 production from the much larger diameter cottonwood logs.

Koch (1968) developed a process for producing 2 x 4's from southern pine cordwood and veneer cores. In this process, warp is controlled by center ripping the cordwood bolt or veneer core, debarking the half bolts, and then blanking the half cores or half bolts oversize on a surfacer-edger. The oversized 2 x 4's are seasoned, and then the distortions are removed by face-jointing, thicknessing, and straight-line ripping to the approximate width. The 2 x 4's are then finished by planing and end-trimming to the appropriate size. While technically feasible, this method does not appear to be practical for the small-sized mills expected to be producing cottonwood 2 x 4's; this is due to the larger diameters of the cottonwood logs, lack of appropriate equipment,
large amount of waste produced, possible lack of sufficient markets for the waste, and the reduced value of the waste material.

Researchers at the U.S. Forest Products Laboratory, Madison, Wisconsin, have developed a new sawing technique called the SDR method (saw, dry, and rip) (Hallock and Bulgrin, 1978), which is an outgrowth of the EGAR system (edge, glue, and rip) (Harpole et al., 1977) and Koch's technique. In the SDR system, the logs are live sawn into two-inch wide flitches, seasoned in flitch form, and then ripped into 2 x 4's. Crook in yellow poplar 2 x 4's was significantly reduced with this method.

Because this technique was developed after the cottonwood project was nearly completed, it was not used. Also, more research needs to be conducted on the SDR system to determine whether the increase in drying cost associated with flitch vs. 2 x 4 seasoning is offset by the increase in lumber value. If that is true, this technique offers a promising future for cottonwood 2 x 4 production.

Research done at the U.S. Forest Products Laboratory on loblolly pine, lodgepole pine, and plantation red pine 2 x 4's indicated that the scragg pattern of sawing was instrumental in reducing crook (Hallock, 1965 and 1969; Hallock and Malcolm, 1972). Unlike the aspen 2 x 4 sawing pattern in Figure 4, the scragg pattern, illustrated in Figure 5, allows the whole log to be sawn into 2 x 4's. Therefore, this method of sawing appeared to be more practical from a producers standpoint and was chosen for use in the cottonwood project.
Figure 5. Scragg sawing pattern
General Seasoning Problems

As in sawing, a major seasoning problem is minimizing crook in 2 x 4's. Another area of concern is that the 2 x 4's be uniform in moisture content. Research done on aspen, southern pine, ponderosa pine, white fir, and eastern cottonwood provided insight into these problems.

Aspen seasoning research

Crook and nonuniformity of moisture content within a piece are both problems in aspen 2 x 4 production. Nonuniformity in moisture content in aspen is associated with a phenomenon known as wetwood, which is an area of excessively high moisture content compared to the surrounding material in a piece of lumber. It is believed to be associated with bacterial action and can cause excessive checking and collapse during seasoning (Panshin and deZeeuw, 1970). Huffman (1972) found that neither high-temperature drying nor mechanical pretreatments resulted in satisfactory drying of lumber with wetwood. Mackay (1975) felt that the only answers to the wetwood seasoning problem were to allow longer drying periods or recycle the wet pieces through a further drying period.

While attempting to solve the wetwood problem, Mackay (1974) also found that crook was the predominant form of degrade in aspen 2 x 4's. Further research by Mackay et al. (1977), led to a technique for reducing excessive crook after seasoning. This involved steaming the 2 x 4's for three hours and then applying a load to the 2 x 4's in the opposite direction of the crook. The load was applied until
the crook disappeared. This technique did not appear to be economical or practical for the small sawmills expected to be producing cottonwood 2 x 4's and was not considered in this project.

**Softwood seasoning research**

Warpage in 2 x 4 production has also been found to be a problem in several softwood species, primarily southern pine but also in ponderosa pine and white fir. In working with ponderosa pine and white fir, Dost and Arganbright (1972) utilized a straightening method along the same line as Mackay's work with aspen. However, they only clamped the 2 x 4's into a straightened position and then steamed the 2 x 4's. This method was not effective in upgrading the defective material.

Several studies have been conducted which utilized modified kiln stickers to reduce crook in southern pine 2 x 4's. Wengert and Baltes (1974) investigated the use of kiln stickers with metal pins inserted vertically in them. The pins restricted the movement of the 2 x 4's and reduced crook by 29 percent. Koch (1974) introduced a method for controlling warp using serrated kiln stickers. These were sharply toothed aluminum stickers held by 50 to 200 pounds force per stick-pair per stud. Crook, bow, and twist were all significantly reduced. While both of these techniques appear feasible, the costs involved appear prohibitive. For instance, the production cost of a 28-inch long serrated sticker was approximately $27.00 in 1974.
Eastern cottonwood seasoning research

Researchers have found that eastern cottonwood is also susceptible to crook and wetwood problems. Walters (1955) found that 8/4 (2 inches thick) cottonwood dried best when the U.S. Forest Products Laboratory's T6-C4 wet streak cottonwood schedule was used (Rasmussen, 1961). Funck (1974) found that the Laboratory's T8-F4 normal cottonwood schedule was not efficient in drying 8/4 eastern cottonwood. The sapwood pieces dried much faster than the heartwood pieces, thus forcing the schedule into an early equalizing equilibrium moisture content (EMC). This resulted in a significant slowing of the drying rate.
OBJECTIVE

The objective of this part of the overall project was to determine the most efficient processing methods for cottonwood 2 x 4 production. The three main areas of intensive study were: (1) sawing techniques, (2) seasoning procedures, and (3) milling methods.
MATERIALS AND METHODS

Sawing Techniques

Cottonwood logs were acquired from each of the three major cottonwood-producing regions in Iowa. Ten logs were obtained from Midwest Walnut Company, Council Bluffs, on August 5, 1975 (Missouri River Valley); twenty logs were obtained from the Yellow River State Forest, near McGregor, on August 27, 1975 (Mississippi River Valley); and fifteen logs were obtained from the Comstock Sawmill, Eddyville, on September 19, 1975 (Des Moines River Valley). To obtain a reasonably representative sample of eastern cottonwood log sizes, both butts and uppers were cut from each of three diameter classes: 12-16 inches (29 logs), 17-21 inches (10 logs), and 22-28 inches (6 logs). Twenty-eight inches represents the maximum diameter the Yellow River sawmill was capable of handling.

To insure uniformity and control, all the 2 x 4's were sawn at the Iowa Conservation Commission's Yellow River State Forest sawmill. Data collected by Funck (1974) indicated that the 2 x 4's needed to be sawn to green dimensions of 1 7/8 inches by 3 7/8 inches to insure sufficient dressed size after seasoning and machining. However, because the Yellow River mill's saw could only be set at 1/4-inch intervals, the green dimensions were two inches by four inches by eight feet. As mentioned before, the scragg pattern of sawing was used to minimize crook.

To allow for statistical analysis of the results, the location of every 2 x 4 was stenciled on the end of each log. The logs were stenciled so that any cross-sectional eccentricity was in the vertical
position with the eccentric side down. After stenciling, each 2 x 4 was numbered so that the following information was known: source of log, log number, butt vs. upper, and 2 x 4 location in the log. The stenciling and numbering systems are illustrated in Figures 6, 7, 8, and 9. Pictures of the end of each log were taken to provide a permanent record of every 2 x 4's location. Information regarding each log was also recorded. This included diameter, length, and any defects.

The 2 x 4's were transported to Bessey Hall, Iowa State University, immediately after sawing. Preliminary measurements were then made on each 2 x 4. These included: amount of warp, dimensions, defects, grain orientation, amount of tensionwood, and heartwood vs. sapwood. Figures 10, 11, and 12 illustrate the methods for taking warp measurements. The width and thickness of each 2 x 4 were measured at 1/4, 1/2, and 3/4 of the length of each piece. The amount of tensionwood was estimated by the degree of fuzziness of the surface of each piece.

Seasoning Techniques

The 2 x 4's from each log within a location were randomly divided into two groups of approximately equal size. One of the two groups from each location was kiln-dried in the dry kiln at Bessey Hall (Figure 13) using standard techniques outlined by Rasmussen (1961). In an attempt to overcome the seasoning difficulties mentioned in the introduction, a modified schedule developed by Mr. John McMillen of the U.S. Forest Products Laboratory, was used. The schedule, shown in Figure 14, was designed to produce faster drying times and less degrade caused by tensionwood or wetwood.
Figure 6. Unstenciled cottonwood log
Figure 7. Spraying the stencil pattern
Figure 8. Partially sawn stenciled log
Figure 9. Headsaw entering stenciled log
Figure 10. Crook measurement
Figure 11. Bow measurement
Figure 12. Twist measurement
Figure 13. Charge ready for kiln-drying
Figure 14. Experimental dry kiln schedule for 8/4 eastern cottonwood
Species: Populus Deltoïdes

Initial moisture condition: Air Dry

Schedule: Temperature T6 modified
Humidity D4 modified

Remarks: Wettest ½ of kiln samples. If below 85% MC use letter C₄

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<th>Moisture Content % From</th>
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<th>Wet Bulb Dep. F.</th>
<th>Wet Bulb F.</th>
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<td>113</td>
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<td>24</td>
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</table>

Start E-I when driest sample reaches 7% M.C.

Start E-II when wettest sample reaches 21% M.C. Estimate when that will occur and lower temperature to 170 F. When ready for E-II, turn steam coil supply valve off. Bring wet-bulb temperature up to 170 F with steam spray. Then turn small amount of steam coils on to bring dry bulb up.
The other group from each location was air seasoned at the Iowa Conservation Commission Nursery, Ames, Iowa. The stacks are shown in Figure 15. The air seasoning was done using standard techniques outlined by Rietz and Page (1971).

Due to a lack of commercial feasibility, Dr. McMillen suggested that the 2 x 4's not be endcoated before seasoning and that no restraint other than top loaded cement blocks be used. His research had shown that a top weight of at least 50 pounds per square foot was necessary to minimize crook in the upper layers of the lumber stack. The cement blocks provided a roof weight of 55 pounds per square foot.

After each group was dried, the moisture content of each 2 x 4 was measured with a moisture meter and recorded. Measurements were taken at 1/4, 1/2, and 3/4 of the length of each piece. The dimensions and amount of warp of each 2 x 4 were remeasured. This second measurement of warp was taken to indicate the amount of distortion resulting from seasoning.

Machining Techniques

After seasoning, the 2 x 4's were again randomly divided into two groups for machining to the proper dry dimensions of 1.5 inches by 3.5 inches. One group was machined on a double surfacing planer at the Becker Sawmill, Garrison, Iowa, while the other group was machined on the U.S. Forest Products Laboratory's moulder. This was done to test whether enough warpage would be removed by the moulder, which machines all four sides at once, to significantly upgrade the material. After
Figure 15. Air seasoning stacks
machining, the final warp measurements were taken. This was done to
determine the amount of distortion removed by machining.

Grading Procedure

After machining, the 2 x 4's were graded by Mr. H. R. Bell, Chief
Inspector for the Northern Hardwood and Pine Manufacturers Association,
Inc., Green Bay, Wisconsin. The 2 x 4's were graded using the light
framing and stud grade rules. However, due to commercial and market
procedures, the 2 x 4's were only separated into the following
categories: stud, utility, economy, and cull.

