

**EVALUATION OF A DIRECT PROCESSING SYSTEM FOR  
CONVERTING NO.3 GRADE RED OAK LOGS INTO  
ROUGH DIMENSION PARTS**

by

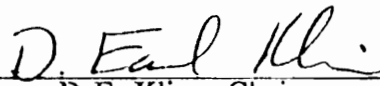
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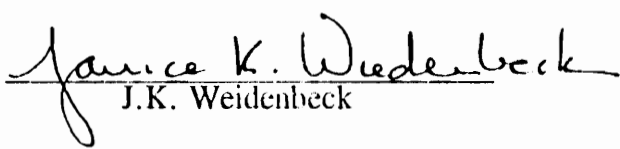
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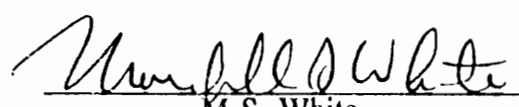
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## **ABSTRACT**

The primary objective of this study was to assess the economic feasibility and profitability of the direct processing system for converting No.3 grade red oak logs into rough dimension parts. In the first part of this study, the cutting yields of green dimension parts and dollar value recovery from No.3 grade red oak logs by the direct processing system were estimated. A combination method of actual log sawing and simulated cutting was used to obtain the dimension yields. Two sawing patterns (live-sawing and five-part-sawing) and two cutting sequences (rip-first and crosscut-first) were tested for their effects on dimension yields, cutting lengths, and dollar value recovery. It was found that live-sawing resulted in significantly higher dimension yield than five-part-sawing. If followed by rip-first, live-sawing also resulted in higher dollar value recovery than five-part-sawing. Rip-first and crosscut-first has no significant differences in dimension yield, however, rip-first can recover more dollar value than crosscut-first if longer cuttings have higher value. The results of this study indicated that the combination of live-sawing and rip-first has the highest dimension yield and dollar value recovery if longer cuttings have higher value.

In the second part of this study, the mill designs of the direct processing system for the various sawing patterns and cutting sequences were developed. The computer simulation/animation models for these designs were built using SIMAN IV/CINEMA. These models were used to predict the dynamic performances and production rates of the various mill designs. Based on simulation results, the direct processing system with one headrig saw can process from 17.8 to 20.5 MBF No.3 grade red oak logs and turn out 11 to 14.3 MBF Clear-two-face, 4/4 random width green dimension parts per shift.

In the third part of this study, a financial analysis using discounted cash flow methods was conducted over a ten year planning horizon to determine the economic feasibility of the direct processing system that processes No.3 grade red oak logs directly into rough dimension

parts. Under the assumptions of this study, measured by both Net Present Value (NPV) and Internal Rate of Return (IRR), all of the six designs evaluated are economically acceptable. With the highest NPV of \$4,193,700 and the highest IRR of 29.6 percent, the design that uses live-sawing and rip-first with manual chop saws was found to be the most economically attractive selection. The profitability of the direct processing system, measured in ROS (Return on Sales), was estimated and compared with the reported profitability for the hardwood dimension and flooring industry. The results indicated that the direct processing system are more profitable than the conventional processing system for making dimension parts.

The sensitivities of NPV and ROS to the changes in dimension part price, log price, labor cost, overhead cost, capital investment, weighting factor for part lengths, green cutting yield and drying and remanufacturing loss were analyzed. Dimension part price, green cutting yield and drying and remanufacturing loss were found to be the most important factors that affect the economic feasibility and profitability of the direct processing system.

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I wish to dedicate this dissertation to my wife, Xiaorong, for her love and moral support throughout my years of graduate study. She spared me a great deal of grief and worry.

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## **Section 1**

### **INTRODUCTION**

#### **1 THE PROBLEM AND ITS SETTING**

##### **1.1 Background**

Hardwood dimension parts (or dimension stock) can be defined as wood products made by machining hardwood lumber into rectangular pieces, including edge-glued panels, suitable for further processing and use in various finished products, primarily in furniture and cabinets (Lawser, 1985). Hardwood dimension parts can be classified as rough, semi-finished, or finished. Rough dimension stock consists of rectangular pieces of wood cut and ripped to specific sizes, including edge-glued panels, normally rough surfaced on two faces (Araman & Lamb, 1990). Semi-finished dimension stock is the rough dimension stock that is machined one or more steps further in the manufacturing process, and such steps may include re-ripping, finish surfacing, moulding, trimming, shaping, and mitering (Araman & Lamb, 1990). Completely finished dimension stock is the completely machined or fabricated dimension parts, with no additional machining to be done by the end user (Lawser, 1985).

The hardwood dimension industry consumes a significant part of hardwood lumber. Based on the figure of 1987, the hardwood lumber consumed by the dimension industry represented about 12 percent of the total hardwood lumber produced in the United States (Luppold, 1991). Since 1983, except for a 7 percent decline in 1991 due to sluggish economy and the decline in furniture production, there has been a significant growth in shipments of hardwood dimension products used in furniture, cabinets and a variety of building products such as flooring, staircase,

interior trim, moulding and millwork (Lawser, 1992). In recent years, there has been a very strong growth in hardwood dimension exports, and this trend is expected to continue (USDC, 1990; USDC, 1991). According to a recent survey of hardwood dimension manufacturers conducted by the National Dimension Manufacturer Association (Lawser, 1992), total dimension sales are expected to increase significantly in 1992, and most of the increase will come from export markets. The expected hardwood dimension exports can reach 150 million dollars in 1992, a 12 percent increase over 1991 (Lawser, 1992).

The conversion of logs into dimension parts in a conventional processing system usually takes place in two steps (see Figure 1.1). First, logs are sawn into lumber and the lumber is then graded in a sawmill according to the grading rules specified by the National Hardwood Lumber Association (NHHLA, 1986). Sawmillers sell standard grade lumber to dimension mill owners, furniture, and/or cabinet makers. Then the lumber is dried and processed into dimension parts in a dimension mill or a rough mill associated with a furniture or cabinet plant.

Usually, 1 Common and 2 Common grade lumber, and some Selects grade, go to the manufacture of dimension parts. The best grade lumber (FAS and F1F) is exported or used directly for making high-quality furniture by domestic consumers. The lowest grade lumber (3A and 3B) are used for making low-value products such as pallet parts and mine props.

## **1.2 Problem Statement**

Though the prospects for the hardwood dimension industry appear encouraging, the hardwood dimension industry is still facing a number of serious problems. These



Conventional Processing System

Direct Processing System

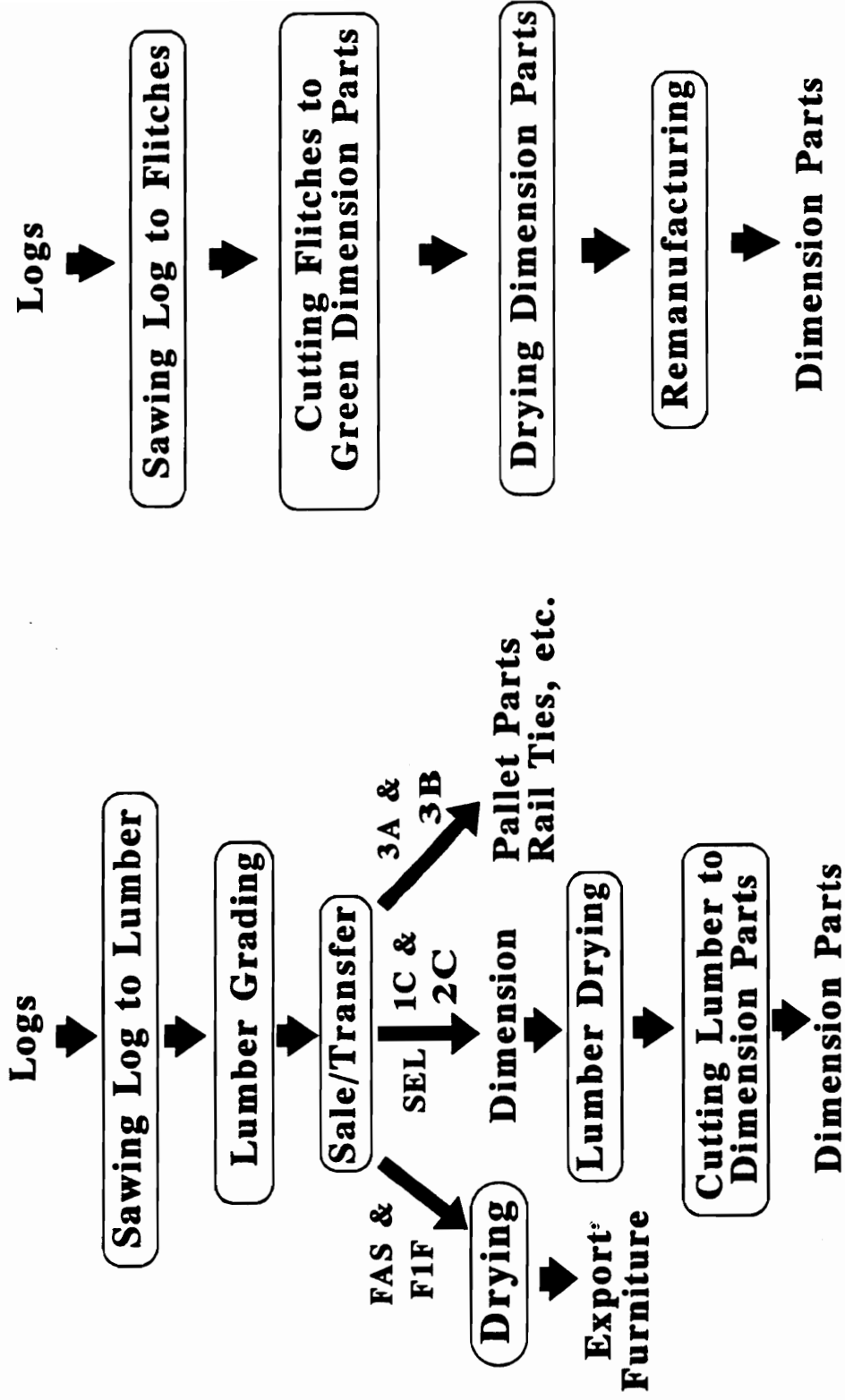


Figure 1.1 Scheme of the Conventional Processing System and Direct Processing System

problems include the strong competition from imported wood furniture and parts, and the escalating costs of doing business. Facing strong world competition, the U.S. hardwood dimension industry not only needs to keep in tune with ever-changing markets, but it also needs to look for new processing technologies which can improve production efficiency and reduce production costs.

In a conventional processing system, the conversion from logs to lumber and the conversion from lumber to dimension parts is usually managed under two independent operations. A lumber manufacturer's concern is to produce as much high-grade lumber as possible. Due to grading constraints, some usable solid wood material from the log is edged off at the sawmill and put into chips to "up-grade" the board and maximize the market value of the boards.

The processing concept of directly converting logs into dimension parts is the result of thinking of the dollar value recovery from logs in terms of furniture parts. A direct processing system of hardwood dimension parts can be defined as a manufacturing system that converts hardwood logs directly into rough green dimension parts without the intermediate steps of lumber manufacturing, lumber grading, lumber trading, lumber shipping, lumber drying and storage. In the direct processing system (see Figure 1.1), logs are sawn into flitches which may or may not be rectangular pieces, depending on the sawing methods used, and these flitches are immediately cut into green rough dimension parts. The green rough dimension parts are then dried and shipped to furniture makers, cabinet makers, and other users of solid wood parts. Some remanufacturing may be needed for those parts that have drying defects such as warp and splits. In the direct processing system, the trading point for lumber no longer exists and only useful material (parts) is traded between suppliers and users of dimension parts. Therefore, trading cost and shipping cost can be reduced.

The direct processing system has been used in Japan and Europe (Araman, 1987), and there is a trend to process dimension parts from logs in the United States (Lawser, 1991; Southern Lumberman, 1992). However, many problems in technology and economics such as cutting yield uncertainty, production costs, economic feasibility and profitability remain unanswered.

For hardwood dimension manufacturers and sawmillers to completely accept this new processing system, they must first find out whether they can produce dimension parts at lower costs and make more profit by using the direct processing system than by using the current conventional processing system given current raw material supplies and economic conditions. In addition, some technical problems such as selecting suitable sawing patterns, selecting an appropriate cutting sequence, and drying dimension parts at low degradation have yet to be solved. So far very little comprehensive research in evaluating the direct processing system has been reported. The information on dimension yield from logs, production costs, economic feasibility and profitability will help U.S. dimension manufacturers to choose appropriate manufacturing methods and marketing strategies. Furthermore, if the direct processing system can profitably process low grade logs into dimension parts, it will provide a greater value-added opportunity for the U.S. hardwood dimension industry with its abundance of low grade material.

### **1.3 The Hypothesis**

It is hypothesized that the direct processing system of producing rough dimension parts from No.3 grade red oak logs is economically feasible and the profitability of the direct processing system will be greater than the that of current conventional processing system for making hardwood dimension parts from standard grade lumber.

### **1.4 The Objectives**

The overall objective of this research is to assess the economic feasibility of the direct processing system for making rough dimension parts from No.3 grade red oak logs and to determine if a direct processing system for producing rough dimension parts from No.3 grade red oak logs can generate more profit than a conventional processing system. The specific subobjectives include:

1. To estimate the dimension yields and dollar value recovery obtainable from No.3 grade red oak logs and detailed cutting information of No.3 red oak logs into dimension parts, and to test the effects of sawing pattern and cutting sequence on the dimension yield, cutting length distribution and dollar value recovery.
2. To develop the various mill designs of the direct processing system for the various sawing patterns and cutting sequences and to investigate the system dynamics of these designed designs by using system simulation techniques.

3. To determine the economic feasibility of the direct processing system for converting No.3 grade red oak logs into rough dimension parts and compare the profitability of the direct processing system with that of the conventional processing system.

## **1.5 Approach**

The overall objective of this dissertation is to assess the economic feasibility and profitability of the direct processing system for making rough dimension parts from No.3 grade red oak logs. Hardwood dimension manufacturers and sawmillers must determine whether the direct processing system is economically sound before they will accept this system.

To make reliable estimates of economic feasibility and profitability, information on the yield of dimension parts and dollar value recovery obtainable from given logs is necessary. Since the yield of dimension parts and dollar value recovery from No.3 grade red oak logs is not known, the second section of this dissertation addresses the issues in dimension yields and dollar value recovery from No.3 grade red oak logs. Since the cutting details of No.3 red oak logs into dimension parts are critical to the input of the subsequent system simulation models of the direct processing system, these details need to be obtained in this section. In making dimension parts from logs, many processing options (including the options of sawing logs into flitches and of cutting flitches into dimension parts) can be used. Since the choice of processing options may affect the dimension yield, the effects of the processing options on the dimension yield and dollar value recovery need to be evaluated to select an appropriate processing option.

Dimension yield and dollar value recovery provide important information for economic evaluation, however, they only indicate what portion of the input raw material is converted into dimension parts and how much value is added to the input raw material. If the increase in the yield and dollar value recovery is realized through intensive machining activities that results in high machining and labor costs, the increase in yield and dollar value recovery may be offset by the increased machining and labor costs. Therefore, the dynamic performance of the different mill designs that use the various processing options need to be thoroughly investigated before they are actually installed. The third section of this dissertation is to develop different mill layouts for the different processing options and to thoroughly investigate the system dynamics of these designed mills. One way to investigate the system dynamics is to experiment with a system. Since no real system that directly process hardwood logs into dimension parts is available for direct experimentation, it will be modeled using system simulation techniques. System simulation techniques will be applied to capture the dynamics of the system so that experimentation can be made. The system simulation models of the direct processing system will provide a detailed understanding of the system dynamics or how changes in cutting practices, machinery resources and labor resources will affect the dynamic performance of the whole system.

Since no one has thoroughly investigated the system dynamics of the direct processing system and no system simulation model for the direct processing system exists, the unique contribution of this dissertation is to develop a methodology to model the "whole system". The application of this methodology can lead to a greater understanding than by studying only the components of the system in "isolation" from one another. For example, a method that provides greater yield may not be the best simply because its productivity may be lower, which in term affects profit.