Statistical Design

Due to the problem of unequal size samples for the various
categories of production techniques, chi-square tests were performed
on the resulting numbers of stud grade material only. The stud grade
criteria was chosen because of the significantly greater economic
value of studs. This testing procedure eliminated the need for selecting
random equal-sized samples from the categories, with the associated
problem of accounting for variances due to that selection procedure.
It also allowed for complete utilization of all possible 2 x 4's from
each sample log. The testing hypotheses used were as follows:

(1) source of log differences

(2) log diameter class differences

   (a) butt logs only

   (b) upper logs only

   (c) whole tree
(3) seasoning technique differences
(4) machining technique differences
(5) seasoning and machining technique interactions.
RESULTS AND DISCUSSION

Sawing Data

Five hundred and eight 2 x 4's were sawn from the 45 logs. Using the Doyle log rule, the percent overrun or underrun was calculated for each location's set of logs. These percentages are calculated by finding the difference between the mill tally and the log scale, dividing that difference by the log scale, and then multiplying by 100. If the lumber output is greater than the amount that the log rule predicted, there is said to be an "overrun". When the lumber sawn is smaller than the log rule predicted, there is an "underrun". The Doyle rule is the rule most often used by Iowa sawmills even though it seriously underestimates the sawn output, particularly when the logs sawn have diameters less than 20 inches (Avery, 1967).

The calculation of overrun and underrun is a form of performance evaluation for a sawmill. It indicates how much lumber, rather than waste material, is being produced. However, as previously pointed out, those percentages are dependent upon the log rule used. Therefore, to give a clearer and more comparable value, Williston (1976) suggests using a value known as the lumber recovery factor (LRF). This value is calculated by dividing the board footage of lumber output by the cubic footage of log input. The overrun or underrun and LRF values for each source of logs are shown in Table 1.

While the overrun-underrun and LRF values were calculated, they cannot be fairly compared with normal sawmill performance data. Previous data indicated that a 20 percent overrun and LRF value of 6.73 should
Table 1. Overrun or underrun and lumber recovery factor (LRF) values for Part I

<table>
<thead>
<tr>
<th>Source of Logs</th>
<th>Overrun (Underrun)</th>
<th>LRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midwest Walnut Co.</td>
<td>(18.5)</td>
<td>5.49</td>
</tr>
<tr>
<td>Comstock Sawmill</td>
<td>5.6</td>
<td>6.06</td>
</tr>
<tr>
<td>Yellow River Sawmill</td>
<td>15.8</td>
<td>5.90</td>
</tr>
</tbody>
</table>

have been expected (Sinclair and Ifju, 1979). Many factors contributed to the poor performance. The dimension measurements taken showed a wide variation within and between boards, thus indicating poor mill performance in general. Other reasons included the fact that the sawyer was trying to follow the diagrammed scragg pattern, and it was his first attempt at the scragg method of sawing. Also, no attempt was made to recover anything other than 2 x 4's, thus resulting in an understatement of the amount of lumber that could possibly have been recovered.

Seasoning Data

Table 2 summarizes the air seasoning data for the 258 2 x 4's that were air seasoned. Because it was not possible to get the 2 x 4's from every source ready for air seasoning at the same time and the logs were sawn in the fall, the 2 x 4's from the Comstock and Yellow River mills remained outside to dry during the winter. However, the low temperatures in fall and winter severely retard moisture loss. In an effort to more accurately compare air-drying times, Rietz (1972)
developed a drying calendar related to changes in the prevailing temperature. Using that calendar, the approximate number of effective air-drying days were estimated for each stack of lumber. It must be remembered that these are only estimates.

As seen in Table 2, the 2 x 4's dried below the target moisture content of 15 percent. Therefore, the air-drying times could be shortened somewhat. The drying times are within the normally expected range (Rietz and Page, 1971). Moisture content data obtained after drying indicated that none of the 2 x 4's exceeded the 19 percent limit.

Table 3 summarizes the kiln seasoning data for the 250 2 x 4's that were kiln-dried. The shorter drying time of the Midwest Walnut Company 2 x 4's was due to the fact that the logs were obtained from the yard, while those from the other locations were freshly cut before sawing. Once again, moisture content data obtained after drying indicated that none of the 2 x 4's exceeded the 19 percent limit.
Table 3. Kiln seasoning data

<table>
<thead>
<tr>
<th>Source of Logs</th>
<th>Drying Time Hrs.</th>
<th>Final Moisture Content of Samples, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midwest Walnut</td>
<td>185</td>
<td>13-16</td>
</tr>
<tr>
<td>Yellow River State Forest</td>
<td>480</td>
<td>11-15</td>
</tr>
<tr>
<td>Comstock Mill</td>
<td>385</td>
<td>10-18</td>
</tr>
</tbody>
</table>

Machining Data

Two hundred and fifty-six 2 x 4's were machined on a double surfacing planer at Becker's Sawmill, Garrison, Iowa; 252 2 x 4's were machined on a moulder, which does all four sides at once, at the U.S. Forest Products Laboratory, Madison, Wisconsin. The finished dimensions were 1.5 inches by 3.5 inches. End trimming to 92 5/8 inches was done in Bessey Hall, Iowa State University, Ames, Iowa.

Grading Data

The 2 x 4's were graded by Mr. H. R. Bell, Chief Inspector for the Northern Hardwood and Pine Manufacturers Association, Inc., on October 15, 1976. The results are given in Table 4. The most common defects in order of importance were: warp, skips, and shake. As expected, crook was the primary warp problem. Shake is a separation of the wood parallel to the annual ring, and skips are areas on a piece that failed to surface or surface clean. The grader felt that the 57 percent stud grade result was close to the average for stud mills sawing other species.
Table 4. Grading results for Part I

<table>
<thead>
<tr>
<th>Grade</th>
<th>Number of Pieces</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stud</td>
<td>291</td>
<td>57.3</td>
</tr>
<tr>
<td>Utility</td>
<td>137</td>
<td>27.0</td>
</tr>
<tr>
<td>Economy</td>
<td>55</td>
<td>10.8</td>
</tr>
<tr>
<td>Cull</td>
<td>25</td>
<td>4.9</td>
</tr>
</tbody>
</table>

Statistical Analysis

The results of the chi-square tests are given in Table 5. Because of the much greater economic value of stud grade material, the tests were performed only on the number of studs obtained.

As can be seen, there were no significant statistical differences between any of the processing techniques or log origins. Therefore, Iowa sawmills may produce the 2 x 4's with the techniques they are presently using. However, if the log diameter classes were slightly rearranged so that the middle class was 16 to 20 inches, that class had a significantly lower number of stud grade pieces.

No explanation could be given for that result. For instance, the amount of tensionwood was the same in both diameter classes, and the percentages of pieces in each diameter class that were rejected for warp, skips, and shake were also the same. Obviously, a very high amount of tensionwood resulted in a lower percentage of stud grade pieces, but this was the same for both diameter classes. Therefore,
Table 5. Chi-square analyses: log sources and diameters; seasoning and machining techniques

<table>
<thead>
<tr>
<th>Source of Log Differences</th>
<th>Log Diameter Class Differences (16-20 inch Class vs. All Others)</th>
<th>Seasoning Technique Differences</th>
<th>Machining Technique Differences</th>
<th>Seasoning-Machining Technique Interaction Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Butt Logs Only</td>
<td>Upper Logs Only</td>
<td>Whole Tree</td>
<td></td>
</tr>
<tr>
<td>Degrees of Freedom</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Chi-square Value</td>
<td>0.975</td>
<td>19.0</td>
<td>13.01</td>
<td>30.1</td>
</tr>
<tr>
<td>Significance</td>
<td>NS</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

* Significant difference at 0.005 level.

NS—No significant difference.
the diameter class problem was examined further in the economics study (Part III).

Utilization Data

Two hundred stud grade 2 x 4's were donated to Mr. Robert Buck of Buck Construction Co., Ames, Iowa. They were then placed in a home at 2824 Greensboro, Ames, Iowa. The studs were placed in both covered walls in the home and exposed walls in the garage so that performance under exposed and unexposed conditions could be monitored. The carpenters reportedly liked working with the cottonwood studs because they were easy to nail, yet did not split easily. No problems have been reported concerning the performance of the studs. Figure 16 shows the cottonwood studs being placed in the home.
Figure 16. Cottonwood studs in frame of home
CONCLUSIONS

The study reported in Part I was designed to analyze different 2 x 4 processing techniques so that the most efficient system could be reported. While previous research indicated that the crook problem could be minimized through the use of special techniques, only the scragg sawing pattern appeared to be economically feasible. The possible exception to that would be the SDR system, for which further study is recommended. If the lumber is to be kiln-dried, it is also recommended that it first be partially air-dried to reduce the long kiln times and associated energy consumption.

No significant statistical differences in the number of stud grade pieces obtained were found between the different sources of logs, seasoning techniques, machining techniques, or seasoning-machining technique interactions. This allows the sawmills to produce the 2 x 4's by whatever method they are presently using. However, the 16- to 20-inch log diameter class did have a significantly lower number of stud grade pieces. Since no explanation could be given for that result, it was analyzed further in Part III. Studs placed in a home have performed well.
PART II.

WORKING STRESS VALUES

AND

SUPPORTIVE STRENGTH DATA
INTRODUCTION

Specific mechanical properties of individual pieces of lumber of the same species and size can differ substantially. This is due to anatomical and chemical properties and physical characteristics such as knots, slope of grain, shake, decay, checks and splits, wane, and pitch pockets. To accommodate this variability, visual grades with corresponding strength values have been established. In visual grading, clear wood mechanical properties of a piece of lumber are altered by factors that take into account the location and sum of all defects and blemishes that can be seen. As stated by Bendtsen and Galligan (1978), this grading system


This allows each piece of lumber to then be separated into classifications and grades established by the National Grading Rule Committee, which was provided for by Product Standard PS20-70 (American Softwood Lumber Standard) published by the U.S. Department of Commerce (1970).

The National Grading Rule classifications chosen for use in this project for eastern cottonwood 2 x 4's were "Light Framing" and "Studs". Reasons for this were discussed in Part I. The light framing
category is further subdivided into "Construction", "Standard", and "Utility" grades.

Construction grade lumber is recommended for general framing purposes and must be of good appearance but is graded primarily for strength and serviceability. Standard grade lumber can be used in conjunction with construction grade lumber, but appearance is not as important. Utility grade lumber is recommended for such uses as blocking, plates, bracing, and rafters. Another light framing grade, known as "Economy", is not recognized in the National Grading Rule, but is used by the various grading associations. It is not recommended for use where strength and appearance are important. Stud grade lumber is suitable for all stud uses, including use in load-bearing walls (Northern Hardwood and Pine Manufacturers Association, Inc., 1979).

While the visual method of stress-rating lumber does help control wood's strength variability, it is not precise; therefore, it must be conservative. As a result, a large portion of visually stress-graded lumber has historically been rated well below its useful and safe load-bearing capacity. In a sample experiment with Douglas-fir and larch, Hoyle, Jr. (1961) found that 95 percent of the lumber tested exceeded the visual bending stress ratings. In fact, 75 percent of the pieces were almost twice as strong as their visual ratings indicated. This low strength certification leaves lumber vulnerable to substitution by other materials (Senft et al., 1962).

While visual grading is a form of nondestructive testing, other techniques have been developed to predict the strength of individual
pieces which permits their actual capabilities to be more fully utilized (Hoyle, Jr., 1968). Many of these techniques are based on the principle that modulus of rupture (MOR), which is a measure of bending strength, can be related to modulus of elasticity (MOE), which is a measure of stiffness. MOE can be measured without damaging the piece of lumber and then correlated to MOR.

One such technique involves measuring transverse free vibrations in lumber. Irvington Company, Portland, Oregon, has developed an analog computer called the E-Computer; this machine measures dynamic modulus of elasticity by the transverse vibration method. A specimen is placed on load cell supports and vibrated by a tap of the hand. The computer then measures the period of vibration over a specified number of vibration cycles. In the case of 2 x 4's, the number of cycles is 40. The dynamic MOE is then computed by solution of the following formula:

\[
\text{MOE} = \frac{W L^3}{79.13 \, \text{bd}^3 T^2}
\]

where:

- \( W \) = specimen weight, pounds
- \( L \) = span, inches
- \( b \) = specimen breadth, inches
- \( d \) = specimen depth, inches
- \( T \) = period of vibration, seconds.