The fourth or final section of this dissertation brings the results together from Section 2 and 3 to assess the economic viability of the direct processing system for making rough dimension parts from No.3 grade red oak logs.

## **1.6 The Significance of The Study**

Little work has been done in studying direct processing of hardwood logs into dimension parts. The quantity and quality of dimension parts that can be made from No.3 grade red oak logs and the production costs of producing dimension parts directly from No.3 grade red oak logs are not yet known. Some substantial information on the overall yield of rough dimension parts and value recovery from No.3 grade red oak logs will be obtained through this research. The results of this study will lead to better understanding of whether the direct processing system is economically feasible for making rough dimension parts directly from No.3 grade red oak logs. And it will also provide information on whether a direct processing system can provide lower production costs and higher profitability for producing red oak dimension parts than the current conventional processing system. In addition, some important questions about the conditions under which the direct processing system is more profitable will be addressed.

## 2.1 Historical Overview of The Direct Processing Concept

The concept of directly converting hardwood logs into dimension stock is not new. Almost three decades ago, Flann (1963) proposed a vertically integrated operation consisting of a sawmill, dry-kilns, and a "rough mill" located adjacent to a supply of hardwood logs. In this mill, hardwood logs would be converted into dimension parts, without lumber grading, selling/purchasing activities. Malmquist (1968) and Koch et al. (1968) suggested bypassing the standard production of graded lumber from logs 8 to 16 feet long by producing furniture parts and other types of dimension stock directly from short logs or bolts. Hamilton (1970) strongly recommended this approach for producing hard maple furniture and pallet dimension from bolts. Smith (1972) put research in producing hardwood dimension directly from logs at the top of the list for the research priorities for Eastern hardwoods. Smith recommended a closer association between the primary converters of the logs and the secondary manufacturers of hardwood dimension parts. Bingham (1976) called the system of directly processing dimension parts from logs as "T-D" (Tree-to-Dimension) system. Under the "T-D" system, the production of rough dimension parts is moved from the furniture plant to the sawmill near the log supply and the whole operation from tree through the rough dimension is placed under one management.

Some research (Dunmire et al., 1972; Rosen et al., 1980; Stewart et al., 1982; and Huber et al., 1983) has been done in studying the feasibility of producing rough dimension parts from logging residue, such as short logs or bolts. Dunmire et al. (1972) reported making black walnut dimension parts from the bolts ranging from 2 to



6-1/2 feet in length and 5-1/2 to 17 inches in diameter. The bolts were "live-sawn" into 1-1/8 inch-thick rough flitches on a portable saw, and then the flitches were ripped first and crosscut into dimension parts with cutting lengths ranging from 12 inches to 78 inches and cutting width ranging from 1 inch to 6 inches. The results showed that yields averaged 72.5 percent of the bolt scale (International 1/4-inch Rule) in usable Clear-Two-Face dimension parts and 74.5 percent in Clear-One-Face and better dimension parts.

In terms of the integrated sawmill-dimension plant, Rosen et al. (1980) conducted research aimed at predicting dimension yield from short logs of low-quality hardwood trees of aspen, soft maple, black cherry, yellow poplar, and black walnut. The logs were 1.9 to 6.7 feet long and 5 to 8 inches in diameter and were cut into rough dimension stock of 1 to 6 inches wide and 12 to 72 inches long with increment of 6 inches. They reported that the percentage yields of rough dimension stock divided by the scaling board footage (International 1/4-inch Rule) of the logs varied between 56 and 70 percent for different species. Rosen et al. (1980) found that integrated sawmill-dimension plants could best use short logs for dimension stock when the cutting bill required narrow cuttings and a large percentage of the cuttings were short.

Using previous yield data obtained by Rosen et al. (1980), Huber et al. (1983) developed a computer program to quickly provide information on cost, yields, and quantities of 4/4 dimension produced by a manufacturer of furniture dimension parts from short logs of black walnut, black cherry, yellow-poplar, soft maple, and aspen. Under the assumption of the common costs, such as labor cost, overhead cost, gluing cost, drying cost, and delivery cost, the computer program was used in an economic analysis to compare the costs of short-log-produced dimension parts with the costs of the same parts produced from standard graded lumber and to determine the break-even

points between standard graded lumber and short-log-produced material. It was found that the cost saving that can be achieved through using short-log-produced parts was greater for high-valued or high-yield bolt species than for low-valued or low-yield bolt species.

According to Araman (1987), the direct processing system has been implemented in Japan and Europe. The Japanese make green rough dimension stock in standard sizes directly from hardwood logs. In their production system, first, the logs are sawn to boards (flitches) using the live-sawing method. The live-sawn boards are then cut into rough dimension stock in the green state and the green dimension stock is sorted, stacked and dried in a conventional drying kiln (Araman).

Recently, a trend toward processing rough dimension parts or other value-added products directly from logs by sawmillers was noted by a few industry experts. The August issue of Southern Lumberman of 1992 reported:

*"Lumber manufacturers are becoming their own users - they are cutting their own lumber into dimension. Those who bought kilns five years ago are buying a dimension mill today".*

In another report, Lawser (1991) noted a similar trend:

*"More sawmills are turning to secondary manufacturing to convert green or rough lumber into more value-added wood products for industrial and consumer market applications. These value-added products include dimension parts and variety of other products".*

## **2.2 Other Processing Systems That Convert Low-grade Hardwood Logs into Dimension Parts**

To process low grade hardwood logs or bolts into dimension parts, one special processing system called SYSTEM 6 was proposed by some researchers (Reynolds & Gatchell, 1982; Reynolds & Araman, 1983; Reynolds et al., 1983; Reynolds & Hansen, 1986). This system combined the sawmill and the manufacturer of dimension stock together, however, it was developed only for processing small-diameter, low quality hardwood timber that meets the following specifications (Reynolds & Gatchell, 1982): minimum length (nominal) should be 6 feet or 8 feet, the sweep should not exceed 1-1/2 inches for any diameter, log diameter should be between 7.6 and 12.5 inches inside the bark on the small end. Input logs that met these specifications were called SYSTEM 6 bolts and the final product of SYSTEM 6 was standard size blanks (Reynolds and Gatchell, 1982).

As described by Reynolds and Gatchell (1982), the process of SYSTEM 6 consists of sawing SYSTEM 6 bolts to two-sided cants instead of lumber, gang-sawing each cant to boards, conventional drying of boards, automatically gang-crosscutting followed by automatically gang ripping to remove the majority of defects, removing end defects using a manually operated crosscut saw, salvage ripping using a manually operated glue-joint rip saw when required, and finally, edge-gluing pieces with similar grain and color into finished standard blanks. There are two major differences between SYSTEM 6 and the conventional processing system. First, logs are converted to standard size blanks directly, without the intermediate product of standard grade lumber. Second, SYSTEM 6 uses highly automated cutting methods to minimize machine operators' decisions.

SYSTEM 6 may be considered as a special case of the direct processing system of hardwood dimension stock. Since SYSTEM 6 was established, its profitability has been tested for: (1) making frame-quality blanks from white oak thinning (Reynolds & Araman, 1983), (2) making kitchen cabinet C2F blanks from low-grade red oak logs (Reynolds et al., 1983), and (3) making black cherry blanks from small-diameter low-grade cherry logs (Reynolds & Hansen, 1986). Results showed that SYSTEM 6 could profitably process small-diameter, low-grade logs into standard size blanks. In making kitchen cabinet blanks from small-diameter and low-grade red oak logs, a 21.3 and 30 percent rate of return on the investment would be possible for a completely new SYSTEM 6 plant and a current dimension mill, respectively (Reynolds et al., 1983). In making black cherry blanks from small-diameter and low-grade black cherry timber, it was estimated that rate of return on the investment would be 39 to 50 percent, depending on the source of the raw material (Reynolds & Hansen, 1986).

However, there are some limitations of SYSTEM 6. First, it only processes very specific raw material (System 6 bolts); therefore the raw material for SYSTEM 6 is limited. Second, the sawing patterns for sawing logs into boards is fixed, that is sawing each log into two cants and gang-cutting each cant to boards. Third, because of the needs of automated gang ripping, only two cant thickness, either 3-1/4 inches or 4 inches, can be made. Furthermore, since it focuses on the cutting automation, when each board is crosscut, only three cutting choices can be made, being end-trimmed to make one long piece or two medium pieces or three short pieces. Because some sound solid wood is cut off during sawing logs to cants and options in cutting boards into dimension stock are so limited, the dimension yield is somewhat reduced. Only 35 percent yield (The yield of blanks from logs was defined as the ratio of board-footage of blanks to the scaling board-footage of logs in International 1/4" Rule) was obtained

in cutting small-diameter, low-grade red oak logs to C2F standard blanks with lengths of 15, 21, 25, 29, and 33 inches (Reynolds et al., 1983).

In spite of some similarities between the proposed direct processing system in this research and SYSTEM 6, there are differences between these two systems in the following aspects: (a) the input logs of the proposed direct processing system will not have the limitations specified for the input logs of SYSTEM 6; (b) in the proposed direct processing system, the boards (flitches) will be cut into dimension parts in green state and then the green dimension parts will be dried; and (c) the proposed direct processing system will not be constrained to fixed sawing patterns and can be either rip-first or crosscut-first.

### **2.3 Hardwood Dimension Market**

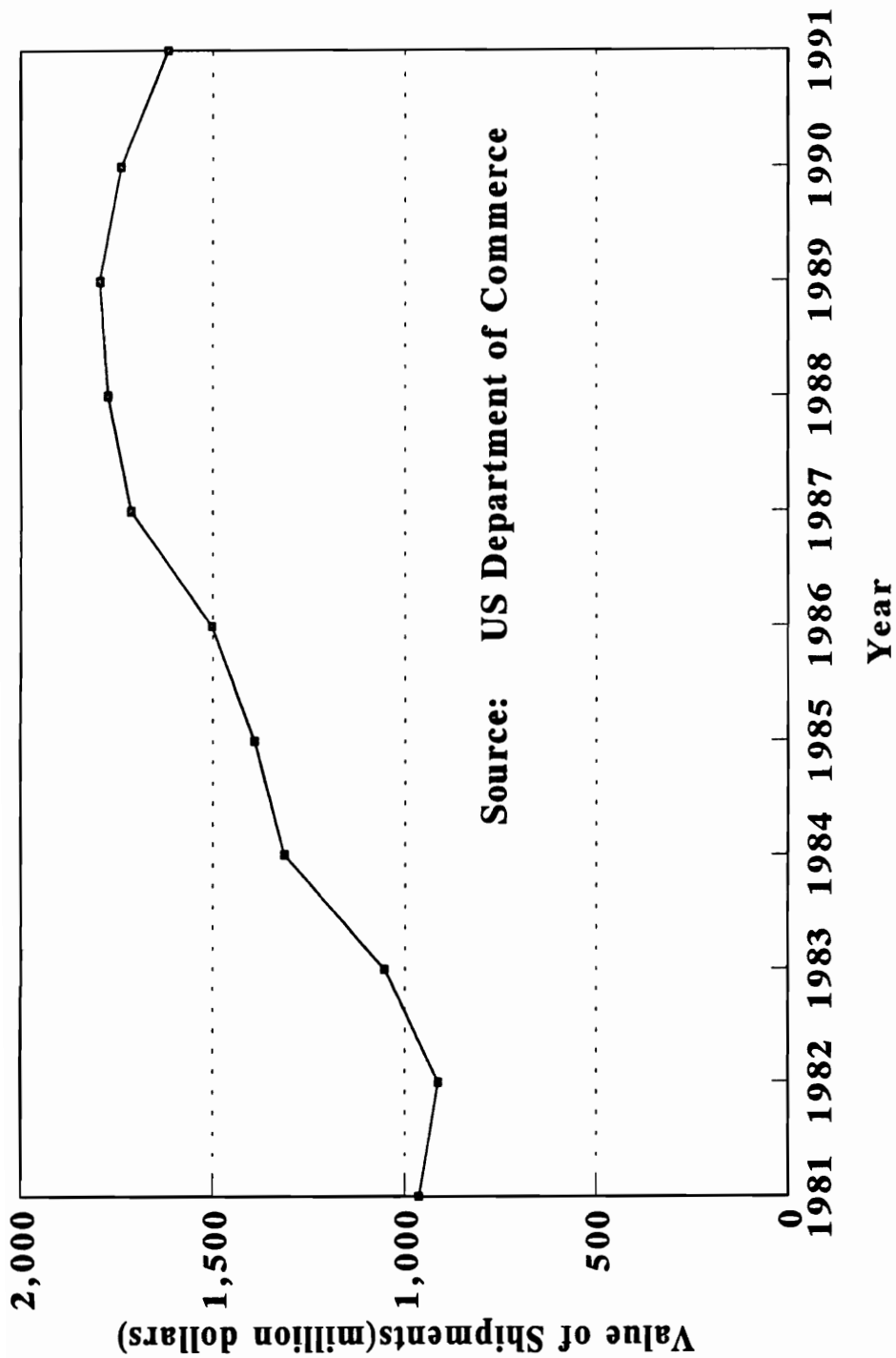
Since hardwood dimension is classified together with hardwood flooring as Hardwood Dimension and Flooring Industry with one Standard Industrial Classification code (SIC 2426) in census data, it is difficult to extract the census data for hardwood dimension from SIC 2426. The Hardwood Dimension and Flooring Industry is divided into three subgroups: hardwood dimension stock, hardwood flooring, and wood frames for household furniture. According to the 1987 U.S. Census of Manufactures Survey of the Hardwood Dimension and Flooring Industry (USDC-BOC, 1987), hardwood dimension stock accounts for 45 percent of the total value of product shipments, hardwood flooring accounts for about 29 percent, wood frames for household furniture for 13 percent, and the remaining 13 percent is not specified by type. Reported

hardwood dimension data (including market and production data) may sometimes include hardwood flooring and wood frames for household furniture.

During the period of 1983 to 1989, there was a significant growth in shipments of dimension products, as show in Figure 1.2. From 1983 to 1989, the value of shipments for the Hardwood Dimension and Flooring Industry increased 96.6 percent (USDC-BOC, 1987; USDC, 1990; USDC, 1991), as shown in Figure 1.2. Due to the general economic recession and the downturn in housing starts, the total shipment of hardwood dimension and flooring declined 3 percent in 1990 and declined an additional 7 percent in 1991 (Lawser, 1992). Participants in a recent market survey conducted by the National Dimension Manufacturers Association (Lawser, 1992) indicated that they anticipated their total dimension sales would increase significantly in 1992. Total shipments of hardwood dimension are expected to reach the level of 2 billion dollars in 1992 (Lawser).

While the domestic markets for hardwood dimension have been sluggish in recent years, there has been a very strong growth in hardwood dimension exports. For example, between 1987 and 1989, U.S. hardwood dimension (including hardwood flooring) increased 100 percent (USDC, 1990) in value of shipments. Though there was a slight decrease in 1990, the increase in hardwood dimension exports has come back since 1991 (USDC, 1991). According to a recent market survey of hardwood dimension manufacturers conducted by the National Dimension Manufacturers Association (Lawser, 1992), hardwood dimension exports are expected to reach 150 million dollars in 1992, a 12 percent increase over 1991. Nearly all of the companies that predict significant sales increases are active exporters.

Lawser (1992) has some explanations for the growing export of U.S. hardwood dimension products. First, U.S. timber processing companies are being encouraged to



**Figure 1.2 Total Value of Shipments by Hardwood Dimension and Flooring Mills**

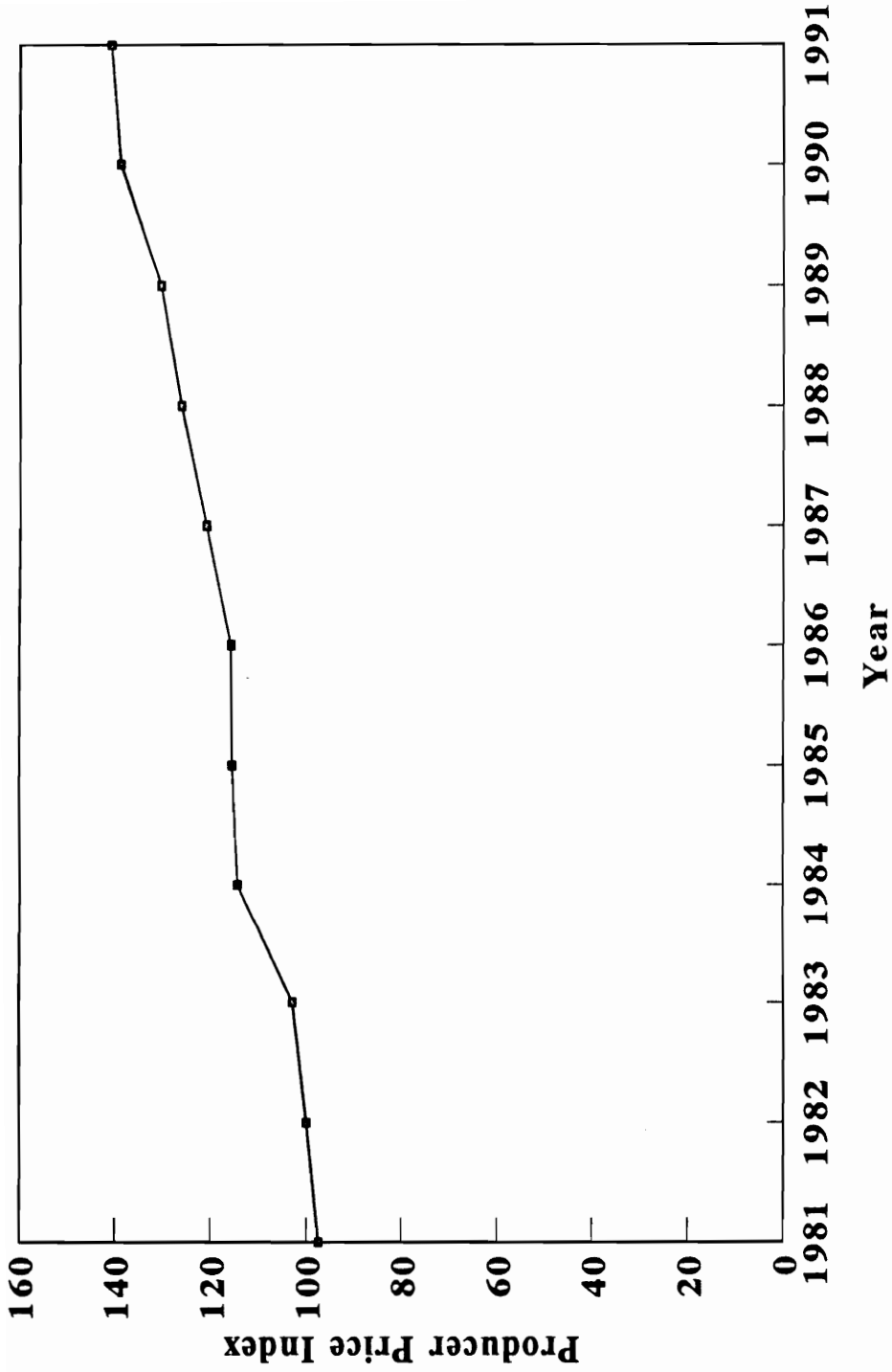
produce more value-added products such as hardwood dimension for export markets. These companies believe that exporting value-added products is more economically beneficial than exporting logs and lumber. Second, the growing concern over U.S. log exports resulted in a greater emphasis on exporting value-added products including dimension stock. Third, the U.S. woodworking industry now realizes that exporting dimension parts enable us to use our abundant supplies of lower-grade lumber to produce more value-added products. Fourth, many furniture and cabinet manufacturers are discovering the advantages of buying dimension products from outside suppliers rather than trying to produce everything themselves. Dimension purchasers pay for only the wood they use and most of the wood waste is left at the dimension mills, therefore, the shipping costs decrease dramatically in relation to the value added to wood products. Fifth, the growing concern over the rapid deforestation of tropical hardwood forest and the export bans by some Southeast Asian countries create a significant interest and demand for U.S. hardwood products as substitutes for threatened tropical species. The recent increase in freight rates and favorable currency exchange may also contribute to growing hardwood dimension exports.

The potential demand for US. hardwood dimension in international markets, especially in Europe and Japan, appears to be excellent based on their demand for U.S. hardwood lumber and inquiries for material such as strip stock and squares (Araman, 1987). Araman proposed exporting standard size rough dimension parts to Japan and Europe. The lengths of the standard size dimension parts range from 12 to 72 inches in 4-inch increments and from 84 to 108 inches in 12-inch increments, and the widths are in groupings of 2+, 2-3/8+, 2-3/4+, and 3-1/8+ inches or in random sizes with a 2-inch minimum.



Although the outlook for exporting hardwood dimension is optimistic, some serious problems that have confronted the U.S. hardwood dimension industry for a long time are still confronting the U.S. hardwood dimension industry. These problems include strong competition from imported wood furniture and parts and the escalating costs of doing business. Strong competition from imported wood furniture and parts has dramatically reduced U.S. produced dimension shipments to the domestic furniture industry (Lawser, 1985). The furniture industry has traditionally been the largest single market for the dimension industry. Increasing imports of wood components creates a very serious problem for the large number of U.S. dimension producers who cater to the domestic furniture industry. The increased imports of partially and completely finished furniture has indirectly reduced the domestic demand for hardwood dimension parts.

Another serious problem facing the U.S. hardwood dimension manufacturers is the escalating costs of doing business. Rising health insurance costs, workers' compensation, taxes and complying with stricter environmental and other government regulations had a significant effects on the bottom line (Lawser, 1992). The escalating costs have resulted in an increasing price for hardwood dimension parts. From 1982 to 1991 the price index for hardwood dimension increased 41 percent (Nolley, 1992), as shown in Figure 1.3. Unfortunately, hardwood dimension manufacturers aren't always able to pass on their additional costs in the form of higher prices due to the competitive nature of the industry. The hardwood dimension business has become extremely competitive, and profit margins are very slim. This has forced several inefficient dimension manufacturers out of business in recent years (Lawser, 1992). The number of U.S. hardwood dimension manufacturers has declined from a high of 890 in 1977 to



**Figure 1.3 Producer Price Index for Hardwood Dimension (1982=100)**

Sources: Producer Price Indexes, U.S. Department of Labor, Bureau of Labor Statistics

739 in 1991 (Lawser, 1992). There has been a trend toward fewer, but larger dimension manufacturers, and this trend is expected to continue (Lawser, 1992).

## **2.4. The Hardwood Resource and Its Availability**

In the United States, most hardwood resources are concentrated in the Eastern part of the country. The inventory of hardwood growing stock totals 275 billion cubic feet in the Eastern United States. It accounts for 90 percent of the hardwood inventory in the United States (Sheffield & Bethtold, 1990). Oak species are the dominant species group in the Eastern United States. They make up about 36 percent of the total hardwood growing stock in the Eastern United States (28 percent in the North and 44 percent in the South (Sheffield & Bethtold, 1990). Since 1952, Eastern hardwood inventories have increased significantly by 70 percent (Sheffield & Bethtold, 1990). This increase is the natural result of the fact that net annual growth has consistently surpassed annual removal in the region. For example, the ratio of hardwood growth to removal in 1986 was 1.8 to 1 (Sheffield & Bethtold, 1990). Recently completed investigations in several Southern States indicate the gap between growth and removal decreased for some individual states due to the increases in the level of annual removal in these states (Sheffield & Bethtold, 1990).

Hardwood inventories are substantial and are larger now than several decades ago. However, timber inventory is not equated with timber supply and much of the total inventory is not now and may never be available for wood products manufacturing. There are a number of factors which make a significant portion of the hardwood growing inventory unavailable for harvest. These factors include landowners' attitudes and objectives toward their growing timber, physical constraints on

harvesting, unmatched timber quality between timber demand and timber growing stock, and environmental concerns, etc.

Since the owners of timberland ultimately determine whether their timber is harvested, the characteristics of landowners and their attitudes toward timber harvesting could be an important factor affecting timber supply. According to Sheffield and Bethtold (Sheffield and Bethtold, 1990), in the Eastern United States, nonindustrial private owners (including farmers and other private owners) hold three-fourths of the total hardwood inventory, while national forest and other public hold only 14 percent, and forest industry owns 11 percent. For many nonindustrial private owners, production of timber is usually not their primary purpose for owning forest land (de Steiguer et al., 1989a). Among the nonindustrial private owners, farmers are more likely to sell timber than nonfarmers. However, more ownerships were shifted from farmers to nonfarmers in the last three decades (de Steiguer et al., 1989b). In the Southern Appalachian region, nonfarmer private owners now control 54 percent of total hardwood timberland, while farmers control only 22 percent (de Steiguer et al., 1989b).

Physical constraints of the resource is another significant factor that limits the supply of hardwood timber (de Steiguer et al., 1989a). Steep slope and accessibility (distance to an access road) are two major physical constraints. For example, in the Southern Appalachian region, almost one-third of the hardwood inventory is on slopes of 61 percent or steeper and/or more than 1500 feet from a road (de Steiguer et al., 1989a). For the most popular hardwood species, select red oak, the situation is even worse. Forty-three percent of red oak is on the slopes of 61 percent and steeper and/or more than 1500 feet from a road (de Steiguer et al., 1989a). The steeper slope and the long distance from an access road create operation problems for economic harvesting.

The physical constraints result in less hardwood timber being economically available than the hardwood timber inventory.

In addition to physical constraints of the resource and landowners' attitudes, another factor affecting the hardwood timber supply is the discrepancy between the quality of growing timber stock and the quality of timber demand from wood industry. The hardwood resource is predominantly low grade, while the hardwoods that have been harvested in the past and for the most part of which will be harvested in the near future have tended to be the higher quality trees and logs (Wengert et al., 1987). This results in a gap between the quality of hardwood timber supply and that of the demand.

According to Sheffield and Bethtold (1990), in the Eastern United States, almost one-half the volume in hardwood sawtimber-size trees exists in the two smallest sawtimber D.B.H classes (the 12- and 14-inch diameter classes). These tree sizes supply the poorest grade of material for uses where log or lumber quality is important. For example, in the Northeast region, only about 10 percent of hardwood stands is in log grade 1, 20 percent in grade 2, and 70 percent in grade 3 or poorer (Anderson, 1981). The hardwood tree grade distribution in Virginia may be typical for the hardwood resource in the Southern Appalachian region. In Virginia, only 8 percent of hardwood trees is in grade 1, 15 percent in grade 2, 38 percent in grade 3 and 39 percent below grade 3 (Wengert et al., 1987). If we assume that grade 1 logs can yield 42 percent No.1 Common and better grade lumber, grade 2 logs can yield 31 percent No.1 Common and better grade lumber, and grade 3 logs can yield 13 percent No.1 Common and better grade lumber (Wengert et al., 1987), and if all grade 1, grade 2 and grade 3 logs in Virginia are processed to lumber, only 21 percent of the produced lumber will be in No.1 Common or better. On the other hand, however, most high-value hardwood products require high grade lumber. Based on the surveys of 252

companies conducted by Bush et al. (1990), the furniture industry uses 73 percent No. 1 Common and better grade lumber, cabinet industry uses 66 percent No. 1 Common and better grade lumber, and dimension industry uses 73 percent No. 1 Common and better grade lumber. As a result of the gap between the quality of hardwood timber supply and demand for high-value hardwood products, much of the hardwood resource is unused or used for low-value products.

Since low quality logs are usually too low in potential value to be profitably harvested and sawn (Wengert et al., 1987), if we take account of the hardwood tree grade distribution, the availability of the qualified hardwood resource for wood industry may not be optimistic. If lower grade hardwoods can be profitably and widely utilized, however, the resource base will be tremendous for the American hardwood industry. Wengert (1987) concluded that *"if lower grade hardwoods are to be profitably utilized, they must be converted into higher valued products, such as furniture parts, rather than into the traditional low-value products such as chips, pallet lumber, or fuel."*

## **2.5. Hardwood Resources in Southwest Virginia**

Southwest Virginia is a heavily forested area where nearly 3 millions acres, or 62 percent of the land is timberland. Seventy percent of the forest land in this region has medium or good site quality capabilities (Muench, 1990). Based on the figure of 1986, farmers and other nonindustrial private owners control 66 percent of timberland in this region, federal, state and local government control 16 percent, the forest industry controls 2.2 percent, and coal companies, railroads and other corporations control 16 percent (Brown, 1986). Of the sawtimber volume growing in this area, 83 percent is

hardwood, and the combined volume of all red and white oak species constitutes 46 percent of the hardwood sawtimber volume (Brown, 1986).

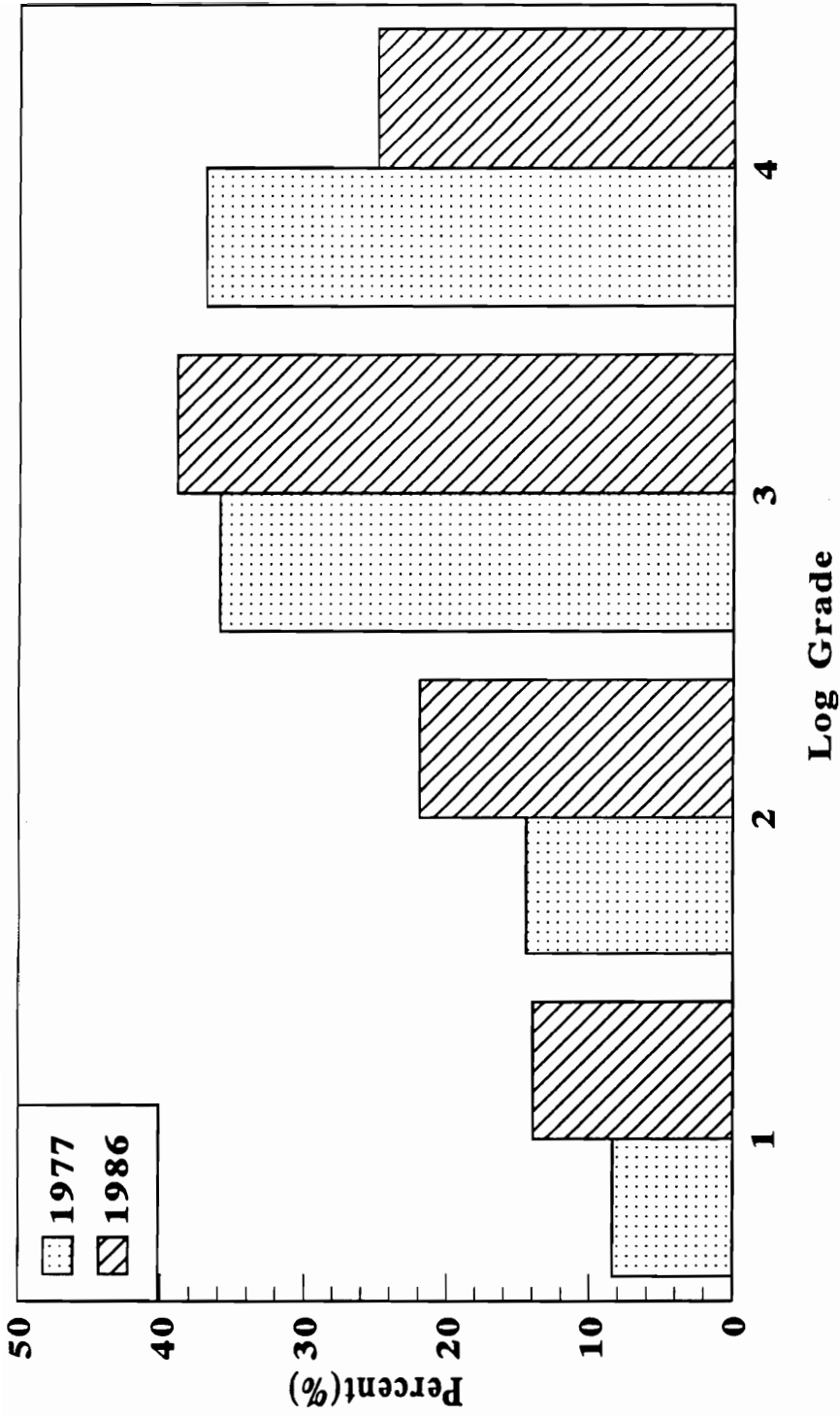
Timber stock in this region has a very rapid rate of growth. Between 1977 and 1986, hardwood growing stock volume increased 27 percent and hardwood sawtimber volume increased 49 percent (Sheffield, 1977; Brown, 1986). This increase is the natural result of the surplus growth of timber. For example, the removal of sawtimber was only 33 percent of annual growth in 1985 (Brown, 1986). As surplus growth of timber accumulated between 1977 and 1986, the quality of hardwood timber has improved (Sheffield, 1977; Brown, 1986), as shown in Figure 1.4.