The E-Computer control panel and its testing setup are shown in Figures 17 and 18.
Figure 17. Irvington E-Computer control panel
Figure 18. Irvington E-Computer testing setup
OBJECTIVES

The objectives of Part II of this project were to:

(1) develop and gain official approval of the working stress values for eastern cottonwood for use as light framing and stud grade lumber;

(2) obtain bending strength and stiffness values for full-sized Iowa cottonwood 2 x 4's as support for the derived working stress values;

(3) determine the degree of association among the three variables modulus of rupture (MOR) and dynamic and static modulus of elasticity (MOE); and

(4) locate and summarize nail withdrawal resistance data.
MATERIALS AND METHODS

Working Stress Values

As stated before, the National Grading Rule applies to all dimension lumber of all species covered by grading rules developed and approved under Product Standard PS20-70. This voluntary product standard is administered by the American Lumber Standards Committee, which is composed of manufacturers through their agencies, wholesalers, dealers, users, specifiers, and various governmental agencies. The manufacturers association responsible for grading softwood lumber in Iowa is the Northern Hardwood and Pine Manufacturers Association, Inc., Green Bay, Wisconsin.

The procedure for gaining official approval of working stress values is shown in Figure 19. For eastern cottonwood in particular, the working stress values were developed by the Iowa State University Forestry Department and then submitted for approval by the Softwood Inspection Bureau of the NH & PMA, Inc., which is its rules writing and grading authority. After the values were approved by the Softwood Inspection Bureau, the values were submitted to the American Lumber Standards Committee (ALSC) for study and approval. The ALSC approved the values and certified the establishment of grade stamps by NH & PMA, Inc. The final officially approved values were published by NH & PMA, Inc., in its grading rules book. Sawmills may use the grade stamps by either becoming members of NH & PMA, Inc., or by just buying its grading service.
Figure 19. Voluntary system of responsibilities for stress grading lumber under the American Softwood Lumber Standard (U.S.D.A. Forest Products Laboratory, 1974)
(1) FORMULATION OF STRESS GRADING PRINCIPLES
- University Staff Members
- Government Researchers
- Industry R & D Staff
- Consumer Representatives

(2) PRODUCT STANDARDS
- American Lumber Standards Committee and its Board of Review
- National Grading Rule Committee
- National Bureau of Standards

(3) FORMULATION AND PUBLICATION OF STRESS-GRADE RULES
- Associations of Manufacturers

(4) GRADING AGENCY CERTIFICATION
- The American Lumber Standards Committee

(5) GRADE MARK SUPERVISION AND REINSPECTION
- Associations of Manufacturers
- Independent Inspection Agencies

(6) MANUFACTURE AND MARKETING OF AMERICAN STANDARD STRESS-GRADED LUMBER
- Sawmills
The procedure used to actually establish the working stress values is specified in sections D2555 and D245 of the Annual Book of American Society for Testing and Materials Standards (1974). The clear, green, straight grain wood strength values, means, and standard deviations for eastern cottonwood were obtained from section D2555. These were adjusted for a 5 percent exclusion limit, with the exceptions of MOE and compression perpendicular to the grain, which used the mean values only.

The allowable stresses for clear, straight grain eastern cottonwood were then calculated using procedures outlined in section D245. The values obtained from section D2555 were divided by reduction factors to compensate for duration of load and provide a safety factor. Bending stress was further reduced by a size factor, and tension parallel to the grain was reduced to compensate for the use of bending stress as the basis for computation. The resulting values for green lumber were then adjusted upward because the 2 x 4's were to be dried below 19 percent moisture content. These adjustments generated the final stresses for clear 2 x 4's. The last step in calculating the actual published working stress values involved reducing these clear wood stresses by appropriate strength ratios established under the National Grading Rule; these strength ratios reflect the effect of various strength reducing characteristics allowed in each grade.
Supportive Strength Data

To check the validity of the calculated working stress values, destructive and nondestructive strength and stiffness data for full-sized eastern cottonwood 2 x 4's were also obtained. A total of 234 of the 2 x 4's obtained in Part I were randomly selected for nondestructive testing. These were placed in a control chamber at the U.S. Forest Products Laboratory (where the nondestructive testing was to be done) to assure a uniform 12 percent moisture content. A dynamic modulus of elasticity (MOE) value was obtained for each specimen by using an Irvington E-Computer.

Fifty of the nondestructively tested 2 x 4's were randomly selected to be destructively tested. These were stored in a control chamber to assure a uniform 12 percent moisture content. Destructive testing on edge was conducted according to the procedures set forth in ASTM D198 (Figure 20). The moisture content and specific gravity of each piece were determined according to Method A of ASTM D2016 and Method B of ASTM D2395, respectively (American Society for Testing and Materials, 1974). The modulus of rupture (MOR) and apparent static modulus of elasticity (MOE) were calculated for each of the 50 destructively-tested pieces. The relationships between the three variables MOR and static and dynamic MOE were analyzed by a least squares regression procedure.
Figure 20. Riehle testing machine used in destructive strength tests
RESULTS AND DISCUSSION

Working Stress Values

The clear, green, straight grain strength values for eastern cottonwood are listed in Table 6. Using procedures outlined in ASTM Standard D 245, the assigned 5 percent exclusion limits for MOR, compression parallel to the grain, and horizontal shear were calculated by multiplying the standard deviation for each strength category given in Table 6 by 1.645 and then subtracting that value from the mean. The mean value was used for MOE and compression perpendicular to the grain. The exclusion limits and mean values are shown in Table 7.

The allowable stresses for clear, straight grain eastern cottonwood were calculated by dividing the exclusion limit or mean values by the reduction factors shown in Table 8. In the case of bending stress, its value was also multiplied by a size factor; any depth greater than two inches must be adjusted downward. The tension parallel to the grain value was also reduced to compensate for the use of bending stress as the basis for its computation. The resulting green wood values were then increased by the respective amounts shown in Table 8 to adjust to the 19 percent maximum moisture content allowed for in 2 x 4 grades. These values are shown in Table 8.

The working stress values for eastern cottonwood light framing and stud grades were calculated by multiplying the 19 percent maximum moisture content allowable stresses in Table 8 by the appropriate strength ratios determined by the National Grading Rule. The strength
Table 6. Basic properties of eastern cottonwood as listed in ASTM D2555-73. Clear, green, straight grain wood strength values unadjusted for end use

<table>
<thead>
<tr>
<th></th>
<th>Modulus of Rupture (psi)</th>
<th>Modulus of Elasticity 1000 psi</th>
<th>Compression Parallel to Grain (psi)</th>
<th>Horizontal Shear Strength (psi)</th>
<th>Compression Perpendicular to Grain (psi)</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>5260</td>
<td>1013</td>
<td>2280</td>
<td>682</td>
<td>196</td>
<td>0.37</td>
</tr>
<tr>
<td>Std.Dev.</td>
<td>842</td>
<td>223</td>
<td>410</td>
<td>95</td>
<td>55</td>
<td>0.037</td>
</tr>
</tbody>
</table>
Table 7. Exclusion limits and assigned mean values for clear, green, straight grain eastern cottonwood

<table>
<thead>
<tr>
<th>Property</th>
<th>Assigned 5% Exclusion Limit psi</th>
<th>Assigned Mean Value psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOR</td>
<td>3875</td>
<td>----</td>
</tr>
<tr>
<td>Compression parallel to grain</td>
<td>1606</td>
<td>----</td>
</tr>
<tr>
<td>Horizontal shear</td>
<td>526</td>
<td>----</td>
</tr>
<tr>
<td>Compression perpendicular to grain</td>
<td>----</td>
<td>196</td>
</tr>
<tr>
<td>MOE (1000 psi)</td>
<td>----</td>
<td>1013</td>
</tr>
</tbody>
</table>
Table 8. Adjustment factors and allowable stresses for clear, straight grain eastern cottonwood

<table>
<thead>
<tr>
<th>Property</th>
<th>Reduction Factor</th>
<th>Other Factors</th>
<th>Exclusion Limit or Mean psi</th>
<th>Moisture Content Factor</th>
<th>Allowable Stress, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Green</td>
</tr>
<tr>
<td>Bending stress</td>
<td>2.30</td>
<td>0.9397</td>
<td>3,875</td>
<td>1.25</td>
<td>1,580</td>
</tr>
<tr>
<td>Tension parallel to grain</td>
<td>2.30</td>
<td>0.550</td>
<td>3,875</td>
<td>1.25</td>
<td>927</td>
</tr>
<tr>
<td>Horizontal shear</td>
<td>4.50</td>
<td>---</td>
<td>526</td>
<td>1.08</td>
<td>117</td>
</tr>
<tr>
<td>Compression perpendicular to grain</td>
<td>1.50</td>
<td>---</td>
<td>196</td>
<td>1.50</td>
<td>131</td>
</tr>
<tr>
<td>Compression parallel to grain</td>
<td>2.10</td>
<td>---</td>
<td>1,606</td>
<td>1.50</td>
<td>765</td>
</tr>
<tr>
<td>MOE</td>
<td>0.94</td>
<td>---</td>
<td>1,013,000</td>
<td>1.14</td>
<td>1,077,660</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,228,532</td>
</tr>
</tbody>
</table>
ratios are given in Table 9, and the working stresses, rounded in accordance with ASTM D245, in Table 10. The repetitive bending stress values in Table 10 were determined by multiplying the single bending stress values by 1.15. This was done to take into account the fact that structural lumber is many times used in situations where three or more pieces, spaced no further than 24 inches apart, are connected by lumber or plywood sheathing. Tests have shown that in such a system, bending stress may be safely increased by 15 percent (Hoyle, 1972).

The working stress values in Table 10 were submitted for official approval by the previously discussed methods and have been officially approved by all appropriate agencies. Northern Hardwood and Pine Manufacturers Association, Inc., has published the values in its latest grading rules book (NH & PMA, Inc., 1979). Table 11 compares eastern cottonwood and previously accepted species stud grade working stress values. Eastern cottonwood compares favorably and is adequate for use as 2 x 4 members.

Supportive Strength Data

The modulus of rupture (MOR) and apparent static modulus of elasticity (MOE) were calculated for each of the 50 destructively-tested pieces and recorded with the corresponding dynamic modulus of elasticity values. A summary of that data is reported in Table 12.

The degree of association among the three variables was then determined. The regression data are shown in Table 13. As was expected, a high correlation was found between static MOE and dynamic MOE.
Table 9. National Grading Rule strength ratios

<table>
<thead>
<tr>
<th>Property</th>
<th>Construction</th>
<th>Standard</th>
<th>Utility</th>
<th>Stud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending stress</td>
<td>0.34</td>
<td>0.19</td>
<td>0.09</td>
<td>0.26</td>
</tr>
<tr>
<td>Tension parallel to grain</td>
<td>0.34</td>
<td>0.19</td>
<td>0.09</td>
<td>0.26</td>
</tr>
<tr>
<td>Horizontal shear</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Compression perpendicular to grain</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Compression parallel to grain</td>
<td>0.56</td>
<td>0.46</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>MOE</td>
<td>0.80</td>
<td>0.80</td>
<td>0.80</td>
<td>0.80</td>
</tr>
</tbody>
</table>
Table 10. Working stresses for eastern cottonwood light framing and stud grades (at 19 percent maximum moisture content)

<table>
<thead>
<tr>
<th>Property</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Construction</td>
</tr>
<tr>
<td>Extreme fiber in bending --single, psi</td>
<td>675</td>
</tr>
<tr>
<td>Extreme fiber in bending --repetitive, psi</td>
<td>775</td>
</tr>
<tr>
<td>Tension parallel to grain, psi</td>
<td>400</td>
</tr>
<tr>
<td>Horizontal shear, psi</td>
<td>65</td>
</tr>
<tr>
<td>Compression perpendicular to grain, psi</td>
<td>195</td>
</tr>
<tr>
<td>Compression parallel to grain, psi</td>
<td>650</td>
</tr>
<tr>
<td>Modulus of elasticity, 1000 psi</td>
<td>1000</td>
</tr>
</tbody>
</table>
Table 11. Comparison of stud grade working stresses for several species

<table>
<thead>
<tr>
<th>Species</th>
<th>Single Loading Bending Stress psi</th>
<th>Tension Parallel psi</th>
<th>Horizontal Shear psi</th>
<th>Compression Perpendicular psi</th>
<th>Compression Parallel psi</th>
<th>MOE 1000 psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspen</td>
<td>500</td>
<td>300</td>
<td>60</td>
<td>185</td>
<td>325</td>
<td>900</td>
</tr>
<tr>
<td>Eastern cottonwood</td>
<td>525</td>
<td>300</td>
<td>65</td>
<td>195</td>
<td>350</td>
<td>1000</td>
</tr>
<tr>
<td>Eastern white pine</td>
<td>525</td>
<td>300</td>
<td>70</td>
<td>220</td>
<td>400</td>
<td>1000</td>
</tr>
<tr>
<td>Englemann spruce</td>
<td>525</td>
<td>300</td>
<td>70</td>
<td>195</td>
<td>350</td>
<td>1000</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>600</td>
<td>350</td>
<td>70</td>
<td>250</td>
<td>425</td>
<td>1000</td>
</tr>
<tr>
<td>Hem-fir</td>
<td>625</td>
<td>375</td>
<td>75</td>
<td>245</td>
<td>500</td>
<td>1200</td>
</tr>
<tr>
<td>Douglas fir-larch</td>
<td>800</td>
<td>475</td>
<td>95</td>
<td>385</td>
<td>600</td>
<td>1500</td>
</tr>
</tbody>
</table>
Table 12. Summary of strength test data for 50 full-sized eastern cottonwood 2 x 4 members

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOR (psi)</td>
<td>7309</td>
<td>2205.67</td>
<td>1905</td>
<td>11,020</td>
</tr>
<tr>
<td>Static MOE (10^6 psi)</td>
<td>1.5076</td>
<td>0.2394</td>
<td>1.09</td>
<td>1.94</td>
</tr>
<tr>
<td>Dynamic MOE (10^6 psi)</td>
<td>1.7214</td>
<td>0.2665</td>
<td>1.29</td>
<td>2.27</td>
</tr>
<tr>
<td>Y Variable</td>
<td>X Variable</td>
<td>Intercept</td>
<td>Slope</td>
<td>Standard Error of Residual ($s_{y</td>
</tr>
<tr>
<td>------------</td>
<td>--------------</td>
<td>-----------</td>
<td>---------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>static MOE</td>
<td>dynamic MOE</td>
<td>0.09359</td>
<td>0.82143</td>
<td>0.09789</td>
</tr>
<tr>
<td>MOR (psi)</td>
<td>static MOE</td>
<td>-3554.31</td>
<td>7205.71</td>
<td>1388.48</td>
</tr>
<tr>
<td>MOR (psi)</td>
<td>dynamic MOE</td>
<td>-2305.81</td>
<td>5585.47</td>
<td>1644.30</td>
</tr>
</tbody>
</table>

$^a$MOE x 10^6 psi.
The regression line generated, shown in Figure 21, explained 83.6 percent of the variation. Due to scaling of the y axis, curving of the confidence limit lines is not apparent over the range plotted. Previous studies by Pellerin (1965) and Walters and Westbrook (1970) showed similar results in softwoods.

Lower correlations resulted when static or dynamic MOE were used to predict MOR. The regression line for MOR vs. static MOE, shown in Figure 22, explained 61.2 percent of the variation. This coefficient of determination corresponds closely with data obtained by Walters and Reiss (1977) using small, clear, green specimens of eastern cottonwood. The regression line for dynamic MOE vs. MOR, shown in Figure 23, explained 45.6 percent of the variation. The inclusion of specific gravity in the MOR regression equations had no effect on either the correlation coefficients or the standard errors of the residuals.

The average specific gravity, based on ovendry weight and volume at 12 percent moisture content was 0.43, which is higher than the 0.40 value given in the Wood Handbook (U.S.D.A. Forest Products Laboratory, 1974).

The dynamic MOE values for the 184 2 x 4's were then placed in the proper regression equations to predict static MOE and MOR for each 2 x 4. Of the 184 pieces for which static MOE values were predicted, only 7 had values of dynamic MOE which fell outside the range of data from which the regression was developed. For the predicted static MOE values, the mean was 1.52 million psi and the standard deviation was
Figure 21. Plot of static vs. dynamic MOE for 50 full-sized eastern cottonwood 2 x 4 members
Figure 22. Plot of MOR vs. static MOE for 50 full-sized eastern cottonwood 2 x 4 members
Figure 23. Plot of MOR vs. dynamic MOE for 50 full-sized eastern cottonwood 2 x 4 members
Dynamic MOE ($10^6$ psi)

MOR (psi)

95% C.L.

14,000
12,000
10,000
8,000
6,000
4,000
2,000
0

0.0
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40

Dynamic MOE ($10^6$ psi)
was 0.2013 million psi. For the predicted MOR values, the mean was 7,392 psi and the standard deviation was 1,369 psi. These predicted values compare quite well with the actual destructive data shown in Table 12.

Nail Withdrawal Resistance Data

The strength and stability of a structure depend heavily upon the fastenings used to hold its components together. Nails are the most common mechanical fasteners used in wood construction, especially where 2 x 4's are used. Therefore, the nail withdrawal resistance of eastern cottonwood is an important consideration.

While no actual tests were conducted at Iowa State University, research done at the U.S. Forest Products Laboratory indicated that the resistance of a nail to direct withdrawal from a piece of wood is related to the specific gravity of the wood, diameter of the nail, and the depth the nail penetrates the wood. Table 14 gives the withdrawal resistance of bright common wire nails for several species as reported by the U.S. Forest Products Laboratory (1965). Eastern cottonwood compares quite favorably with other common low density species used as 2 x 4's.
Table 14. Side grain nail withdrawal resistance data for several common 2 x 4 species

<table>
<thead>
<tr>
<th>Species</th>
<th>Relative Nail Load&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Englemann spruce</td>
<td>500D</td>
</tr>
<tr>
<td>Hem-fir</td>
<td>740D</td>
</tr>
<tr>
<td>Ponderosa pine</td>
<td>790D</td>
</tr>
<tr>
<td>Lodgepole pine</td>
<td>830D</td>
</tr>
<tr>
<td>Eastern cottonwood</td>
<td>830D</td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>970D</td>
</tr>
</tbody>
</table>

<sup>a</sup>Load in pounds per inch of nail penetration. D = nail diameter in inches.
CONCLUSIONS

The working stress values for eastern cottonwood light framing and stud grades were developed, and official approval of the values was obtained from the Northern Hardwood and Pine Manufacturers Association, Inc., and American Lumber Standards Committee. The values have been published in NH & PMA's latest grading rules book. Nondestructive and destructive bending strength and stiffness data for full-sized eastern cottonwood 2 x 4 members indicated that eastern cottonwood 2 x 4's have sufficient strength characteristics to be utilized as light framing and stud grade lumber. The degree of association between the three variables MOR, static MOE, and dynamic MOE was typically quite strong. Nail withdrawal resistance data presented showed eastern cottonwood compared favorably with other common 2 x 4 species.
PART III.

ECONOMIC STUDY
INTRODUCTION

In Part I of this study, the most efficient processing methods for producing 2 x 4's from eastern cottonwood were determined and found to be feasible. Consumer reaction to cottonwood 2 x 4's was also found to be good. Part II traced the procedure used to develop and gain approval of the working stress values for light framing and stud grade cottonwood 2 x 4's. However, before Iowa sawmills can be expected to produce cottonwood 2 x 4's, the production economics need to be determined and potential markets located. While little information was known concerning Iowa sawmill economics and 2 x 4 markets in particular, research conducted in other areas of the United States on other species provided insight into the need for such information.

Economic Data

As in most operations, the objective in 2 x 4 production is to realize a gross profit. This is determined by subtracting the total cost of production from the total revenue realized. In other words, the benefits received should exceed the sacrifices made. Therefore, information about the costs associated with producing a product is extremely useful and necessary in managing the production process. The cost information is not only needed to prepare financial statements and determine the profitableness of an operation; it can also provide management with a detailed analysis of production, such as unit costs, labor productivity, excessive costs, and the use and waste of production materials (Muncy, 1955; Nelson and Miller, 1977).
One method that can be used to understand the way costs may be classified is to visualize the physical flow through a manufacturing process. This flow diagram is shown in Figure 24. Raw materials, also known as direct materials, are defined as the physical items of input that actually become part of the finished product. In 2 x 4 production, this would be the logs. Direct labor includes the efforts of those employees who are involved directly in the manipulation and transformation of the raw materials into the finished products. These workers would be such people as the log handler, sawyer, edger operator, trim saw operator, and stackers. Overhead includes all the other production efforts which do not conveniently fit into the raw material or direct labor categories. This includes such things as the costs of supplies, supervision, power, and insurance (Nelson and Miller, 1977; Schattke et al., 1969).

![Figure 24. Physical flow through a manufacturing process](image)

Figure 24. Physical flow through a manufacturing process
Another method of cost classification associates the reaction of production costs to variations in the volume of production. This results in categories of fixed, variable, and semifixed or semivariable costs. Fixed costs are those costs that do not vary with the production rate. For example, the same property taxes must be paid regardless of the production rate. While fixed costs remain constant in total, they vary inversely with production when expressed on a per unit basis. Variable costs are those costs that change depending upon the production level. An obvious example is power. As more lumber is produced, more power is required. The total variable cost will vary directly with production, but will remain constant on a per unit basis. Some of the variable costs may be fixed in nature, and vice versa. This is the semifixed or semivariable category. For example, a minimum amount of power or maintenance may be required no matter what the production level is but will increase as production increases. For ease of computation, these types of costs are classified as either fixed or variable, depending on which category best describes their nature (Nelson and Miller, 1977).

It must be understood that this second system of classification is meaningful only in relationship to a stated time frame. For instance, in the very long-run, all costs are variable because management will have the opportunity to change any aspect of the firm it wishes. Conversely, in the very short-run, all costs are fixed because management does not have the ability to change the production system that quickly.
Therefore, the cost-revenue data presented later in this paper will be analyzed using a time frame of one year.

Market Analysis

While a cost-revenue analysis will determine the profitableness of producing a new product such as cottonwood 2 x 4's, that is not the only necessary part of an economic study. As shown in the overall project flow diagram (Figure 2, GENERAL INTRODUCTION), market and product promotion and communication of production feasibility results must also be conducted. The necessity of these types of efforts is underscored by the results already obtained with aspen and yellow poplar 2 x 4's.

Research done on aspen 2 x 4's indicated that when attempting to establish a market for a new 2 x 4 species, it is advisable to first promote the sale of stud grade material only. Stud demand was identified as the major market for 2 x 4's (Hendricks et al., 1969). The aspen research, as well as yellow poplar data, also indicated that intensive quality control programs are necessary to insure standards are being met, thereby avoiding reinforcement of any existing negative opinions (Thompson, 1974; Schick and Grinell, 1979).