Southwest Virginia's abundant timber resource could provide the raw material necessary for establishing a number of forest products companies. One production possibility suggested by Muench (1990) is making hardwood dimension stock which can be a potential value-added products for the abundant hardwood resources in this region.

## **2.6 The Effects of Processing Methods on Dimension Recovery**

### **2.6.1 The Effects of Sawing Patterns on Dimension Recovery**

When logs are directly converted into rough dimension parts, the first step is to break logs into flitches. Several studies on the effects of sawing patterns on the dimension yield were reported (Neilson et al., 1970; Pnevmaticos & Bousquist, 1972; Robichaud et al., 1974). Neilson et al. (1970) studied the effects of sawing patterns on the furniture components from Factory Grade 1 hard maple logs, and they found that



**Figure 1.4 Hardwood Sawtimber Grade Distribution in Southwest Virginia, 1977 & 1986**  
 Sources: Va Department of Forestry & USDA Forest Service



Live-Sawing resulted in a 15 percent increase in the dollar value of furniture components compared to Around-Sawing, but Live-Sawing had a high proportion of edge-grain and mixed color parts. Pnevmaticos and Bousquet (1972) reported that Live-Sawing Factory Grade 2 hard maple logs resulted in a 14 percent average increase in the dollar value of dimension parts from each log over Around-Sawing. For Factory Grade 3 logs, however, they found that there was no significant difference in yield and dollar value between the Live-Sawing and Around-Sawing method. In another study, Robichaud et al. (1974) found that Live-Sawing provided 11 percent more dollar value than Around-Sawing for aspen logs consisting of all Factory Grade 1 through Grade 4, but Live-Sawing produced more edge-grain and mixed color cuttings than Around-Sawing.

Most of the previous studies have shown that sawing patterns for breaking logs to flitches affected dimension yield and value recovery from logs. The value recovery of dimension parts from logs can affect the profitability. Therefore, the selection of sawing patterns for sawing logs to flitches can finally affect the profitability of a mill that produces dimension parts directly from logs.

### **2.6.2 The Effects of Cutting Sequences on Making Dimension Parts**

In the conventional processing system of dimension parts, cutting standard grade lumber into dimension parts is usually done in a dimension mill or a rough mill. There are two principal cutting sequences in cutting lumber into dimension parts: crosscut-first and gang-rip-first. The choice of crosscut-first or gang-rip-first was identified as one of the four most important factors affecting dimension yields in a conventional

rough mill (Gatchell, 1987b). The other three factors affecting rough mill yields are lumber input, cutting bill, and operator's efficiency.

Does the cutting sequence to cut the flitches directly derived from logs affect the dimension yield from logs and the overall performance of a direct processing mill? If it does, the designer of a direct processing mill which processes hardwood logs directly into rough dimension parts still face the decision of whether to choose gang-rip-first or crosscut-first cutting sequence. The operation of cutting flitches into rough dimension parts in a direct processing system is similar to that of cutting standard grade lumber into dimension parts in a conventional rough mill. For cutting standard grade lumber into dimension parts, many studies in the characteristics of the gang-rip-first and crosscut-first operations have been published (Araman, 1978; Brunner et al., 1989; Gatchell, 1987a; Gatchell, 1987b; Gatchell, 1987c; Hall et al., 1980; Hallock & Giese, 1980; and Lucas & Araman, 1975). These studies examined the differences of these two principal cutting sequences in parts yield (volume of parts vs. volume of lumber input), value recovery (part value vs. lumber value), yields of individual lengths of parts, and production cost.

Lucas and Araman (1975) compared the yield and production costs of interior furniture parts from different cutting sequences by using computer simulation. For cutting No.1 Common and No.2 Common 4/4" kiln-dried yellow-poplar lumber into parts with 11 cutting lengths from 13 to 73 inches and cutting widths of 1-11/16 inches, they found that the selection of cutting sequences did not affect the overall percentage yield (part volume vs. lumber volume), but affected the cost per part. In another study, Araman (1978) compared four manufacturing sequences in the yield of furniture core material using computer simulation. For cutting No.1 Common and No.2 Common yellow-poplar lumber to furniture core material with 10 lengths from 16-1/4 to 81

inches and widths of 2-1/4 inches, he found that the average yield of core material from combined lumber grades of No.1 Common and No.2 Common was similar for crosscut-first and rip-first sequences.

An in-plant study conducted by Hall et al. (1980) showed similar overall yield of dimension parts between crosscut-first and gang-rip-first while processing No.1 Common red oak lumber into dimension parts of six different lengths ranging from 13 inches to 49 inches (the yield difference between crosscut-first and gang-rip-first lines was within 2 percent), however, the gang-rip-first line produced more longer cuttings than crosscut-first line did. Hall et al. (1980) reported that when both rip-first and crosscut-first lines were operating on a longest-length-first basis the gang-rip-first line produced 20% more of the longest cutting (49 inches) than the crosscut-first line and the crosscut-first line produced 23% more intermediate length (37 inches) cuttings. Other yields (cutting lengths 13, 26, 31, and 43 inches) were similar in both crosscut-first and gang-rip-first lines. Hall et al. (1980) also found that the labor costs were slightly higher for the crosscut-first line, but these were offset by slightly lower material costs, per volume of cutting, than that for the gang-rip-first line; therefore, the difference in total production cost between rip-first and crosscut-first was not statistically significant.

One of the advantages of gang-rip-first is that it can produce high yields in longer cuttings from lower, less expensive grades of lumber. While studying the part length distributions from gang-ripped No.2 Common red oak lumber, Gatchell (1987b) found that gang-ripping No.2 Common red oak lumber could yield more than the amount of longer lengths needed by the furniture and cabinet industries and not enough short pieces. Because the narrower strips resulting from gang-ripping can be inspected quickly and crosscut out defects easily, gang-rip-first allows more flexibility in

processing than crosscut-first. As indicated by Gatchell (1987c), the disadvantage of gang-rip-first is the need for straight, flat, skip-planed boards to be gang-ripped into glueline-quality edges. Gatchell (1987a) suggested that the decision of whether to choose gang-rip-first or crosscut-first should be based on the quality of input raw material and the cutting bills. He proposed an either-way rough mill (Gatchell, 1987b; Gatchell, 1987c) where the decision of whether to gang-rip-first or crosscut-first is based on the width and quality of each board. The highest grades, including the best of the No.1 Common lumber, go crosscut first to obtain long, wide pieces free of gluelines. All other parts are produced by gang ripping the lower grade lumber. Since the crosscut operator can easily determine where to place the crosscuts on a narrow board, all narrow boards (boards with width below 4-1/2 inches), regardless of grade, go crosscut-first.

In the conventional processing system which processes standard grade lumber to dimension parts, previous studies showed that crosscut-first versus gang-rip-first had no significant effect on the overall yield of dimension parts and production costs, but had a substantial effect on the yields of individual lengths. If the dimension stock is produced directly from logs rather than standard grade lumber, the effects of the cutting sequences on dimension yield and production costs is not yet known. If cutting sequence does affect the dimension yield and the production costs, it will become a very important factor affecting the profitability of making dimension parts directly from logs.

## **2.7 The Concerns Over Drying Dimension Parts**

When processing logs directly into rough dimension parts, a dimension maker needs to dry the small pieces of dimension parts instead of standard grade lumber. Industry people questioned about drying hardwood dimension parts cited the following objections to the system: (1) the multitude of sizes of dimension parts creates almost insurmountable handling problems; and (2) there is likely to be an excessive amount of degradation during drying. Because most handling equipment is designed for full-size lumber, it does not process small pieces efficiently. One way to solve the problem is to use a large revolving table and a series of pallets or skids at the tail of the production line to allow workers to sort parts by length and stack them for drying in a unit package in one operation (Rice, 1968). The unit package can be tightened with a steel belt during drying, and workers can move the unit package with small forklifts. This method has been successfully used in Japan and France.

Excessive drying degrade is another concern for drying dimension parts. Simpson and Schroeder (1980) conducted a quantitative research in which mixed hardwood dimension parts with length ranging from 14 to 82 inches and widths ranging from 1-1/8 to 5-1/4 inches were dried using three different schedules: (1) a mild schedule with a maximum temperature of 115 °F accomplished with a dehumidifier dryer, (2) a conventional schedule recommended in the Dry Kiln Operator's Manual (Schedule Number T4-D2) with maximum temperature of 180 °F, and (3) an accelerated schedule with temperature from 115 °F to 230 °F. Each drying schedule was tested with and without the application of end-coating. It was found that neither the kiln schedule nor the end treatment had a significant effect on the rejection rate of parts for interior frame of upholstered furniture (Simpson & Schroeder, 1980). However, the part length was found to have a significant effect on the rejection rate. The longer parts had a higher

rejection rate which was almost exclusively caused by crook, and the shorter parts had a lower rejection rate. For example, approximately 40 percent of the longest cuttings were rejected, but less than 4 percent of the parts shorter than 20 inches were rejected (Simpson & Schroeder, 1980).

In Simpson and Schroeder's study (Simpson and Schroeder, 1980), the dimension parts dried were of mixed hardwood species and in frame-quality. If the green dimension parts to be dried contain only one species and in Clear-two-face quality, better drying results can be expected.

In another study, Simpson (1982) found that the crook and twist of dimension parts during drying could be reduced by applying a restraint system. The results of this study showed that crook was reduced by up to 35 percent and twist was reduced by 25 to 50 percent (Simpson, 1982).

Rice (1964) compared the yields of usable parts from No.2A Common, air-dried, red oak lumber by the three different treatments: (1) lumber was kiln-dried before being cut into parts, (2) air-dried lumber was cut into Clear-One-Face dimension parts and then kiln-dried with the application of end-coating, and (3) air-dried lumber was cut into Clear-One-Face dimension parts and then kiln-dried without the application of end-coating. When the boards were cut into dimension parts with lengths of 17, 25-1/2, 33, and 39 inches and with random widths from 1-1/2 to 7 inches, it was found that the yield of usable parts was 41 percent for the groups in which dimension parts were dried without the application of end-coating, and 46 percent for both the group in which dimension parts were dried with the application of end-coating and the group in which lumber was kiln-dried prior to being cut into dimension parts (Rice, 1964). The effect of end-coating treatment on the yield of usable parts was statistically significant (Rice, 1964).

When dimension parts are dried, only usable material is dried; while lumber is dried, some waste that will be cut off after drying is also dried. When lumber is cut into dimension parts, the potential waste can vary from 10 to 50 percent depending on cutting size and the input lumber grade (Rice, 1968). If the drying costs are calculated on the basis of per unit of usable parts, the cost for drying dimension parts can be less than the cost for drying the lumber needed for producing the same amount of usable parts. If dimension parts are dried, the compactly stacked unit packages can be so placed as to utilize all of the drying space (Rice, 1968). Additionally, the short, narrow parts can be dried in faster than long, wide boards of the same species and thickness, often as much as 20 percent faster (Rice, 1968). Even with a 10 percent loss in volume due to degrade and shrinkage, the costs of drying dimension based on per unit of usable parts can be 10 to 20 percent less than for drying the same material lumber (Rice, 1968).

## **2.8 Computer Simulation Techniques**

Computer simulation techniques have been widely used in modeling sawmill and rough mill operations. Computer simulation can be categorized into two types: system simulation and object simulation. System simulation is the dynamic characterization of the system components as they change over time. Object simulation involves the static, time-independent representation of an activity or a system, and its objective is to observe the reaction of the system to an induced change. Most computer simulation programs for simulating sawing logs to lumber (Occena & Tanchoco, 1988; Peter, 1967; Pnevmaticos et al., 1974; Pnevmaticos & Mouland, 1978; Richards, 1973; Richards et al., 1980; Richards & Newman, 1979) and cutting sequences of cutting

standard grade lumber to dimension parts (Brunneret, 1989; Giese & Danielson, 1983; Giese & McDonald, 1982; Hoff et al., 1991a; Stern & Bulgrin, 1978) belong to the category of the object simulation.

### **2.8.1 Computer Simulation for Sawing Logs**

Because computer simulation allows sawing the identical log with different sawing patterns, it has been used for simulating both log and sawing patterns of log breakdown in studying the effect of sawing patterns on the lumber yield. A model published by Richards (1973) simulated logs as frustums of cones. It was used for studying the effect of sawing patterns, edging methods, saw kerf width, log diameter, log length and taper on the lumber yield. However, this model did not consider any log defects, thus the study (Richards, 1973) dealt with volume yield only, without respect to lumber grade or value. To consider log defects, Richards and Newman (1979) developed another simulation model in which a simulated log has a cone defect and conic surface knots that are randomly located along and around each half of the log. However, this model did not consider sweep and hidden defects. Later models (Richards et al., 1980) considered hidden defects and defect clusters, and each knot was simulated as a cone, but the central cone was assumed to be so defective that it yielded no allowable clear-face cuttings as a centrally located cylinder that extended the length of the log. Pnevmaticos and Mouland (1978) developed a model that could randomly generate logs, and the model simulated the internal defects inside log as rectangular solid.

Log and log breakdown have also been simulated through computer graphics. Pnevmaticos et al. (1974) introduced the first graphic simulation model of sawing a log



using a hybrid graphics terminal. A log was simulated and displayed on a cathode ray tube as a cylinder or truncated cone by inputting the two diameters and the length of the log. They used rectangular boxes to approximate defects. The interaction of a log with the cutter was treated as a linear programming problem. More recently, Occena and Tanchoco (1988) developed a new graphic simulator of hardwood log sawing. This graphic simulator represented the hardwood logs and their defects as irregular polyhedra and provided an interactive representation of log sawing using CAD solid modeling with Boundary Representation.

All previous simulation models of log and log sawing mentioned above were developed for simulating sawing logs into standard grade lumber. The computer simulation has been proved to be an effective method in studying the effect of sawing patterns on lumber yield. The only difference between sawing logs into standard lumber and sawing logs into flitches is that sawing log into flitches does not require an edging and trimming operation. Thus, computer simulation can be used to simulate sawing log into flitches.

### **2.8.2 Computer Simulation Techniques in The Dimension Yield Study**

The first computer simulation program for studying dimension yields was developed by Thomas (1962). The simulation program simulated the crosscut-first operations but did not allow for factors such as kerf width and number of operations. The computer program YIELD, developed by Wodzinski and Hahn (1966) at the U.S. Forest Products Laboratory, was the next major advancement in estimating dimension yield from standard grade lumber. This program simulated either the crosscut-first and rip-first operations and was used for developing nomagrams for estimating dimension yield

(Ehglert & Schumann, 1969). Lucas and Araman (1975) and Araman (1978) used computer simulation in simulating the different cutting sequences for comparing the dimension yields from four different cutting sequences. In their studies, the computer program simulated the actual rules used in real mills.