When pricing a new 2 x 4 species, both the aspen and yellow poplar studies indicated the need to establish prices under those paid for traditional softwood species. The aspen studs were sold at $2 under the going softwood price (Thompson, 1974), and the yellow poplar study indicated that the producer's selling price differential should not
exceed 10 percent of the softwood price. This would still allow the wholesaler and retailer to use higher than normal markups during the initial establishment of the market. If the 2 x 4's are produced mainly for a limited geographic distribution around the producing mills, much of the price differential could come in the form of lower transportation costs (Schick and Grinell, 1979).
OBJECTIVES

The objectives of Part III were to:

(1) re-analyze the 16- to 20-inch diameter class falldown problem;

(2) obtain cost-revenue information specific to eastern cottonwood 2 x 4 production by Iowa sawmills; and

(3) analyze potential markets for eastern cottonwood 2 x 4's.
MATERIALS AND METHODS

Log Diameter Class Analysis

The results in Part I indicated that the 16- to 20-inch diameter class logs produced a significantly lower percentage of stud grade 2 x 4's than did all the other diameter class logs. Since no explanation could be given for that result, it was analyzed further. Two mills, Midwest Walnut Company, Council Bluffs, Iowa, and Becker Sawmill, Garrison, Iowa, agreed to cooperate by sawing more 2 x 4's.

On July 12, 1978, 13 eastern cottonwood logs were sawn into 324 2 x 4's by Midwest Walnut Company. Twelve logs were sawn into 247 2 x 4's at the Becker Sawmill on September 8, 1978. The scragg pattern of sawing was used by both mills, and the green 2 x 4 dimensions were again two inches by four inches. The sawing pattern was not stenciled on the logs this time, but each 2 x 4 was numbered so that the mill location and log diameter were known. Once again, information regarding each log was also recorded; this included diameter, length, and any defects. The lumber recovery factor (LRF) and percent overrun or underrun were calculated for each sawmill.

Each mill seasoned its own 2 x 4's to a target moisture content of 15 percent; the Becker Sawmill used kiln drying and Midwest Walnut Company used air drying. Because of mechanical problems at Midwest Walnut Company, the seasoned 2 x 4's were all planed to finished dimensions of 1.5 inches by 3.5 inches on a double surfacer at the Becker mill. End trimming to 92 5/8 inches was done in Bessey Hall, Iowa State University.
Grading was once again done by Mr. H. R. Bell, Chief Inspector for Northern Hardwood and Pine Manufacturers Association, Inc., Green Bay, Wisconsin. The grade categories chosen were the same as in Part I: stud, utility, and economy. A chi-square test was conducted on the number of stud grade pieces obtained from the 16- to 20-inch diameter class logs versus all others.

Economic Data

Because no detailed cost-revenue data existed for 2 x 4 production by Iowa sawmills, this data needed to be obtained. To do so, a cost-revenue data form, part of which is shown in Figure 25, was constructed. The rest of the data form is included in the Appendix. This form simply attempts to identify all the major costs and revenues that are associated with dimension lumber production by small sawmills. It also helps the sawmill operator determine whether the mill is attaining its desired before tax rate of return, which is simply the before tax profit divided by the total cost of production.

The cost classification system using fixed and variable categories was chosen because it produces fewer cost categories than the other system mentioned in the introduction. This is important because the data sheet was constructed with the intent of providing small sawmill owners, who might lack accounting backgrounds, with some form of profit analysis. The fixed cost, variable cost, and revenue sections were further subdivided into appropriate major subcategories. Many of these subcategories were identified through previous cost accounting
Figure 25. Sawmill cost-revenue data form
II. Costs Per Thousand Board Feet

<table>
<thead>
<tr>
<th>Category</th>
<th>Stud Production</th>
<th>Present Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Fixed Costs Per Thousand Board Feet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Administrative and direct supervisory salaries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Wages</td>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>b. Fringe benefits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Insurance (life, health, disability, etc.)</td>
<td></td>
<td>(2)</td>
</tr>
<tr>
<td>(2) Vacation</td>
<td></td>
<td>(3)</td>
</tr>
<tr>
<td>(3) Sick leave</td>
<td></td>
<td>(4)</td>
</tr>
<tr>
<td>(4) Pensions</td>
<td></td>
<td>(5)</td>
</tr>
<tr>
<td>(5) Holidays</td>
<td></td>
<td>(6)</td>
</tr>
<tr>
<td>c. Social Security</td>
<td></td>
<td>(7)</td>
</tr>
<tr>
<td>d. Unemployment Ins.</td>
<td></td>
<td>(8)</td>
</tr>
<tr>
<td>e. Workmen's Compensation</td>
<td></td>
<td>(9)</td>
</tr>
<tr>
<td>f. Others</td>
<td></td>
<td>(10)</td>
</tr>
<tr>
<td>2. Rent</td>
<td></td>
<td>(11)</td>
</tr>
<tr>
<td>3. Taxes (excluding income)</td>
<td></td>
<td>(12)</td>
</tr>
<tr>
<td>4. Depreciation</td>
<td></td>
<td>(13)</td>
</tr>
<tr>
<td>5. Office supplies</td>
<td></td>
<td>(14)</td>
</tr>
<tr>
<td>6. Insurance (fire, accident, etc.)</td>
<td></td>
<td>(15)</td>
</tr>
<tr>
<td>7. Interest on debt</td>
<td></td>
<td>(16)</td>
</tr>
<tr>
<td>8. Others</td>
<td></td>
<td>(17)</td>
</tr>
<tr>
<td>Total (add lines 1 through 17)</td>
<td></td>
<td>(18)</td>
</tr>
</tbody>
</table>
B. Variable Costs Per Thousand
Board Feet

1. Direct labor
   a. Wages
   b. Fringe benefits
      (1) Insurance (life, health, disability etc.)
      (2) Vacation
      (3) Sick leave
      (4) Pensions
      (5) Holidays
   c. Social Security
   d. Unemployment Ins.
e. Workmen's Compensation
   f. Others

2. Raw materials
   a. Logs
   b. Others

3. Direct supplies
   a. Saw blades, teeth, etc.
   b. Tools
   c. Other

4. Utilities (power, heat, light, water, etc.)

5. Maintenance & repairs

6. Selling & shipping

7. Seasoning

8. Grading

9. Others

   Total (add lines 19 through 39)

Figure 25 (Continued)
### C. Total Cost Per Thousand Board Feet
(Add lines 18 and 40)  
(41)

### III. Revenues Per Thousand Board Feet

#### A. Sale of 2 x 4's
1. Stud grade (number produced per thousand board feet of production times selling price per stud)  
   (42)
2. Utility grade  
   (43)
3. Economy grade  
   (44)
4. Total (add lines 42, 43, and 44)  
   (45)

#### B. Sale of Pallet Material (byproduct per thousand board feet of stud production)  
   (46)

#### C. Sale of Chips
1. Gross revenue  
   (47)
2. Cost of transportation  
   (48)
3. Net revenue (subtract line 48 from line 47)  
   (49)

#### D. Sale of Present Product  
   (50)

#### E. Total Revenue Per Thousand Board Feet (add lines 45, 46, 49, and 50)  
   (51)

### IV. Gross Profit or Loss Per Thousand Board Feet (subtract line 41 from line 51)  
(52)

### V. Desired Revenue Per Thousand Board Feet

#### A. Desired After Tax Rate of Return  
   (53)

#### B. Tax Rate  
   (54)

#### C. Before Tax Rate of Return  
   (55)

#### D. Desired Minimum Total Revenue  
   (56)

Figure 25 (Continued)
research (Bowyer, 1974; Heebink and Fobes, 1971; McEwan, 1974; Muncy, 1955; Reynolds and Gatchell, 1971).

For ease of computation and analysis, values are entered on a per thousand board feet basis. Therefore, the yearly totals may simply be divided by the yearly production in thousand board feet units. The data sheet also provides for analysis of 2 x 4 production figures versus the sawmill's present product figures. This will enable the mill operator to not only determine whether 2 x 4 production would be economical, but whether it is more or less economical than production of the mill's present product. It also allows for product mixing.

It must be recognized that the time value of money is not considered. However, the analysis is only over a one-year period, and it should not affect the values very much. Examples of the method used in calculating each value on the sheet are presented in the Appendix.

The cost data for eastern cottonwood 2 x 4 production by Iowa sawmills was obtained from many sources. Actual cottonwood 2 x 4 production cost data was obtained from the two cooperating mills used in the second analysis of the log diameter class falldown problem. The form was also sent to operators of Iowa sawmills with annual production rates greater than 750,000 board feet per year to obtain their estimates of costs associated with cottonwood 2 x 4 production. Also, cost data was obtained from a review of literature on the
subject (Bowyer, 1974; Wengert, 1977) and personal communications. Revenue data was obtained from: (1) the sale of stud grade material produced by the two cooperating mills, (2) information supplied on the cost-revenue data form by surveyed mills, (3) personal communication, and (4) a survey of current prices paid by lumber dealers in the Ames-Des Moines, Iowa, market area. The lumber dealer survey will be explained further in the following section on market analysis.

Market Analysis

As stated in the introduction, even though eastern cottonwood 2 x 4's may be economically produced, markets must be established for sale of the products if sawmills are to be expected to produce them. A questionnaire was constructed, shown in Figure 26, and sent to ten Ames-Des Moines, Iowa, area lumber dealers. This questionnaire surveyed by grade the: (1) dealer's willingness to purchase cottonwood 2 x 4's, (2) current softwood 2 x 4 buying and selling prices, and (3) their firm's history of buying from cooperating mills.

---


2 Jennet, J., Walnut Lane Wood Products, Rural Route 1, Nevada, Iowa, personal communication, 1979.
Figure 26. 2 x 4 market questionnaire
1. Would you be willing to sell cottonwood 2 x 4's, assuming you received your normal markup above purchase cost?

<table>
<thead>
<tr>
<th>Grade</th>
<th>Stud</th>
<th>Construction</th>
<th>Standard</th>
<th>Utility</th>
<th>Economy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maybe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Don't know</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. What is the current price you pay for softwood 2 x 4's ($/M bd. ft.)?

<table>
<thead>
<tr>
<th>Stud</th>
<th>Construction</th>
<th>Standard</th>
<th>Utility</th>
<th>Economy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. What is the present annual quantity of softwood 2 x 4's you purchase?

<table>
<thead>
<tr>
<th>Stud</th>
<th>Construction</th>
<th>Standard</th>
<th>Utility</th>
<th>Economy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. How much would you be willing to pay for cottonwood 2 x 4's ($/M bd. ft.)?

<table>
<thead>
<tr>
<th>Stud</th>
<th>Construction</th>
<th>Standard</th>
<th>Utility</th>
<th>Economy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. What is the estimated annual quantity of cottonwood 2 x 4's you would be willing to purchase?

<table>
<thead>
<tr>
<th>Stud</th>
<th>Construction</th>
<th>Standard</th>
<th>Utility</th>
<th>Economy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. What is your current selling price for softwood 2 x 4's?

Stud ____________________________
Construction _____________________
Standard __________________________
Utility ____________________________
Economy __________________________

7. What would be your estimated selling price for cottonwood 2 x 4's?

Stud ____________________________
Construction _____________________
Standard __________________________
Utility ____________________________
Economy __________________________

8. Do you feel cottonwood 2 x 4's would perform adequately as framing lumber?

Yes _____________________________
Maybe ____________________________
No __________________________________
Don't know _________________________

If other than yes, why not?_____________________________________________________

_____________________________________________________

_____________________________________________________

This information will be strictly confidential.