RIPYLD (Stern & McDoland, 1978) and MULRIP (Stern and Bulgrin, 1978) which simulated the multiple rip-first operations and were incorporated with optimization algorithm for optimizing dimension yield. OPTYLD (Giese & McDonald, 1982) extended RIPYLD and MULRIP to include a re-rip operation (rip-first, crosscut, and re-rip sequence). On the basis of OPTYLD, Giese and Danielson (1983) developed a computer simulation program called CROMAX. This program incorporated an optimization algorithm of optimizing crosscut-first yields. However, due to the large number of cutting combinations it considered, the lengthy computing time of CROMAX limited its practical application.

Recently, Hoff et al. (1991a, 1991b, 1992) developed a new computer program, called GR-1ST (gang-rip-first), which is a modified version of MULRIP. GR-1ST expands MULRIP to evaluate different gang-rip-first options. There are three saw arbor configurations available in the GR-1ST program, variable saw arbor option, fixed saw arbor option, and equally spaced saw blades with a movable outer blade. The variable saw arbor option allows the program to vary the gang saw spacings to obtain the optimum yield of parts from each board, and the program evaluates all possible combinations of saw spacings for a given board. The fixed saw arbor option allows the user to specify the saw spacing to be used in determining the part yield from a board, and the user needs to specify a width for all six of the required saw spacings. The third option represents a gang-rip saw with five equally spaced saws plus a sixth saw that is movable on the arbor. In the simulated operation of GR-1ST, the boards are first

ripped into strips which are then crosscut into primary (full width) parts and the salvage sections are then ripped and crosscut to produce salvage parts. The optimum solutions produced by the GR-1ST program are based on the surface area yield of primary parts (salvage parts are not considered). Another advanced feature of the GR-1ST over its predecessor is that the output of GR-1ST provides plots of each boards plus the resulting saw cuts and parts produced.

CORY is another computer simulation program developed by Brunner (Brunner et al., 1989) based on the earlier program YIELD. In terms of computing time, CORY is much faster than the previous programs. CORY is also an optimization program for determining the best cutting solution for a given board. The unique feature of CORY is that it can simulate either the crosscut-first or rip-first operations, and it can be used for comparing the dimension yields from rip-first and crosscut-first operations.

All previous simulation programs for studying dimension yields were designed for cutting standard grade lumber into dimension parts. No computer simulation programs have been developed for converting flitches into dimension parts. However, some of the previous programs such as CORY can be modified to accomplish the conversion from flitches to dimension parts. The problem is how to represent the irregular shape of flitches in the format of the input of the existing programs.

### **2.8.3 Computer Simulation Techniques in Studying The Dynamic Behavior of Wood Processing Systems**

System simulation has been used in helping sawmill and remanufacturing plant design, modification and evaluation. Wagner and Taylor (1983) developed a southern pine sawmill model called SPSM which used a combined network and discrete-event

model programmed in SLAM. The SLAM network simulated the log breakdown section of the SPSM model and the discrete-event simulation modeling described the systems involved in the processing of logs into finished lumber. Another sawmill simulation model, DESIM, was developed by Adams (1984a, 1984b, 1985) for designing and evaluating hardwood sawmills. It was programmed in GASP IV FORTRAN-based simulation language. The system requires the use of a large computer, a mainframe computer or a minicomputer. According to Adams' report (Adams, 1988), the system can be realistically simulate the operation of relatively complex hardwood sawmills. When comparing the individual values for a number of test variables from one 10-hour operating shift with the corresponding frequency distributions for 100 simulated 10-hour shifts, the actual values for all of the test variables are reasonably close (within two standard deviations of the mean simulated values).

Computer simulation techniques have also been used in designing the rough mill (Araman & Lucas, 1975). With this technique, production problems and bottlenecks can be found and eliminated before a mill is actually built (Araman & Lucas). Anderson (1983) used computer simulation in evaluating rough mill costs. In Anderson's study, a conventional crosscut-first rough mill was simulated for determining production costs on an individual part basis. According to Anderson (1983), this model could be easily modified through changes in input variables and minor internal changes to reflect the operating characteristics of any conventional crosscut-first rough mill. Kline et al. (1992) developed a simulation/animation model for a crosscut-first rough mill using object-oriented simulation techniques. This model was used to demonstrate the application and utility of the simulation/animation method applied to wood products manufacturing systems.

All previous system simulation models for studying the dynamic behavior of the wood processing systems, either simulated the operations within a sawmill or the operations within a rough mill. No such model that simulates the integrated system of a sawmill and a rough mill has been developed. To study the dynamic behavior and estimate the output rate of a direct processing system that produces rough dimension parts directly from logs, a simulation model which simulates the integrated system for converting logs directly into rough dimension parts will be needed.

## **2.9 Economic Evaluation of Proposed Projects**

### **2.9.1 Financial Analysis Techniques**

Among the many methods for evaluating investment proposals, four commonly used are: payback method (or payback period), return on assets (ROA) or return on investment (ROI), net present value (NPV) method, and internal rate of return (IRR) (Weston & Copeland, 1986).

The payback method is expressed in the number of years required to return the original investment. This method is easy to use, however, it does not consider all cash flows and fails to discount them (Weston & Copeland, 1986).

Return on assets (ROA) or return on investment (ROI) is the average rate of return on assets employed. It is computed by averaging the expected cash flows over the life of a project and then dividing the average annual cash flow by the initial investment outlay (Weston & Copeland, 1986). This method was used by Martens and Hansen (1980) in studying the feasibility of manufacturing hardwood parquet flooring from southern hardwoods. ROA was also used by Huber et al. (1980) in studying the

feasibility projection for a small furniture dimension plant using low grade hardwoods. The major problem with ROA and ROI is that they do not take the time value of money into account (Weston & Copeland).

Net present value, one of the discounted cash flow techniques, is defined as the present value of expected future cash flows discounted at the appropriate cost of capital, minus the cost of the investment. If the net present value is positive, the project earns more than the required rate of return, thus, the project should be accepted; if the net present value is negative, it should be rejected (Weston & Copeland, 1986).

Internal rate of return, another discounted cash flow techniques, is defined as the interest rate that equates the present value of the expected future cash flows to the initial cost outlay. If IRR is greater than the cost of capital (interest rate of capital), the project should be accepted; otherwise, it should be rejected (Weston & Copeland, 1986).

NPV and IRR are the most favored methods used in analyzing investment opportunities in wood product manufacturing. Araman and Hansen (1983) used NPV and IRR as evaluation criteria in an economic feasibility study of a conventional processing system of standard-size edge-glued blanks for furniture and cabinet parts. They used the cash flow computer program developed by Harpole (1978) to obtain IRR and NPV values in their study. IRR was also used in evaluating System 6 for making kitchen cabinet C2F blanks from small-diameter, low-grade red oak logs (Reynolds et al., 1983) and for making black cherry blanks (Reynolds & Hansen, 1986). Stewart et al. (1982) applied IRR and NPV methods in determining the economic feasibility and comparison of different processing systems for producing dimension products from short logs (bolts) of black walnut, black cherry, and yellow-popular. Recently, Huber

et al. (1989) used IRR and NPV in an economic analysis of cutting hardwood dimension parts with an automated processing system.

### **2.9.2 Measurements of Profitability**

Profitability is the most important criteria for evaluating a firm's performance. Usually, profitability can be measured in three different manners (Weston & Copeland, 1986). One measurement is the return on sales (or profit margin on sales) which is defined as the ratio of the net profit to the sales. Another measurement of profitability is the return on net worth which is defined as the ratio of the net profit to the net worth, it measures the rate of return on the stockholders' investment. The other measurement of profitability is return on assets (or return on investment) which is defined as the ratio of the net profit to the total assets of the firm. Dun and Bradstreet (Dun & Bradstreet Yearly Report) provides the profitability data of over 800 different lines of business as defined by the U.S. Standard Industrial Classification (SIC) code number, including the hardwood dimension and flooring industry, classified as SIC 2426.

### **2.9.3. Depreciation Methods and Their Uses in The Economic Analysis of Wood Processing Industry**

To determine the after-tax economic feasibility of a proposed project, a depreciation method that divides the costs of the equipment and the cost of building into their life period is necessary. There are four principal methods of depreciation: straight line, sum-of-years'-digits, declining balance, and units of production (Weston

& Copeland, 1986). With the straight line method, a uniform annual depreciation charge is obtained by simply dividing the economic life into the total cost of the equipment or building minus the estimated salvage value. Under the sum-of-years'-digits method, the yearly depreciation allowance is determined by first calculating the sum of the years' digits in the life period and then dividing the number of remaining years by the sum-of-years-digits and multiplying by the depreciable cost (total cost minus salvage value) of the asset. Under the units of production method, the expected useful life in hours is divided into the depreciable cost to arrive at an hourly depreciation rate. With the unit of production method, depreciation charges can not be estimated precisely ahead of time. Under the declining balance method, the annual depreciation charge is calculated by multiplying a fixed rate times the undepreciated balance (the cost less accumulated depreciation). The declining balance method has been used for economic analysis of manufacturing systems of wood products in several cases (Araman & Hansen, 1983; Huber et al., 1989; Reynolds et al., 1983).

After the enactment of the Tax Reform Act of 1986 the investment tax credit has been eliminated , and the Modified Accelerated Cost Recovery System (MACRS), which is mandatory for most tangible depreciable assets, became the principal means for computing depreciation (DeGarmo et al., 1989). Under MACRS, no salvage value is allowed in the depreciation schedule, and useful life estimate is not directly used in calculating depreciation. MACRS allows business to recover the cost basis of recovery property over a recovery period which is determined by the class life of the property. The class life which is determined by Internal Revenue Service is the life that would apply for depreciation purposes and is different from the useful life of an asset (DeGarmo et al.). The cost basis of assets in 3, 5, 7, 10 year properties classes is recovered at a rate based on the 200% declining balance method, and the cost basis of



assets in the 15 and 20 year classes are recovered using 150% declining balance method. The details of the MACRS are fully described in IRS Publication 534, *Depreciation* (USDT-IRS, 1991).

### 3.

## REFERENCES

Adams, E. L. 1984a. DESIM: a system for designing and simulating hardwood sawmill systems. USDA Forest Service, Northeastern Experiment Station, General Technical Report NE-89, Broomall, PA, 10 pp.

\_\_\_\_\_. 1984b. DESIM user's manual: a procedural guide for designing and simulating hardwood sawmill systems. USDA forest Service, Northeastern Experiment Station, General Technical Report NE-94, Broomall, PA, 58 pp.

\_\_\_\_\_. 1985. DESIM data manual : a procedural guide for developing equipment processing and down time data. USDA Forest Service, Northeastern Experiment Station, General Technical Report NE-102, Broomall, PA, 23 pp.

\_\_\_\_\_. 1988. Testing DESIM for designing and simulating the operation of hardwood sawmills. *Forest Products Journal* 38(7/8):41-45.

Anderson, R. B. 1981. Potential for upgrading use of low-valued hardwoods. Proceedings of The Ninth Annual Hardwood Symposium, Hardwood Research Council, Pipesten, WV, May 25-28, 1981.

Anderson, R. B. 1983. Furniture rough mill costs evaluated by computer simulation. USDA Forest Service, Northeastern Experiment Station, Research Paper NE-518, 11 pp.

Araman, P. A. 1978. A comparison of four techniques for producing high-grade furniture core material from low-grade yellow-poplar. USDA Forest Service, Northeastern Experiment Station, Research paper NE-429, Princeton, WV, 7 pp.

Araman, P. A. 1987. Standard sizes for rough dimension exports to Japanese and European fine hardwood users. A report for the scientific and technical exchange program with Japan. USDA Forest Service, Northeastern Forest Experimental Station, Princeton, WV.

Araman, P. A., and B. G. Hansen. 1983. Conventional processing of standard-size edge-glued blanks for furniture and cabinet parts: a feasibility study. USDA Forest Service, Northeastern Experiment Station, Research Paper NE-524, Princeton, WV, 11 pp.

Araman, P. A. and F. M. Lamb. 1990. Hardwood dimension stock and furniture parts including export opportunities. In "Industrial Development Opportunities For Wood Products In Virginia". School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, Blacksburg, VA., 19 pp.

Araman, P. A., and E. L. Lucas. 1975. An automated rough mill for the production of interior furniture parts. USDA Forest Service, Northeastern Experiment Station, Research Paper NE-335, Princeton, WV, 5 pp.

Bingham, S. A. 1976. The feasibility of using short length lumber in furniture manufacture. Proceedings of The Fourth Annual Hardwood Symposium, Hardwood Research Council, Cashier, North Carolina, April 29- May 1, 1976.

Brown, J.J. 1986. Forest Statistics for The Southern Mountains of Virginia. Resource Bulletin SE-86. USDA Forest Service, Southeastern Forest Experiment Station, Asheville, North Carolina. 55 pp.

Brunner, C. C., M.S. White, F.M. Lamb, and J.G. Schroeder. 1989. CORY: A computer program for determining dimension stock yields. Forest Products Journal 39(2):23-24.

Bush, R. J., S. A. Sinclair, and P. A. Araman. 1990. Match your hardwood lumber to current market needs. Southern Lumberman, July 1990.

DeGarmo, E. P., W. G. Sullivan, and J. A. Bontadelli. 1989. Engineering Economy. Eighth Edition. Macmillan Publishing Company, New York, 765 pp.

de Steiguer, J. E., L. W. Hayden, D. L. Holley, Jr., W. G. Luppold, W. G. Martin, D. H. Newman, and R. M. Sheffield. 1989a. Southern Appalachian Timber Supply. USDA Forest Service, Southeastern Experiment Station, General Technical Report SE-56, Asheville, NC.

de Steiguer, J. E., L. W. Hayden, D. L. Holley, Jr., W. G. Luppold, W. G. Martin, D. H. Newman, and R. M. Sheffield. 1989b. Southern Appalachian hardwood timber market trends. Southern Journal of Applied Forestry 13(1):29-33.

Dun and Bradstreet. Industry Norms and Key Business Ratios. Dun and Bradstreet Credit Services, New York. (Yearly published statistic report).

Dunmire, D. E., E. F. Landt, R. E. Bodkin. 1972. Logging residue is a source of valuable black walnut dimension. Forest Products Journal 22(1):14-17.

Ehlerth, G. H., and D. R. Schumann. 1969. Charts for calculating dimension yields from hard maple lumber. USDA Forest Service, Forest Products Lab., Research Paper FPL-118, Madison, WI, 12 pp.

Flann, I.B. 1963. Hardwood dimension stock - its future in Canada. Canadian Wood Product Industry. 63(1):42-45.

Gatchell, C. J. 1987a. Rethinking the design of the furniture rough mill. Forest Products Journal 37(3):8-14.

Gatchell, C. J. 1987b. Impact of rough mill practices on yields. In White, J. L., ed. Eastern hardwoods: the resource, the industry, and the market: Proceedings of the symposium, 1985 September 9-11, Harrisburg, PA. Forest Products Research Society, 146-156.

Gatchell, C. J. 1987c. Want to use more low-grade lumber? Why not rip first. Wood & Wood Products 92(8): 113-115. July 1987.

Giese, P. L., and J. D. Danielson. 1983. CROMAX a crosscut-first computer simulation program to determine cutting yield. USDA Forest Service, Forest Products Lab., General Technical Report FPL-38, Madison, WI, 39 pp.

Giese, P. J., and K. A. McDonald. 1982. OPTYLD- a multiple rip-first computer program to maximize cutting yields. USDA forest Service, Forest Products Lab., Research Paper FPL-412, Madison, WI, 17 pp.

Hall, S. P., E. M. Wengert, R. A. Wysk and M. H. Agee. 1980. Yield distributions and cost comparisons of a crosscut-first and a gang-rip-first rough mill producing hardwood dimension stair parts. Forest Products Journal 30(5):34-39.

Hallock, H. and P. J. Giese. 1980. Does gang ripping first hold the potential for higher clear cutting yields. USDA Forest Service, Forest Products Lab., Research Paper FPL-369, Madison WI.

Hamilton, J. F. 1970. Maximum tree use - new concept for hardwood dimension production. Institute of Wood Research, Michigan Tech University, Houghton, Michigan, 100 p.

Harpole, G. B. 1978. A cash flow computer program to analyze investment opportunities in wood product manufacturing. USDA Forest Service, Forest Products Lab., Research Paper FPL-305, Madison, WI, 24 pp.

Hoff, K. G., E. L. Adams, and E. S. Walker. 1991a. GR-1ST: PC Program for evaluating gang-rip-first board cut-up procedures. USDA Forest Service, Northeastern Experiment Station, General Technical Report NE-150, Radnor, PA, 16 pp.

\_\_\_\_\_. 1991b. GR-1ST User's Guide. USDA Forest Service, Northeastern Experiment Station, General Technical Report NE-156, Radnor, PA, 14 pp.

\_\_\_\_\_. 1992. Computer optimization of hardwood parts yield using gang-rip-first procedures. Forest Products Journal 42(3):57-59.

Huber, H. A., H. N. Rosen, and H. A. Stewart. 1980. Feasibility projection for a small furniture dimension plant using low grade hardwoods. Proceedings: The Utilization of Low-grade Southern Hardwoods - Feasibility Studies of 36 Enterprises. Forest Research Society, Nashville, Tennessee, 289 pp.

Huber, H. A., H. N. Rosen, H. A. Stewart, and S. B. Harsh. 1983. A financial analysis of furniture parts from short bolts. Forest Products Journal 33(9):55-58.

Huber, H. A., S. Ruddell, K. Mukherjee, and C. McMillin. 1989. Economics of cutting hardwood dimension parts with an automated system. Forest Products Journal 39(5):46-50.

Kline, D. E., J. K. Wiedenbeck, and P. A. Araman. 1992. Management of wood products manufacturing using simulation/animation. Forest Products Journal 42(2):45-52.

Koch, C.B., G.W. Galliger, and N.C. Jackson. 1968. Yield from sprout cherry trees sawn with a short log bolter saw. West Virginia University, Agriculture Experiment Station, Bulletin Number 569, Morgantown, West Virginia, 11 pp.

Lawser, S. V. 1985. The changing marketplace for hardwood dimension products. Proceedings of The Thirteenth Annual Hardwood Symposium, Hardwood Research Council, High Point, North Carolina, May 22-24, 1985.

\_\_\_\_\_. 1991. Value added opportunities for primary processors. Proceedings of The Nineteenth Annual Hardwood Symposium, Hardwood Research Council, Starkville, Mississippi, March 10-12, 1991.

\_\_\_\_\_. 1992. Hardwood dimension sales beginning to rebound. Wood Digest, 1992(June):9.

Lucas, E. L., and P. A. Araman. 1975. Manufacturing interior furniture parts: a new look at an old problem. USDA Forest Service, Northeastern Experiment Station, Research paper NE-334, Princeton, WV.

Luppold, W. G. 1991. Hardwood lumber demand in the 1990's. Proceedings of The Nineteenth Annual Hardwood Symposium, Hardwood Research Council, Starkville, Mississippi, March 10-12, 1991.

Malmquist, W. 1968. Producing and marketing precut hardwood dimension in New England. Northern Logger and Timber Processor, Aug. 1968:6-7.

Martens D. G. and B. G. Hansen. 1980. Manufacturing hardwood parquet flooring from southern hardwoods. Proceedings: The Utilization of Low-grade Southern Hardwoods - Feasibility Studies of 36 enterprises. Forest Products Research Society, Nashville, Tennessee, 289 pp.

Muench, J. 1990. Forest-Based Economic Development Opportunities in Southwest Virginia: Why and How. Economic Development Assistance Center, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, October 1990.

National Hardwood Lumber Association (NHLA). 1986. Rules for the Measurement and Inspection of Hardwood and Cypress Lumber. NHLA, Memphis, Tenn.

Neilson, R. W., D. W. Bousquet, and S. M. Pnevmaticos. 1970. Sawing pattern effect on the yield of furniture components from high quality hard maple logs. Forest Products Journal 20(9):92-98.

Nolley, J. W. 1992. Bulletin of hardwood market statistics: Fall 1991. USDA Forest Service, Northeastern Experiment Station, Research Note NE-348, Radnor, PA, 41 pp.

Occena, L.G. and J. M. A. Tanchoco. 1988. Computer graphics simulation of hardwood log sawing. Forest Products Journal 38(1):72-76.

Peter, R.K. 1967. Influence of sawing methods on lumber grade yield from yellow poplar. Forest Products Journal 17(11):19-24.

- Pnevmaticos, S. M. and D. W. Bousquist. 1972. Sawing pattern effect on the yield of lumber and furniture components from medium and low grade hard maple logs. *Forest Products Journal* 22(3):34-41.
- Pnevmaticos, S. M., P. E. Dress, and F. R. Stocker. 1974. Log and sawing simulation through computer graphics. *Forest Products Journal* 24(3):53-55.
- Pnevmaticos, S. M. and P. Mouland. 1978. Hardwood Sawing simulation techniques. *Forest Products Journal* 28(4):26-30.
- Reynolds, H. W. and P. A. Araman. 1983. System 6: making frame-quality blanks from white oak thinnings. USDA Forest Service, Northeastern Experiment Station, Research Paper NE-520, 9 pp.
- Reynolds, H. W. and C. J. Gatchell. 1982. New technology for low-grade hardwood utilization: System 6. USDA Forest Service, Northeastern Experiment Station, Research Paper NE-504, 7 pp.
- Reynolds, H. W., C. J. Gatchell, P. A. Araman, and B. G. Hensen. 1983. Syetem 6 used to make kitchen cabinet C2F blanks from small-diameter, low-grade red oak. USDA forest Service, Northeastern Experiment Station, Research Paper NE-525, Princeton, WV, 11 pp.
- Reynolds, H. W. and B. G. Hansen. 1986. Making black cherry blanks from system 6. USDA Forest Service, Northeastern Experiment Station, Research Paper NE-574, Princeton, WV, 10 pp.
- Rice, W.W. 1964. Kiln-dry dimension parts instead of boards - and save money. *Southern Lumberman* 209:141-145, December 1964.
- Rice, W.W. 1968. Hardwood dimension drying - is it feasible? *Woodworking Digest* 70(9):24-25
- Richards, D. B. 1973. Hardwood lumber yield by various simulated sawing methods. *Forest Products Journal* 23(10):50-58.
- Richards, D. B., W. K. Adkins, H. Hallock, and E. H. Bulgrin. 1980. Simulation of hardwood log sawing. USDA Forest Service, Forest Products Lab., Research Paper FPL-355, Madison, WI, 8 pp.
- Richards, D. B. and J. A. Newman. 1979. Sawing high-quality red oak logs. *Forest Products Journal* 29(9):36-39.
- Robichaud, Y, F. J. Petro, and M. C. Kingsley. 1974. Aspen lumber and dimension stock recovery in relation to sawing pattern. *Forest Products Journal* 24(3): 26-30.
- Rosen, H. N., H. A. Stewart, and D. J. Polak. 1980. Dimension yields from short logs of low-quality hardwood trees. USDA Forest Service, Forest Products Lab., Research Paper FPL-184, Madison, WI, 21 pp.

- Sheffield, R.M. 1977. Forest Statistics for The Southern Mountain Region of Virginia. Resource Bulletin SE-42. USDA Forest Service, Southeastern Experiment Station, Asheville, North Carolina. 33 pp.
- Sheffield, R. M. and W. A. Bechtold. 1990. Volume and availability of eastern hardwoods. Proceedings of The Eighteenth Annual Hardwood Symposium, Hardwood Research Council, Cashier, NC, May 6-9, 1990.
- Simpson, W.T. 1982. Warp reduction in kiln-drying hardwood dimension. Forest Products Journal 32(5):29-32.
- Simpson, W.T. and J.G. Schroeder. 1980. Kiln-drying hardwood dimension parts. USDA Forest Service, Forest Products Lab. Research Paper FPL-388, Forest products Lab., Madison, Wis.
- Smith, W. R. 1972. Research Priorities For Eastern Hardwoods. Hardwood Research Council, Statesville, NC, 29 pp.
- Southern Lumberman. 1992. Another Trend. Southern Lumberman, August 1992.
- Stern, A. R. and E. H. Bulgrin. 1978. An unpublished computer program. USDA Forest Service, Forest Products Laboratory, Madison, WI.
- Stern, A. R. and K. A. McDonald. 1978. Computer optimization of cutting yields from multiple-ripped boards. USDA Forest Service, Forest Products Lab., Research Paper FPL-318, Madison, WI.
- Stewart, H. A. H. N. Rosen, H. A. Huber, and A. A. Rasher. 1982. 4/4 hardwood dimension from short bolts: economic and processing comparison of conventional and innovative production. Forest Products Journal 32(11/12):71-76.
- Thomas, R. J. 1962. The rough-end research program. Forest Products Journal 12(11):536-537.
- U.S. Department of Commerce (USDC). 1990. 1990 U.S. Industrial Outlook. U.S. Government Printing Office.
- U.S. Department of Commerce (USDC). 1991. 1991 U.S. Industrial Outlook. U.S. Government Printing Office.
- U.S. Department of Commerce-Bureau of the Census (USDC-BOC). 1987. Logging, Sawmill, and Planing Mills. 1987 Census of Manufactures. Preliminary Report, Industry Series No. MC87-I-24A(P).
- U.S. Department of Treasury - Internal Revenue Service (USDT-IRS). 1991. Depreciation. Internal Revenue Service Publication 534.
- Wagner, Jr., F. G. and F. W. Taylor. 1983. SPSM-A Southern Pine Sawmill Model. Forest Products Journal 33(4):37-42.

Wengert, M. E., R. W. Rice, and J. G. Schroeder. 1987. Development of grading systems for short-length lumber. Proceedings of The Fifteenth Annual Hardwood Symposium, Hardwood Research Council, Memphis, TN, May 10-12, 1987.

Weston, J. F. and T. E. Copeland . 1986. Managerial Finance. 5th Edition. The Dryden Press, Chicago, New York, 1035 pp.

Wodzinski, C. and E. Hahn. 1966. A computer program to determine yields of lumber. USDA Forest Service, FPL-unnumbered publication, Forest Products Lab., Madison, WI.



## Section 2

# **DIMENSION YIELDS AND DOLLAR VALUE RECOVERY FROM NO.3 FACTORY GRADE RED OAK LOGS BY THE DIRECT PROCESSING SYSTEM**

### 1. ABSTRACT

The objectives of this section were: (1) to estimate the cutting yields of green dimension parts and dollar value recovery from No.3 grade red oak logs by the direct processing system, (2) to obtain cutting details of converting No.3 red oak logs into rough dimension parts, and (3) to test the effects of sawing pattern and cutting sequence on the cutting yield and dollar value recovery. A combination method of actual log sawing and simulated cutting was used to obtain the dimension yields. Logs were actually sawn into flitches, whereas, cutting flitches into dimension parts was simulated by using a computer cut-up program (CORY). Cutting details of each flitch was obtained from CORY output. Two sawing patterns (live-sawing and five-part-sawing) and two cutting sequences (rip-first and crosscut-first) with four cutting bills were tested for their effects on the dimension yield, average cutting length and dollar value recovery.

If all of the four combinations of sawing patterns and cutting sequences used the same cutting length priority, Live-sawing resulted in significantly higher dimension yield than Five-part-sawing, and the choice of the cutting sequence had no significant effects on the dimension yield. However, if different cutting length priorities were used to force the different combination of sawing patterns and cutting sequences to have the similar average cutting lengths, the effect of sawing pattern on dimension yield depended on subsequent cutting sequence and the cutting bill used. Yield differences were not significant between live-sawing

and Five-part-sawing for two of the four cutting bills under crosscut-first. Rip-first resulted in notably higher dimension yield than crosscut-first for three of the four cutting bills processed under live-sawing.

In terms of average cutting length, rip-first produced longer cuttings than crosscut-first, independent of the previous log sawing pattern and cutting bills. And the effect of sawing pattern on the average cutting length depended on the cutting bill used.

If all part lengths have equal value, the results indicated that live-sawing recovered more dollar value than five-part-sawing and that cutting sequence had no significant effect on the dollar value recovery. However, if longer parts have more value, the effects of sawing pattern and cutting sequence on the dollar value recovery depended on the level of each other and the cutting bill used. Live-sawing followed by rip-first has the highest dollar value recovery.

A strong negative linear relationship was detected between the scaling yield and the average cutting length within each combination of the sawing patterns and cutting sequences.

## 2.

## INTRODUCTION

Although the concept of processing hardwood dimension parts directly from logs was introduced a long time ago, no comprehensive research has been performed to study the direct processing system. Before hardwood dimension manufacturers and sawmillers accept the direct processing system for making hardwood dimension parts, they must find out whether the direct processing system is economically sound. As stated in the last section, the overall objective of this dissertation was to assess the economic feasibility and profitability of the direct processing system for making rough dimension parts from No.3 grade red oak logs.

To make reliable estimates of the economic feasibility and profitability, information on the yield of dimension parts and dollar value recovery is necessary. This is because the potential revenue obtainable from running a direct processing mill is related to the yield of dimension parts and dollar value recovery that can be achieved. The information on the dimension yield from given log inputs is also needed for the production planning in a direct processing mill. In addition, since the cutting details of No.3 red oak logs into rough dimension parts are critical to the input of the system simulation models that are used to capture the system dynamics of the direct processing system, information on the cutting details needs to be obtained in this section. In processing dimension parts from logs, many processing options (sawing patterns and cutting sequences) can be used. Since the choice of processing options may affect the dimension yield, the effects of the various processing options on the dimension yield and dollar value recovery need to be evaluated. Then the selection of appropriate processing options can be made.

## 2.1 Previous Work

Dimension yield from No.3 red oak logs is not known. The only published information in dimension yield from hardwood logs is the dimension yields from short logs or bolts obtained from logging residue. In one study by Dunmire et al. (1972), black walnut bolts of 2 to 6-1/2 feet long and 5-1/2 to 17 inches in diameter were cut into 4/4 dimension parts of 12 to 78 inches long by using Live-sawing and Rip-first. They found that the average percentage yield (the ratio of board footage of dimension parts to the International 1/4-inch scaling board footage of logs) was 72.5 percent for Clear-two-face dimension parts and 74.5 percent for Clear-one-face dimension parts. In another study conducted by Rosen et al. (1980), the short logs of aspen, soft maple, black cherry, yellow poplar and black walnut with lengths from 1.9 to 6.7 feet and diameters from 5 to 8 inches were cut into rough dimension parts of 1 to 6 inches wide and 12 to 72 inches long. They found that the percentage yields of rough dimension parts divided by the scaling board footage (International 1/4-inch Rule) of the logs were between 56 and 70 percent, varying for different species.

The dimension yield and dollar value recovery from logs can be affected by many factors, such as processing method, the quality of the input logs, cutting bills, operator's skill and processing methods. It is obvious that dimension yield from given quality of logs can be higher for cutting short parts than for cutting long parts and experienced operators can obtain higher yield than novices. However, how processing methods affect dimension yield and dollar value recovery from logs is not known. Since the conversion from logs to dimension parts involves two steps of processing, sawing logs into flitches and cutting flitches into rough parts, various sawing patterns and cutting sequences can be used for processing logs into rough dimension parts.

Some previous studies showed that sawing patterns had a significant influence on dimension yield and value recovery from logs. In one study that cut No.1 grade hard maple logs into furniture parts (Neilson et al., 1970), it was found that Live-sawing produced 15 percent more in the dollar value of parts than Around-sawing. In another study Pnevmaticos and Bousquet (1972) reported that for No.2 grade hard maple logs Live-sawing resulted in a 14 percent increase in dollar value of dimension parts over Around-sawing. However, for No.3 grade hard maple logs they found that the difference in yield and dollar value between Live-sawing and Around-sawing was not significant. Studies by Robichaud et al. (1974) indicated that Live-sawing provided 11 percent more dollar value of dimension parts than Around-sawing for aspen logs consisting of all Grade 1 through Grade 4, but Live-sawing produced more edge-grain and mixed color cuttings than Around-sawing.