Figure 26 (Continued)
prices and quantities, and (3) expected cottonwood 2 x 4 buying and selling prices and quantities if the dealer would accept cottonwood 2 x 4's.
RESULTS AND DISCUSSION

Log Diameter Class Analysis

A total of 571 2 x 4's were sawn from the 25 logs in this study. As in Part I, the percent overrun or underrun and lumber recovery factor (LRF) were calculated for each sawmill. These data are summarized in Table 15. As indicated in Part I, a 20 percent overrun and LRF value of 6.73 are considered average. Midwest Walnut Company's results appear very favorable in this regard. The Becker Sawmill results are much lower because no attempt was made to recover any material other than 2 x 4's. Also, the values for both mills were probably lowered by the sawyers' inexperience in sawing by the scragg method.

Table 15. Overrun or underrun and lumber recovery factor (LRF) values for Part III

<table>
<thead>
<tr>
<th>Mill</th>
<th>Overrun (Underrun)</th>
<th>LRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midwest Walnut Co.</td>
<td>17</td>
<td>7.56</td>
</tr>
<tr>
<td>Becker Sawmill</td>
<td>(5.3)</td>
<td>6.02</td>
</tr>
</tbody>
</table>

The 2 x 4's were graded by Mr. H. R. Bell, Chief Inspector for the Northern Hardwood and Pine Manufacturers Association, Inc. The results are given in Table 16. These values compare quite closely with the results obtained in Part I (Table 4).
Table 16. Grading results for Part III

<table>
<thead>
<tr>
<th>Grade</th>
<th>Number of Pieces</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stud</td>
<td>304</td>
<td>53.2</td>
</tr>
<tr>
<td>Utility</td>
<td>166</td>
<td>29.1</td>
</tr>
<tr>
<td>Economy</td>
<td>57</td>
<td>10.0</td>
</tr>
<tr>
<td>Cull</td>
<td>44</td>
<td>7.7</td>
</tr>
</tbody>
</table>

A chi-square test indicated that there was no significant difference in the number of stud grade pieces obtained from the logs in the 16- to 20-inch diameter class versus logs of all other diameters. This is in direct contradiction of the result obtained in Part I. However, no rational reason can be given for any diameter class differences.

Market Analysis

Five of the ten lumber dealers returned the 2 x 4 market questionnaire. Results from those questionnaires indicated that lumber dealers in the Ames-Des Moines area are paying the following prices per thousand board feet as of May, 1979: $260 for stud grade, $110 for utility grade, and $80 for economy grade. The manager of Plywood Minnesota, Des Moines, Iowa, was the only dealer indicating a willingness to purchase stud grade cottonwood 2 x 4's.

Therefore, the 304 stud grade pieces obtained from the cooperating mills in the second study were sold to Plywood Minnesota at $15 under the current market price. The lower price was agreed upon to help
introduce cottonwood 2 x 4's and is within the 10 percent differential range previously cited as acceptable to introduce new species. Because it is the chain's main distributor for central Iowa, acceptance of cottonwood studs by the Des Moines Plywood Minnesota store can provide a potentially large market. The store's manager also felt that buying studs produced in Iowa would be very economical in terms of savings in shipping costs, which currently run about $25 per thousand board feet.

Economic Data

A completed version of the cost-revenue data form showing the average costs and revenues associated with cottonwood 2 x 4 production by Iowa sawmills is given in Figure 27. Results indicated that the average cost for Iowa sawmills to produce cottonwood 2 x 4's is $166.69 per thousand board feet. The average log cost was $91.67 per thousand board feet of actual production, based on a scaled cost of $110 per thousand board feet and assuming a 20 percent overrun. This results in a production cost of $75.02 per thousand board feet.

The projected total revenue is $201.00 per thousand board feet, resulting in a gross profit of $34.31 per thousand board feet. To arrive at those figures, the weighted average of the number of pieces obtained in each grade was determined from the two analyses of production results previously discussed. The stud grade average was then multiplied by the $260 selling price obtained from the market surveys.
Figure 27. Completed cost-revenue data form showing average costs and revenues associated with cottonwood 2 x 4 production by Iowa sawmills
Annual Production 750,000-2,500,000 bd. ft.

II. Costs Per Thousand Board Feet

<table>
<thead>
<tr>
<th>Study Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Fixed Costs Per Thousand Board Feet</strong></td>
<td></td>
</tr>
<tr>
<td>1. Administrative and direct supervisory salaries</td>
<td></td>
</tr>
<tr>
<td>a. Wages</td>
<td>$22.00</td>
</tr>
<tr>
<td>b. Fringe benefits</td>
<td></td>
</tr>
<tr>
<td>(1) Insurance (life, health, disability, etc.)</td>
<td>0.10</td>
</tr>
<tr>
<td>(2) Vacation</td>
<td>0.10</td>
</tr>
<tr>
<td>(3) Sick leave</td>
<td>0.10</td>
</tr>
<tr>
<td>(4) Pensions</td>
<td>----</td>
</tr>
<tr>
<td>(5) Holidays</td>
<td>0.10</td>
</tr>
<tr>
<td>c. Social Security</td>
<td>1.06</td>
</tr>
<tr>
<td>d. Unemployment Ins.</td>
<td>0.53</td>
</tr>
<tr>
<td>e. Workmen's Compensation</td>
<td>0.19</td>
</tr>
<tr>
<td>f. Others</td>
<td>----</td>
</tr>
<tr>
<td>2. Rent</td>
<td>0.10</td>
</tr>
<tr>
<td>3. Taxes (excluding income)</td>
<td>0.10</td>
</tr>
<tr>
<td>4. Depreciation</td>
<td>3.00</td>
</tr>
<tr>
<td>5. Office supplies</td>
<td>0.20</td>
</tr>
<tr>
<td>6. Insurance (fire, accident, etc.)</td>
<td>0.50</td>
</tr>
<tr>
<td>7. Interest on debt</td>
<td>3.00</td>
</tr>
<tr>
<td>8. Others</td>
<td>----</td>
</tr>
<tr>
<td><strong>Total (add lines 1 through 17)</strong></td>
<td><strong>$31.08</strong></td>
</tr>
</tbody>
</table>
### B. Variable Costs Per Thousand Board Feet

1. **Direct labor**
   - **a. Wages**
     - $23.80
   - **b. Fringe benefits**
     - (1) Insurance (life, health, disability etc.)
       - 0.10
     - (2) Vacation
       - 0.12
     - (3) Sick leave
       - 0.12
     - (4) Pensions
     - (5) Holidays
       - 0.12
   - **c. Social Security**
     - 1.15
   - **d. Unemployment Ins.**
     - 0.57
   - **e. Workmen's Compensation**
     - 1.53
   - **f. Others**

2. **Raw materials**
   - **a. Logs**
     - 91.67
   - **b. Others**

3. **Direct supplies**
   - **a. Saw blades, teeth, etc.**
     - 0.40
   - **b. Tools**
     - 0.03
   - **c. Other**

4. **Utilities (power, heat, light, water, etc.)**
   - 4.00

5. **Maintenance & repairs**
   - 2.00

6. **Selling & shipping**
   - 2.00

7. **Seasoning**
   - 4.00

8. **Grading**
   - 4.00

9. **Others**

   **Total (add lines 19 through 39)**
   - $135.61

---

*Figure 27 (Continued)*
### C. Total Cost Per Thousand Board Feet
(Add lines 18 and 40)

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>$166.69</td>
<td>(41)</td>
</tr>
</tbody>
</table>

### III. Revenues Per Thousand Board Feet

#### A. Sale of 2 x 4's

1. Stud grade (number produced per thousand board feet of production times selling price per stud)
   
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>114.40</td>
</tr>
<tr>
<td></td>
<td>(42)</td>
</tr>
</tbody>
</table>

2. Utility grade __________________________ (43)

3. Economy grade __________________________ (44)

4. Total (add lines 42, 43, and 44)
   
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>114.40</td>
</tr>
<tr>
<td></td>
<td>(45)</td>
</tr>
</tbody>
</table>

#### B. Sale of Pallet Material (by-product per thousand board feet of stud production)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>83.85</td>
</tr>
<tr>
<td></td>
<td>(46)</td>
</tr>
</tbody>
</table>

#### C. Sale of Chips

1. Gross revenue __________________________ (47)

2. Cost of transportation __________________________ (48)

3. Net revenue (subtract line 48 from line 47)
   
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td>(49)</td>
</tr>
</tbody>
</table>

#### D. Sale of Present Product

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(50)</td>
</tr>
</tbody>
</table>

#### E. Total Revenue Per Thousand Board Feet (add lines 45, 46, 49, and 50)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>201.00</td>
</tr>
<tr>
<td></td>
<td>(51)</td>
</tr>
</tbody>
</table>

### IV. Gross Profit or Loss Per Thousand Board Feet (subtract line 41 from line 51)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$34.31</td>
</tr>
<tr>
<td></td>
<td>(52)</td>
</tr>
</tbody>
</table>

### V. Desired Revenue Per Thousand Board Feet

#### A. Desired After Tax Rate of Return

<table>
<thead>
<tr>
<th></th>
<th>15%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(53)</td>
</tr>
</tbody>
</table>

#### B. Tax Rate

<table>
<thead>
<tr>
<th></th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(54)</td>
</tr>
</tbody>
</table>

#### C. Before Tax Rate of Return

<table>
<thead>
<tr>
<th></th>
<th>18.75%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(55)</td>
</tr>
</tbody>
</table>

#### D. Desired Minimum Gross Revenue

<table>
<thead>
<tr>
<th></th>
<th>$197.94</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(56)</td>
</tr>
</tbody>
</table>

Figure 27 (Continued)
However, because the utility and economy grade selling prices are considerably lower than the $150 per thousand board feet that can be obtained for pallet material, it is recommended that everything other than stud grade pieces be resawn into pallet material. While this will incur greater production costs, the higher revenue will make it worthwhile. Therefore, approximately 560 board feet per thousand board feet of production will be pallet material. The rest will be stud grade material. If it is assumed that the mill operator desires an after tax rate of return of 15 percent and the tax rate is 20 percent, the minimum total revenue necessary to produce that rate of return will be $197.94. In actuality, the projected $201.00 total revenue figure represents a 20.58 percent before tax rate of return. Based on the 20 percent tax rate, that is a 16.5 percent after tax rate of return.

In analyzing the production costs, it must be remembered that in any particular category, individual sawmill costs will vary. However, with the exception of a few mills, the $75.02 total production cost figure appeared to be quite uniform throughout the surveys. The log cost figure will be lower if the sawmills operate at an overrun greater than 20 percent. This would appear quite likely once the sawmill employees became used to 2 x 4 production techniques.

The seasoning cost was based on a $2 per thousand board feet per summer month cost. It is assumed the 2 x 4's would take two summer months to dry. Due to the long dry kiln times, it is recommended that cottonwood 2 x 4's be partially air-dried before placement in a kiln.
This would reduce kiln charges. Also, please note that there are several different ways to obtain grading services, and the cost will depend on the production rate. Contact Northern Hardwood and Pine Manufacturers Association, Inc., Green Bay, Wisconsin, for the most economical method.

Revenues can be expected to increase if the sawmills produce more than 55 percent stud grade pieces, which is the basis for the results in Figure 27. Due to the difference in price, it is recommended that all pieces below stud grade be resawn into pallet material. By not doing so, the 20.58 percent before tax rate of return would be lowered to 11.4 percent. Also, if the sawmill does not have a market for its chips, that loss of revenue would reduce the before tax rate of return from 20.58 percent to 18.9 percent.
CONCLUSIONS

The study reported in Part III was designed to: (1) re-analyze the 16- to 20-inch diameter class falldown problem, (2) obtain representative cost-revenue data for eastern cottonwood 2 x 4 production by Iowa sawmills, and (3) locate potential markets for cottonwood 2 x 4's. While the results obtained in Part I indicated logs in the 16- to 20-inch diameter class produced a lower percentage of stud grade pieces than logs of all other diameters, no reason could be given for that result. Further analysis in this part showed no difference. Grading results obtained in Part III were very similar to those obtained in Part I.