Almost all of the previous work in studying the effect of cutting sequence on the dimension yield focused on cutting standard grade lumber into dimension parts. Information on how cutting sequence and the interaction of sawing patterns and cutting sequences affect dimension yield and dollar value recovery is not available for the direct conversion of logs into dimension. In cutting standard grade lumber into dimension parts, previous studies showed that whether the lumber was Crosscut-first or Rip-first had no significant effect on the overall yield of dimension parts, but had a substantial effect on the yields of individual length parts (Lucas & Araman, 1975; Hall et al., 1980), and Rip-first produced more longer parts than Crosscut-first (Hall et al., 1980; Gatchell, 1987).

## 2.2 Yield Study Methods

There are two approaches that can be taken when studying recovery or yield: actual cutting and computer simulation. In the studies by Dunmire et al. (1972) and Rosen et al. (1980), the actual cutting method was used in both sawing logs into flitches and cutting flitches into dimension parts. Although computer simulation program allows sawing the identical log with different sawing patterns, the application of simulated log sawing is very limited. This is due to the difficulty and intensive time-consuming in recording internal defect data of a log and reconstructing a log using recorded data.

Computer simulation for cutting lumber or flitches into dimension parts has many advantages. First, it allows testing different cutting bills for identical input material. Second, some computer programs such as CORY allow for testing different cutting sequences for the same input material. However, because most of the computer program are incorporated with optimization, the results from running computer simulation programs may not be realistic and must be interpreted with caution.

It has been three decades since the first computer-based cut-up programs in dimension yield studies was developed. CORY and GR-1ST are two of the new generation of computer-based cut-up programs. These two programs incorporate optimization algorithms. CORY can perform either Rip-first or Crosscut-first operations, while GR-1ST can perform three different gang-rip configurations but does not perform Crosscut-first analysis. Comparing the results from running CORY and that from in-mill studies (Crosscut-first mill) for the same lumber input, Yun (1989) found that the overall yield obtained from running CORY was not significantly different from the yield obtained in in-mill cutting, but CORY generated more longer parts than in-mill cutting.

Some studies of dimension yield from logs (Neilson et al., 1970; Robichaud et al., 1974) used the combination method of actual cutting and computer simulation. In the combination method logs were actually sawn into flitches on real saws and the crosscutting and ripping of flitches into dimension parts were simulated by a computer program.

### **3 OBJECTIVES**

The objectives of this section was: (1) to estimate the dimension yield, dollar value recovery from No.3 grade red oak lofs, (2) to obtaine cutting details of converting No.3 grade red oak logs into rough dimension parts, and (3) to test the effects of sawing pattern and cutting sequence on the dimension yield, average cutting length and dollar value recovery.

## **4. MATERIAL AND METHODS**

### **4.1 Raw Material**

Twelve Factory Grade 3 red oak logs were obtained from a sawmill at Natural Bridge, Virginia. The logs were eight feet long and 10 to 15 inches in small-end diameter. The log diameter was the average value of two measurements obtained in two directions perpendicular to each other. The log scaling board footage was measured by

the International 1/4-inch Rule. All logs were re-graded at Virginia Tech according to USDA Forest Service Factory Grade Log Rules (Rast et al. 1973). Among the twelve logs, two were found to qualify for the No.2 grade, therefore they were discarded. The remaining ten logs were verified to be No.3 grade.

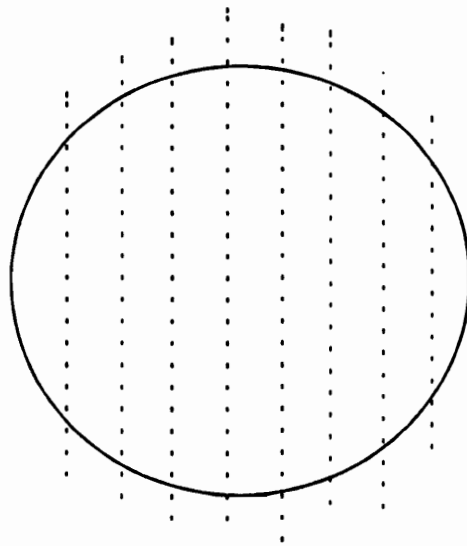
## **4.2 Methods**

### **4.2.1 Sawing Patterns and Cutting Sequences**

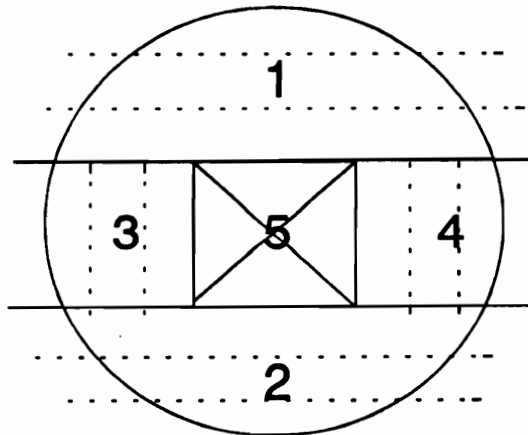
Two sawing patterns for sawing logs to flitches, Live-sawing and Five-part-sawing (Figure 2.1), were investigated in this study. These two sawing patterns are currently used in many hardwood sawmills. The Five-part-sawing has been widely used for sawing low-grade hardwood logs into lumber and cants. In Five-part-sawing, part 1 and part 2 (see Figure 2.1) are usually sawn on a headrig saw and part 3 and part 4 are sawn on a gang resaw. Part 5, a 4"x4" cant is removed from the center of each log. This cant can be used for making pallet parts rather than dimension parts.

The two principle cutting sequences currently used in rough mills, Rip-first and Crosscut-first, were used in this study for cutting flitches into rough dimension parts to estimate the dimension yield and dollar value recovery under the two cutting sequences and to assess the effect of cutting sequence on the dimension yield and dollar value recovery from No.3 grade red oak logs.





**Live-Sawing**



**Five-Part-Sawing**

**Figure 2.1 Sawing Patterns**

#### 4.2.2 Collecting Flitch Data

The ten No.3 red oak logs were Live-sawn into 1-1/8-inch flitches using a carriage and circular saw with a kerf of 0.28 inch. The first opening face of each log was randomly selected. Ninety-five flitches were obtained. The flitch data for the five-part-sawing was obtained from the live-sawn flitches. Assuming that the position of the first open face on a log was identical for both live-sawing and five-part-sawing, the flitch data of part 1 and part 2 in five-part-sawing was obtained directly from the live-sawing flitches, and the flitch data of part 3 and part 4 in five-part-sawing was obtained by resawing the three central live-sawing flitches in the perpendicular direction to the live-sawing kerf. Thus, the live-sawing and five-part-sawing simulation used the same log samples.

After the logs were sawn into flitches, each flitch, including the shape and all defects on it, was mapped on a transparent sheet. All defects on a flitch such as knots, worm holes, decay and splits were represented by a rectangle. Although this is rarely the case in nature, the rectangular shape is a good approximation because this is the practical shape in which defects are eliminated during sawing.

After mapping, digital data of each flitch, including internal defects and outline, was recorded by using a digital table with a 1/4 inch grid system. All measurements were in 1/4 inch units.

Since the computer program CORY requires the input boards to be rectangular in shape and all Live-sawing flitches and most of the Five-sawing flitches were not rectangular, each flitch was treated as a rectangle which contains an empty area inside (Figure 2.2). Whereby the empty area refers to wane. The enclosed empty area was then treated as an unsound defect which was divided into segments of five inches long and each segment was treated as a small rectangle, as shown in Figure 2.2.

Empty area is treated  
as segments of defects

Outlines of flitch

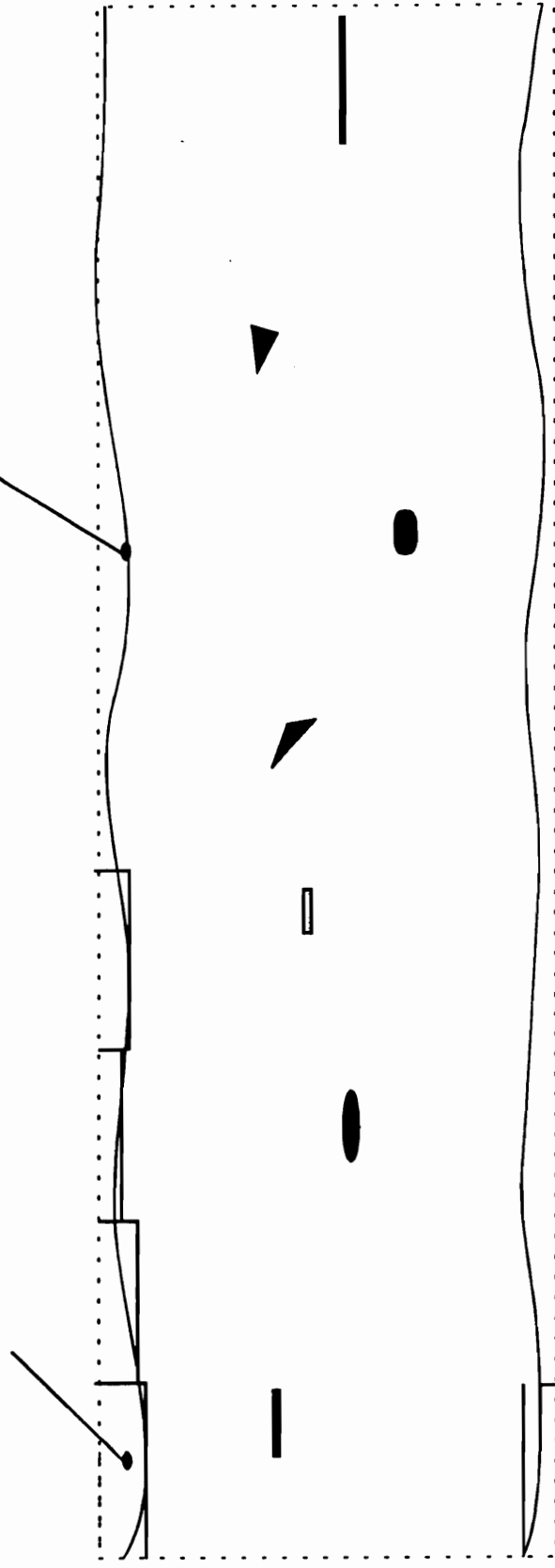


Figure 2.2 Treatment of flitches

### **4.2.3 Re-verification of Log Samples**

To verify whether the ten log samples used in this study were representative of the No.3 grade red oak logs, all Live-sawing flitches from the ten log samples were "edged" and then the "edged boards" were graded using an edging/grading computer program. This program was developed at Virginia Tech for edging training and it provides visual display of the flitch and the edging lines placed by an edging operator. The program also gives the grade of each "edged board". The results showed that if the ten log samples used in this study were sawn to standard grade lumber, the lumber grade distribution from these ten logs was similar to that obtained from a large sample of No.3 red oak logs by Hanks et al (1980) (Figure 2.3).

### **4.2.4 CORY Computer Simulation Program**

CORY (Brunner et al. 1989), a computer-based cut-up program, was used to simulate both the Rip-first and Crosscut-first operations of cutting flitches into rough dimension parts. The random-width version of the program CORY rather than the fixed-width version was used in this study because: (1) the rough dimension parts obtained from the CORY simulated cut-up were in the green state and the final width of the dry parts is difficult to control by controlling the width of green parts, and (2) the majority of the Eastern U.S. furniture and cabinet rough mills produce a large percentage of their cuttings in random width (Wiedenbeck, 1992).

The data collected from Live-sawing and Five-part-sawing flitches was used as the input to the program CORY. CORY output provides information on the board footage of dimension parts produced, percentage recovery of individual length parts,

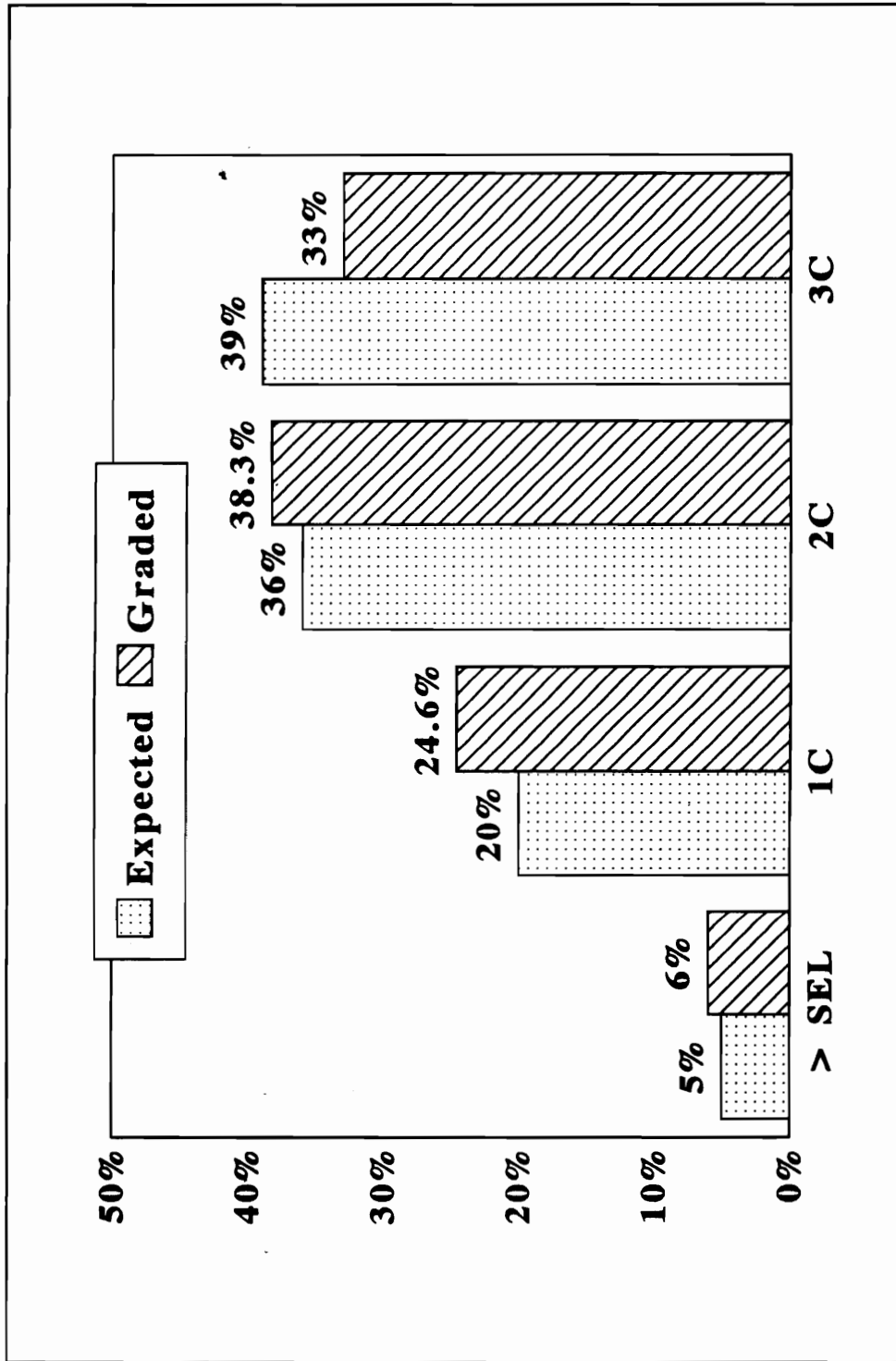


Figure 2.3 Lumber grade distribution from No3. red oak logs,

average length of parts produced from given input, and cutting solutions of each flitch. The two-stage version of CORY was used in this study for the following reasons: (1) the two-stage cutting provides more conservative estimation of dimension yield than three-stage cutting so that the economic performance of the direct processing system will not be over-estimated, and (2) the two-stage cutting is sometimes found in rough mills producing random width parts (Wiedenbeck, 1992). In the two-stage version of CORY, no salvage cuttings are allowed.