Selling prices in the Ames-Des Moines, Iowa, area were determined for stud, utility, and economy grade 2 x 4's. These were used to determine the revenue associated with 2 x 4 production. Also, a potential market for stud grade material was located, and the studs obtained from the cooperating mills were sold.

Representative cost-revenue figures for cottonwood 2 x 4 production by Iowa sawmills were determined. The total cost was $166.69 per thousand board feet, and the total revenue was projected to be $201.00 per thousand board feet. This resulted in a 20.58 percent before tax rate of return. While those figures are only averages, they can be used by Iowa sawmill operators to indicate potential high cost problem areas and the economic feasibility of producing cottonwood 2 x 4's.
PROJECT SUMMARY

This dissertation has presented the results of a feasibility study on the efficient processing and use of eastern cottonwood (*Populus deltoides* Bartr.) for wall framing lumber. It was determined that any of the processing techniques presently utilized by sawmills similar to those found in Iowa are suitable for cottonwood 2 x 4 production. It is recommended that the scragg sawing pattern be used, however. Also, the new SDR system (saw, dry, and rip) appears to hold promise as a more efficient processing technique.

The working stress values for eastern cottonwood light framing and stud grades have been officially approved and published in the latest Northern Hardwood and Pine Manufacturers Association, Inc., grading rules book. Supportive strength data for full-sized eastern cottonwood 2 x 4 members and nail withdrawal resistance data indicate that eastern cottonwood will perform adequately as 2 x 4 members.

Representative cost-revenue figures for cottonwood 2 x 4 production by Iowa sawmills indicate that the total cost and total revenue can be expected to be $166.69 and $201.00 per thousand board feet, respectively. This represents a 20.58 percent before tax rate of return. Also, a potentially large market has been identified for cottonwood 2 x 4's.

All this information points to the fact that it is technically and economically feasible to produce 2 x 4's from eastern cottonwood.
LITERATURE CITED


ACKNOWLEDGMENTS

I would like to express my deepest appreciation to my major professor, Dr. D. W. Bensend, for his gentlemanly guidance and encouragement during my undergraduate and graduate studies. Special thanks are also extended to Dr. D. R. Prestemon for his assistance above and beyond the call of project leader.

I would also like to thank my other committee members, Dr. G. W. Thomson, Dr. C. E. Smith, Dr. A. E. Bergles, and Dr. G. H. Junkhan for their willing assistance. Thanks also to Dr. S. E. Jungst for his statistical assistance.

The academic freedom and responsibilities afforded me by the Iowa State University Forestry Department have been invaluable and are deeply appreciated.

Throughout this project, the personnel at the U.S. Forest Products Laboratory, especially Mr. J. H. Kaiserlik, have been most helpful and courteous.

Thanks are also in order for the many sawmill operators, U.S. Forest Service, and Iowa Conservation Commission, particularly Mr. D. Michel, without whom this project would have been impossible.

Finally, special thanks to my parents for their continuous encouragement, and very special thanks to my wife, Kathi, for cheerfully putting up with the life of a graduate student.

These are difficult debts to repay.
I. Introduction

This computation sheet has been devised to help you analyze the economic feasibility of producing cottonwood 2 x 4's. Therefore, it is only a personal guide and is not usable for tax purposes. You should be able to list most of the revenues and costs associated with producing your present product. However, you will need to estimate what you feel your costs and revenues will be when studs are produced. Estimate carefully; this computation sheet is obviously only as accurate as the information you enter.

A completed computation sheet has been included to help you. The data included is based on 1978 information; note any changes in the information. If any of the lines on the sheet are not applicable to your operation, simply leave them blank.

The values entered are per thousand board feet. To determine costs and revenues per thousand board feet, divide your yearly figure by your yearly production in thousand board feet units.

Example: You pay $15,000 per year for equipment and land rentals; you produce 500,000 board feet per year. The rent value you enter on line 11 would be $15,000 divided by 500 thousand board feet, or $30 per thousand board feet.

Some of the variable costs may be fixed in nature, and vice versa. For example, a minimum amount of power or maintenance may be required no matter what your production level is. However, for ease of computation, simply consider the total amount to be variable in nature. Also for ease of computation, this sheet assumes that you will need no new equipment to produce studs. If you will need more equipment, please contact the Extension Forester, Iowa State University (515-294-1168), for help in determining the added cost. It must also be recognized that the time value of money is not considered. However, the analysis is over a very short time period, and it should not affect the values very much.

If you need any help in filling out the sheet, please contact the Iowa State University Extension Forester.

II. Costs Per Thousand Board Feet

A. Fixed Costs Per Thousand Board Feet

Fixed costs are those costs that do not vary with the production rate. For example, the same property taxes must be paid no matter what the production rate is.
1. Administrative and direct supervisory salaries

This category includes your salary, foremen's salaries, secretaries' salaries, and all other salaries except direct laborers' salaries. There will probably be no difference between salaries for stud production versus your present product, unless you feel there will be different managing and paperwork time requirements.

a. Wages

Example: Assume your mill produces 2,500,000 board feet per year. Your wages totaled $15,000 and you paid one secretary $8,000. Wages per thousand board feet would then be $15,000 \div 2,500 = $9.20.

b. Fringe benefits

Assume you provided no insurance or pensions. Vacation, sick leave, and holidays would be left blank because you and your secretary are salaried. Therefore those values are already included in section 1.a.

c. Social Security

Your share of the Social Security is presently 6.05% of the first $17,700 in salaries, or in this example: 

\[ \times 0.0605 \times 23,000 = $1391.50 \]

The value entered would be $1391.50 \div 2500 = 0.557.

d. Unemployment Insurance

Unemployment Insurance is dependent upon many factors. You will receive a statement from the Iowa Department of Job Service indicating the amount due. For this example it is assumed that your rate is 3%. The value entered would be 

\[ (23,000)(0.03) \div 2500 = 0.276 \]

e. Workmen's Compensation

Workmen's Compensation rates may be obtained from:

Northcentral Compensation Rating Bureau
2525 E. Euclid
Des Moines, IA 50317
515-266-2101

For this example, the clerical rate is $0.14 per $100 total payroll, and assuming most of your time is in
sales, $0.65 per $100 total payroll. The value entered would be \[ \left( \frac{8000}{100} \times 0.14 \right) + \left( \frac{15,000}{100} \times 0.65 \right) \] \div 2500 = 0.043.

2. Rent

This includes such things as land or equipment that will need to be rented. An example might be land rented for a seasoning yard. In the example computation sheet provided, it is assumed that nothing is rented.

3. Taxes (excluding income)

An example of this might be property taxes. The sample sheet assumes $2500 in taxes, so the value entered would be \[ 2500 \div 2500 = 1.00. \]

4. Depreciation

This is a sum of all depreciable items such as buildings and equipment. Depreciable items are those that require a present cash outlay and produce benefits extending over two or more years into the future. A major exception to that definition is land, which is not depreciable. Use straight-line depreciation, unless your present accounting system uses another method.

The accepted formula for calculating straight-line depreciation is:

\[
\text{yearly depreciation} = \frac{B - V}{n}
\]

where:

- \( B \) = first cost = original cost of item plus such things as installation and transportation costs.
- \( V \) = net salvage = value of equipment after its life of \( n \) years minus such things as removal costs.
- \( n \) = depreciable life

The accepted depreciable lives associated with permanent sawmill operations are:

- buildings 45 years
- equipment 10 years

If data on freight, installation, and tax costs are unavailable, use 15% of equipment cost as an estimate.

Example:
You bought a new edger for $5,000. Installation will cost $350, freight $250, and tax $150. In ten years you expect to be able to sell it for $500, but it will cost you $200 to remove it. The yearly depreciation would be:

\[
B = 5000 + 350 + 250 + 150 = 5750 \\
V = 500 - 200 = 300 \\
D = \frac{5750 - 300}{10} = 545 \text{ per year}
\]

For the sample sheet, it is assumed that your total capital investment is $200,000. The value entered would be \((200,000 - 10) ÷ 2500 = 8.00\). This assumes fully depreciated buildings.

5. Office supplies

This would include such things as paper, pens, stamps, etc. For the sample sheet, it is assumed you spend $1000 per year. The value entered would be \(1000 ÷ 2500 = 0.40\).

6. Insurance

Insurances covered include such things as fire and accident. Do not include wage fringe benefit insurances. In this example, it is assumed that you pay $1000 per year. The value entered would be \(1000 ÷ 2500 = 0.40\).

7. Interest on debt

This includes any money spent as interest on debts incurred purchasing land and equipment or any other form of debt related to your sawmill operation. For the sample sheet, it is assumed that you borrowed half of the $200,000 capital investment at a 10% interest rate. The value entered would be \(\left(\frac{100,000}{2}\right)(.10) ÷ 2500 = 4.00\).

8. Others

If any of the previous categories did not include particular fixed costs you incur while operating your sawmill, include them here.

B. Variable Cost Per Thousand Board Feet

Variable costs are those costs that will change depending upon your production level. An obvious example is power. As you produce more lumber, your energy requirements will increase.
1. Direct labor

This category includes those people directly involved in producing lumber, for instance, the head sawyer. On the sample computation sheet, it is assumed that no insurance or pensions are provided. The following is an assumed breakdown of the hours per employee:

\[
\begin{align*}
&52 \text{ weeks/year} \\
&\times 40 \text{ hours/week} \\
&= 2080 \text{ hours/year} \\
&- 80 \text{ hours/year vacation (2 weeks)} \\
&- 40 \text{ hours/year holidays (5 days)} \\
&- 96 \text{ hours/year sick leave (12 days)} \\
&= 1864 \text{ hours/year worked}
\end{align*}
\]

The breakdown for a six employee operation would then be:

<table>
<thead>
<tr>
<th>Employee</th>
<th>Hourly Rate</th>
<th>Wages (1864 hrs/yr)</th>
<th>Vacation (80 hrs/yr)</th>
<th>Holiday (40 hrs/yr)</th>
<th>Sick Leave (96 hrs/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yard-Log Deck</td>
<td>$4</td>
<td>$7,456</td>
<td>$320</td>
<td>$160</td>
<td>$384</td>
</tr>
<tr>
<td>Sawyer</td>
<td>5</td>
<td>9,320</td>
<td>400</td>
<td>200</td>
<td>480</td>
</tr>
<tr>
<td>Edger</td>
<td>4</td>
<td>7,456</td>
<td>320</td>
<td>160</td>
<td>384</td>
</tr>
<tr>
<td>Trimmer</td>
<td>4</td>
<td>7,456</td>
<td>320</td>
<td>160</td>
<td>384</td>
</tr>
<tr>
<td>2-Stackers</td>
<td>4 each</td>
<td>14,912</td>
<td>640</td>
<td>320</td>
<td>768</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
\text{Total:} & \quad $46,600 \quad $2,000 \quad $1,000 \quad $2,400
\end{align*}
\]

a. Wages

Based on the above information, the value entered on the computation sheet would be

\[
46,600 \div 2,500 = 18.64.
\]

b. Fringe Benefits

Since it was assumed that no insurance or pensions were provided, those spaces would be blank. Vacation would be 2,000 \div 2,500 = 0.80, sick leave would be 2,400 \div 2,500 = 0.96, and holidays would be 1,000 \div 2,500 = 0.40.

c. Social Security

Your share of Social Security is presently 6.05% of the first $17,700 in salaries, not including wages
paid for sick leave. The amount paid in the example would be: 
\[(0.0605)(46,600 + 2000 + 1000) = 3000.80.\]
The value entered on the sheet would be 
\[3000.80 \div 2500 = 1.20.\]

d. Unemployment Insurance

Unemployment Insurance is dependent upon many factors. This was discussed under the fixed costs section. If the rate is assumed to be 3%, the amount paid would be 
\[(0.03)(46,600 + 2000 + 1000 + 2400) = 1560.\]
The value entered on the sheet would be 
\[1560 \div 2500 = 0.624.\]

e. Workmen's Compensation

Once again, the rates may be obtained from the bureau listed in the fixed costs section. For this example, sawmill employees are rated at $8.03 per $100 total payroll. The value entered would be 
\[(52,000 \div 100)(8.03) \div 2500 = 1.67.\]

2. Raw materials

The main component of the section is the log cost per thousand board feet. Remember, you are assuming the same volume input, so the log price must be adjusted to indicate any overrun or underrun.

Example:
You pay $80 per thousand board feet for your logs. However, you have a 20% overrun in stud production. Therefore, you are really only paying 
\[(80)(1.00-0.20) = 64\] per thousand board feet.

3. Direct supplies

For this category, add up the total yearly costs of all materials directly involved in producing your product and divide that total by your yearly production rate in thousand board feet units. Do not include seasoning supplies.

Example:
Your total direct supplies cost $1000 per year, and you produce 2,500,000 board feet per year. The value entered would be 
\[1000 \div 2500 = 0.40.\]

For the sample computation sheet, this has been included in the maintenance and repairs section, rather than here.

4. Utilities

This includes power, heat, light, water, etc. Add these yearly values together and divide by your yearly production rate in thousand board feet units. On the sample sheet, it is assumed that your yearly bill is $15,000. The value entered would be 
\[15,000 \div 2500 = 6.00.\]
5. Maintenance and repairs

Calculate this in the same manner as sections 3 and 4. The sample sheet assumes $15,000 per year, so the value entered would be $15,000 \div 2500 = 6.00.

6. Selling and shipping

This will include any costs incurred while marketing your product. Once again, divide the total by your yearly production rate in thousand board feet units. Do not include any chip sale transportation costs. The sample sheet assumes $15,000 per year, so the value entered would be $15,000 \div 2500 = 6.00.

7. Seasoning

This cost will depend upon your method of seasoning (air vs. kiln). If you are air drying your lumber, you may assume the cost to be $2 per month per thousand board feet. This includes yard costs, pile foundation and cover costs, sticker costs, etc. It does not include labor costs, which are included in the direct labor section. It also does not include degrade loss, which will be considered in the revenue section. Cottonwood 2 x 4's will need to be air seasoned for at least two summer months. The value entered would be ($2/month/M bd. ft.)(2 months) = 4.00.

Example:

You pay $80 per thousand board feet for your logs. However, you have a 20% overrun in stud production. Therefore, you are really only paying $(80)(1.00-0.20) = $64 per thousand board feet.

8. Grading

Grading costs will vary slightly, but a good approximation is $4 per thousand board feet.

C. Total Cost Per Thousand Board Feet

Add the total fixed and total variable costs together.

III. Revenues Per Thousand Board Feet

A. Sale of 2 x 4's

After grading, assume that you have 60% stud grade material, 30% utility grade, and 10% economy grade. Since there are 188 2 x 4's per thousand board feet, you would have 113 studs, 56 utility grade 2 x 4's, and 19 economy grade 2 x 4's.

1. Stud grade

If stud grade material sells for $1.33 per stud ($250/M bd. ft.), the value entered would be (113)(1.33) = 150.
2 & 3. Utility and economy grade

In this example, it is assumed that utility and economy grade material is worth more as pallet material, so these will be resawn and sold as pallet material.

B. Sale of Pallet Material

This includes pallet material produced as a by-product and the resawn utility and economy grade material. If 150 board feet of pallet material was produced, and the resawn 2 x 4's equal \((75-2 \times 4's)(5.33 \text{ bd. ft./2 x 4})\) or 400 board feet, the total pallet material produced would be 550 board feet. If it is assumed that pallet material sells for $150 per thousand board feet, the value entered would be \((150 \times 550 \div 1000) = 82.50\).

C. Sale of Chips

1. Gross revenue

If it is assumed that 0.5 tons of salable chips are produced per thousand board feet of lumber production, and the selling price of chips at the mill is $10.50 per ton, the value entered would be \((0.50)(10.50) = 5.25\).

2. Cost of transportation

If transportation costs to the mill are $5 per ton, the value entered would be \((5)(0.50) = 2.50\).

3. Net revenue

This is simply the difference between 1 and 2, or in this case 2.75.

D. Sale of Present Product

This will only be used when analyzing your present situation, rather than 2 x 4 production.

E. Total Revenue Per Thousand Board Feet

Add together the sale of 2 x 4's, pallet material, and chips.

IV. Gross Profit or Loss Per Thousand Board Feet

This is simply the difference between the total revenue and total cost. In this example, the difference is $97.08, which represents a before tax rate of return of \(97.08 \div 138.17 = 70\%\). Remember, this is a before tax value.

By comparing the values on line 52 for stud production vs. your present product, you will be able to determine which type of production is more profitable. If you plan on producing both studs and your present product, simply determine what percentage of time will be spent on each product, and multiply the values on line 52 by those percentages.
Example:
You plan to produce studs 50% of the time and your present product 50% of the time. If line 52 is $97 for stud production and $60 for your present product, the gross profit per thousand board feet would be $(97)(0.5) + (60)(0.5) = $78.50.

V. Desired Revenue Per Thousand Board Feet
A. Desired After Tax Rate of Return
Each mill owner must decide what rate of return is most desirable. For many mills this is 15%.

B. Tax Rate
If the mill's profit is taxed as personal income for the mill owner, the tax rate will be the owner's personal income tax rate. If the mill is controlled by a corporation, the tax rate will be approximately 50%.

C. Before Tax Rate of Return
If $t$ = tax rate, MARR = minimum attractive rate of return, and BTRR = before tax rate of return, the mill owner may compute BTRR using the formula $BTRR = \frac{MARR}{1-t}$. For the sample sheet, if the tax rate is 20% and MARR is 15%, then $BTRR = \frac{(0.15)}{(1-0.2)} = 18.75\%$.

D. Desired Minimum Gross Revenue
The desired minimum gross revenue is found by multiplying the total cost by BTRR plus 1.0. For the sample sheet, the desired minimum gross revenue would be $(138.17)(1.875) = $164.08. Since the total revenue on line 51 is greater than $164.08, the mill has done better than the desired 15% after tax rate of return.

Note:
If line 56 is less than line 52, it does not necessarily mean you will not be making a profit. Profit or loss is determined on line 52. It does mean you will not be making the desired 15% after tax rate of return.
### Annual Production: 2,500,000 bd. ft.

#### Costs Per Thousand Board Feet – Illustrative Sample Values

<table>
<thead>
<tr>
<th></th>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Fixed Costs Per Thousand Board Feet</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Administrative and direct supervisory salaries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Wages</td>
<td>9.20</td>
<td></td>
</tr>
<tr>
<td>b. Fringe benefits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Insurance (life, health, disability, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) Vacation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Sick leave</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4) Pensions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) Holidays</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Social Security</td>
<td>0.557</td>
<td></td>
</tr>
<tr>
<td>d. Unemployment Ins.</td>
<td>0.276</td>
<td></td>
</tr>
<tr>
<td>e. Workmen's Compensation</td>
<td>0.043</td>
<td></td>
</tr>
<tr>
<td>f. Others</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Rent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Taxes (excluding income)</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>4. Depreciation</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>5. Office supplies</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>6. Insurance (fire, accident, etc.)</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>7. Interest on debt</td>
<td>4.00</td>
<td></td>
</tr>
<tr>
<td>8. Others</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total (add lines 1 through 17)</strong></td>
<td><strong>23.876</strong></td>
<td></td>
</tr>
</tbody>
</table>
### B. Variable Costs Per Thousand Board Feet

<table>
<thead>
<tr>
<th>Description</th>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Direct labor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Wages</td>
<td>18.64</td>
<td></td>
</tr>
<tr>
<td>b. Fringe benefits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Insurance (life, health, disability etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>(2) Vacation</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>(3) Sick leave</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>(4) Pensions</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>(5) Holidays</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>c. Social Security</td>
<td>1.20</td>
<td></td>
</tr>
<tr>
<td>d. Unemployment Ins.</td>
<td>0.624</td>
<td></td>
</tr>
<tr>
<td>e. Workmen's Compensation</td>
<td>1.67</td>
<td></td>
</tr>
<tr>
<td>f. Others</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td><strong>2. Raw materials</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Logs</td>
<td>64.00</td>
<td></td>
</tr>
<tr>
<td>b. Others</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3. Direct Supplies</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Saw blades, teeth, etc.</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>b. Tools</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>c. Other</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td><strong>4. Utilities (power, heat, light, water, etc.)</strong></td>
<td>6.00</td>
<td></td>
</tr>
<tr>
<td><strong>5. Maintenance &amp; repairs</strong></td>
<td>6.00</td>
<td></td>
</tr>
<tr>
<td><strong>6. Selling &amp; shipping</strong></td>
<td>6.00</td>
<td></td>
</tr>
<tr>
<td><strong>7. Seasoning</strong></td>
<td>4.00</td>
<td></td>
</tr>
<tr>
<td><strong>8. Grading</strong></td>
<td>4.00</td>
<td></td>
</tr>
<tr>
<td><strong>9. Others</strong></td>
<td>---</td>
<td></td>
</tr>
<tr>
<td><strong>Total (add lines 19 through 39)</strong></td>
<td>114.294</td>
<td></td>
</tr>
</tbody>
</table>
C. Total Cost Per Thousand Board Feet
(Add lines 18 and 40)

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>138.17</td>
<td></td>
</tr>
</tbody>
</table>

III. Revenues Per Thousand Board Feet

A. Sale of 2 x 4's

1. Stud grade (number produced per thousand board feet of production times selling price per stud)

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>150.00</td>
<td></td>
</tr>
</tbody>
</table>

2. Utility grade

3. Economy grade

4. Total (add lines 42, 43, and 44)

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>150.00</td>
<td></td>
</tr>
</tbody>
</table>

B. Sale of Pallet Material (by-product per thousand board feet of stud production)

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>82.50</td>
<td></td>
</tr>
</tbody>
</table>

C. Sale of Chips

1. Gross revenue

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.25</td>
<td></td>
</tr>
</tbody>
</table>

2. Cost of transportation

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.50</td>
<td></td>
</tr>
</tbody>
</table>

3. Net revenue (subtract line 48 from line 47)

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.75</td>
<td></td>
</tr>
</tbody>
</table>

D. Sale of Present Product

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

E. Total Revenue Per Thousand Board Feet (add lines 45, 46, 49, and 50)

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>235.25</td>
<td></td>
</tr>
</tbody>
</table>

IV. Gross Profit or Loss Per Thousand Board Feet (subtract line 41 from line 51)

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>97.08</td>
<td></td>
</tr>
</tbody>
</table>

V. Desired Revenue Per Thousand Board Feet

A. Desired After Tax Rate of Return

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>15%</td>
<td></td>
</tr>
</tbody>
</table>

B. Tax Rate

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td></td>
</tr>
</tbody>
</table>

C. Before Tax Rate of Return

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.75%</td>
<td></td>
</tr>
</tbody>
</table>

D. Desired Minimum Gross Revenue

<table>
<thead>
<tr>
<th>Stud Production</th>
<th>Present Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>$164.08</td>
<td></td>
</tr>
</tbody>
</table>