In CORY, the cutting priorities for different part lengths are determined by the relative value of each cutting length to others in a cutting bill. By assigning an exponential weighting factor (wf) to cutting length, the relative value of each cutting is determined based on the value of  $\text{Width} \times \text{Length}^{\text{wf}}$ . A weighting factor of 1 means that all cutting lengths in a cutting bill have equal priority, while a weighting factor of larger than 1 attaches higher value to the longer cuttings. The larger the weighting factor, the higher the priority of longer cuttings and the more longer cuttings are generated. Usually, using a high weighting factor results in lower yield because more longer cuttings are generated. Longer parts imply more value even though yield decreases. A weighting factor of 1.3 was used in this study. This number was determined by the relative costs of different lengths of dimension parts obtained by Yun (1989).

The cutting solutions generated by both the Rip-first and Crosscut-first CORY program were verified by drawing out the kerf lines of the computer-generated cutting solutions on the corresponding input flitches (recorded on a transparent sheet). The verification of the cutting solutions included determining whether there were any cuttings that contained defects, and if the number of each cutting size obtained from the

drawing matched that obtained from the CORY output. Ten randomly selected flitches were verified for each of the two cutting sequences (Rip-first and Crosscut-first).

#### **4.2.5 Determination of Dimension Yield**

Two measurements of the dimension yield from logs were used: scaling yield and cubic yield. The scaling yield was defined as the ratio of board footages of rough dimension parts produced to the scaling board footages of the input logs. Logs were scaled using the International 1/4-inch Rule (Rast et al, 1973). The cubic yield was defined as the ratio of cubic footages of rough dimension parts produced to the actual cubic footages of input logs. The cubic yield can eliminate the influence of the overrun and underrun in log scaling.

#### **4.2.6 Part Valuation**

Since longer parts are usually more difficult to obtain than shorter parts for given raw material, especially for low quality raw material, longer parts have more value than shorter parts. Therefore, yield and dollar value are not necessarily the same. In this study, the cants produced by Five-part-sawing were not taken account in dimension yield. However, these cants are a part of the dollar value recovered from input logs and need to be taken account in dollar value recovery.

Different definitions of value exist in the literature and in practice (Weston & Copeland, 1986). In this study, the value of dimension parts and cants is defined as the monetary return that can be realized if the products are sold in the market. The estimation of product value is a very complex task. First, price is a very sensitive issue

to product manufacturers; the majority of them are not willing to give their price information to others. Second, the price for the same product varies between various companies and changes over times.

To estimate the dollar value recovery from No.3 grade red oak logs by the direct processing system, a survey of the price of 4/4 red oak dimension parts was conducted. The information obtained through this survey was not intended to be an average for all dimension manufacturers, but rather a rough reference for value estimation in this study. Five responses were returned among the 15 surveys mailed out. One issue in estimating the dollar value of dimension parts is how to determine the relative value of different cutting lengths. Of the 5 responses received, three indicated that they had different prices for different cutting lengths, and two indicated that no different prices were applied to different cutting lengths.

To investigate the effects of cutting size on dollar value, Yun (1989) conducted a survey of selected rough mills. In Yun's survey, the obtained data was the relative cost per board foot referenced to a base value of 1000 (unitless) per board foot for a 23.25" cutting. Using the data obtained from the survey, Yun established a linear regression equation to calculate the relative dollar value of different length.

Because the relative value of a cutting is determined by the value of  $\text{Width} \times \text{Length}^{wt}$  in CORY, an exponential regression was conducted using the price data obtained in this study's survey and the data obtained in Yun's survey (Yun, 1989). The regression equation can be expressed as:

$$\text{Relative Value} = A * \text{Length}^{wt}$$

Where, A and wt are the parameters to be determined. Our main concern is the value of wt which is actually the weighting factor used in CORY. The results showed that the wt value (or weighting factor) was 1.25 based on the price data obtained in this study



and 1.3 for Yun's data. The  $R^2$  value of the regression analysis were 0.93 and 0.90, respectively. The high  $R^2$  value indicated that the exponential relationship between the relative value of parts and part lengths was very significant.

In this study, the average price for 4/4 red oak dimension parts (the price for 33" long parts) was assumed to be \$2,200 per thousand board feet and the price for 4"x4" pallet cants was assumed to be \$190 per thousand board feet. The price for dimension parts was based on this study's survey and the price for 4"X4" cants was obtained from pallet manufacturers. The dollar value of dimension parts was estimated and compared using the following two valuation scenarios: (1) all part lengths have equal value per board foot and no cutting length is favored over another, and (2) the longer parts have more value than shorter parts and the relative value of parts and part lengths have an exponential relationship with a part length weighting factor equal to 1.3.

Since the yields of dimension parts obtained from running CORY were the yields of green parts, while the estimation of dollar value was based on the yields of dry parts, some assumptions were made to convert green yields to dry yields. It was assumed that the width shrinkage of parts from green to the final moisture content of 6 percent was 7 percent and the drying degradation was 15 percent. Here, the drying degradation was defined as the percentage of part volume lost during after-drying recutting due to the presence of drying defects such as warp, checks and splits.

#### **4.2.7 Experimental Framework and Statistical Treatments**

A two by two factorial design was used to examine the effects of sawing pattern, cutting sequence, and the interactions between sawing patterns and cutting sequences on the dimension yield (scaling yield only), average cutting length and dollar value

recovery. Live-sawing and Five-part-sawing were selected as the two levels of sawing patterns and the Rip-first and Crosscut-first were selected as the two levels of cutting sequences. The experimental unit was a log rather than a flitch. There were ten observations (logs) in each cell. Since the different sawing patterns and cutting sequences used the same log samples, pairwise comparisons between the two sawing patterns and between the two cutting sequences were free of any sampling bias.

A two-way analysis of variance (ANOVA) was performed using the SAS statistical software package to analyze the effects of sawing pattern, cutting sequence, and the interactions between these sawing patterns and cutting sequences on the dimension yield (scaling yield only), average cutting length and dollar value recovery from No.3 grade red oak logs. When the ANOVA tests showed further comparisons between the two sawing patterns and the two cutting sequences to be necessary, T-test procedures were used for pairwise comparisons between the two sawing patterns under a given cutting sequence and between the two cutting sequences under a given sawing pattern.

Four cutting bills, as listed in Table 2.1, were used in the analysis. The cutting lengths in these cutting bills were adopted from the standard sizes recommended by Araman et al. (1982). The first cutting bill covers the whole range of cutting lengths from 15 to 75 inches, the second cutting bill includes only short cuttings with length shorter than or equal to 33 inches, the third cutting bill represents one with short-to-medium cutting lengths, and the fourth cutting bill represents one with medium-to-long cuttings. The purpose of using different cutting bills was to provide information on how the dimension yields might change as the cutting bill was changed. The cutting quality used for each of the cutting bills was Clear-two-face.

**Table 2.1 Cutting bills used in this study**

| Cutting Bill# | Length Category | Cutting Length (inches)                    | Cutting Width* (inches) |
|---------------|-----------------|--|-------------------------|
| #1            | whole range     | 15, 18, 21, 25, 29, 33, 38, 45, 50, 60, 75 | Random Width            |
| #2            | short length    | 15, 18, 21, 25, 29, 33                     | Random Width            |
| #3            | short-medium    | 15, 18, 21, 25, 29, 33, 38, 45             | Random Width            |
| #4            | medium-long     | 33, 38, 45, 50, 60, 75                     | Random Width            |

\* With minimum width of 1 inch.

## **5.1 Dimension Yield from No.3 Grade Red Oak Logs**

### **5.1.1 Overall Yields**

The overall scaling and cubic yields of rough green dimension parts produced from the ten No.3 red oak logs are tabulated for the four cutting bills and the four combinations of the sawing patterns and cutting sequences (Tables 2.2 and 2.3). Depending on the cutting bill used, the average scaling yield (Table 2.2) ranges from 62.2 to 74.2 percent for the processing scenario of Live-sawing followed by Rip-first (L-R), from 57.7 to 75 percent for Live-sawing followed by Crosscut-first (L-X), from 53.8 to 62.8 percent for Five-part-sawing followed by Rip-first (F-R), and from 53 to 65.4 percent for Five-part-sawing followed by Crosscut-first (F-X). For the Five-part-sawing (either followed by Rip-first or Crosscut-first), a 22.7 percent yield of 4" by 4" cants was not included in the scaling yield of dimension parts. The average cubic yield (Table 2.3), also depending on the cutting bill used, ranges from 35.4 to 42.3 percent for the processing scenario of L-R, from 32.9 to 42.7 percent for L-X, from 30.6 to 35.8 percent for F-R, and from 30.2 to 37.3 percent for F-X. For the Five-part-sawing (either followed by Rip-first or Crosscut-first), a 12.9 percent yield of 4" by 4" cants was excluded from cubic yield of dimension parts.

**Table 2.2 Overall scaling yield\* of rough green dimension parts from No.3 grade red oak logs ( % )**

| Cutting Bill | Processing Method |      |       |       |
|--------------|-------------------|------|-------|-------|
|              | L-X               | L-R  | F-X** | F-R** |
| #1           | 72.3              | 73.4 | 63.1  | 61.7  |
| #2           | 75.0              | 74.2 | 65.4  | 62.8  |
| #3           | 74.7              | 73.5 | 64.3  | 62.1  |
| #4           | 58.3              | 61.9 | 53.0  | 53.8  |

\* Scaling yield was defined as the ratio of board footages of rough green dimension parts to the International 1/4-inch scaling board footages of the input logs.

\*\* A 22.7 percent scaling yield of 4" by 4" cants from Five-Part-Sawing was not included in the figures shown in this table.

- L - X: Live-sawing followed by Crosscut-First cutting.
- L - R: Live-sawing followed by Rip-first cutting.
- F - X: Five-part-sawing followed by Crosscut-first cutting.
- F - R: Five-part-sawing followed by Rip-first cutting.

**Table 2.3**

**Overall cubic yield\* of rough green dimension parts  
from No.3 grade red oak logs ( % )**

| Cutting Bill | Processing Method |      |       |       |
|--------------|-------------------|------|-------|-------|
|              | L-X               | L-R  | F-X** | F-R** |
| #1           | 41.3              | 41.8 | 35.9  | 35.2  |
| #2           | 42.7              | 42.3 | 37.3  | 35.8  |
| #3           | 42.3              | 41.9 | 36.7  | 35.4  |
| #4           | 32.9              | 35.4 | 30.6  | 30.2  |

\* Cubic yield was defined as the ratio of the cubic footages of rough green dimension parts to the cubic footages of the input logs.

\*\* A 12.9 percent cubic yield of 4" by 4" cants from Five-Part-Sawing was not included in the figures shown in this table.

L - X: Live-sawing followed by Crosscut-first cutting.

L - R: Live-sawing followed by Rip-first cutting.

F - X: Five-part-sawing followed by Crosscut-first cutting.

F - R: Five-part-sawing followed by Rip-first cutting.

### **5.1.2 The Effects of Sawing Pattern and Cutting Sequence on Dimension Yield**

Analysis of variance (ANOVA) was performed to investigate the effects of sawing patterns and cutting sequences on the scaling yield of rough green parts from No.3 grade red oak logs. It was hypothesized that the scaling yields produced in different sawing patterns and different cutting sequences are significantly different. The ANOVA results for scaling yield are shown in Table 2.4.

The results indicate that for all of the four cutting bills the sawing pattern has significant effects on yield. However, the selection of the cutting sequences does not have significant effects on the scaling yield, and there are no interactions between the sawing patterns and the cutting sequences in affecting scaling yield. Since only two levels of sawing patterns were involved in the tests and no interactions were detected between the sawing patterns and the cutting sequences, it can be concluded from Tables 2.2 and 2.4 that for all of the four cutting bills Live-sawing produces significantly higher yield than Five-part-sawing.

### **5.1.3 The Effects of Sawing Pattern and Cutting Sequence on Average Cutting Length**

Table 2.5 gives the average cutting lengths of parts by the different processing methods and cutting bills. Two-way ANOVA was used to test the effects of the sawing patterns and the cutting sequences on the average cutting length of rough dimension parts from each log. It was hypothesized that both the sawing patterns and the cutting sequences significantly affect the average cutting length. As shown in Table 2.6, the ANOVA results indicate that for all of the four cutting bills tested, the average cutting

**Table 2.4 Analysis of Variance Results: Overall scaling yield\***

| Cutting Bill | Source            | Significance at $\alpha=0.05$ | P-value (Pr > F) |
|--------------|-------------------|-------------------------------|------------------|
| #1           | Sawing Patterns   | S                             | 0.0001           |
|              | Cutting Sequences | NS                            | 0.5813           |
|              | Interaction       | NS                            | 0.5092           |
| #2           | Sawing Patterns   | S                             | 0.0001           |
|              | Cutting Sequences | NS                            | 0.2140           |
|              | Interaction       | NS                            | 0.6606           |
| #3           | Sawing Patterns   | S                             | 0.0001           |
|              | Cutting Sequences | NS                            | 0.2807           |
|              | Interaction       | NS                            | 0.7005           |
| #4           | Sawing Patterns   | S                             | 0.0052           |
|              | Cutting Sequences | NS                            | 0.3950           |
|              | Interaction       | NS                            | 0.5251           |

\* Scaling yield was defined as the ratio of the board footages of rough green dimension parts to the International 1/4-inch scaling board footages of the input logs.

S: Significant at  $\alpha=0.05$  level

NS: Not significant at  $\alpha=0.05$  level.



**Table 2.5                      Average cutting lengths (inches) of dimension parts  
by various processing methods and cutting bills**

| Cutting Bill | Processing Method |       |       |       |
|--------------|-------------------|-------|-------|-------|
|              | L-X               | L-R   | F-X   | F-R   |
| #1           | 26.56             | 38.35 | 35.05 | 42.82 |
| #2           | 22.05             | 26.57 | 24.79 | 27.02 |
| #3           | 24.33             | 32.76 | 29.84 | 34.85 |
| #4           | 43.19             | 51.20 | 47.92 | 52.56 |

- L - X: Live-sawing followed by Crosscut-First cutting.
- L - R: Live-sawing followed by Rip-first cutting.
- F - X: Five-part-sawing followed by Crosscut-first cutting.
- F - R: Five-part-sawing followed by Rip-first cutting.

**Table 2.6 Analysis of Variance Results: Average cutting length**

| Cutting Bill | Source            | Significance at $\alpha=0.05$ | P-value (Pr > F) |
|--------------|-------------------|-------------------------------|------------------|
| #1           | Sawing Patterns   | S                             | 0.0001           |
|              | Cutting Sequences | S                             | 0.0001           |
|              | Interaction       | NS                            | 0.2216           |
| #2           | Sawing Patterns   | S                             | 0.0033           |
|              | Cutting Sequences | S                             | 0.0001           |
|              | Interaction       | S                             | 0.0432           |
| #3           | Sawing Patterns   | S                             | 0.0002           |
|              | Cutting Sequences | S                             | 0.0001           |
|              | Interaction       | NS                            | 0.0767           |
| #4           | Sawing Patterns   | S                             | 0.0407           |
|              | Cutting Sequences | S                             | 0.0001           |
|              | Interaction       | S                             | 0.0306           |

S: Significant at  $\alpha=0.05$  level.

NS: Not Significant at  $\alpha=0.05$  level.

lengths of dimension parts produced by Live-sawing and Five-part-sawing are significantly different. And the differences in the average cutting length resulting from the two different cutting sequences are also statistically significant for all of the four cutting bills. However, the interactions between the sawing patterns and the cutting sequences were detected in cutting bill #2 and #4. In other words, the effects of the cutting sequences on the average cutting length for cutting bill #2 and #4 depend on which sawing pattern was used and vice versa. Therefore, paired T-tests were performed to further test the differences in the average cutting length between Live-sawing and Five-part-sawing under a given cutting sequence and between Rip-first and Crosscut-first under a given sawing pattern.

All these tests were one-side tests. It was hypothesized that Five-part-sawing produces longer cuttings than Live-sawing under both Rip-first and Crosscut-first, and Rip-first produces longer cuttings than Crosscut-first under both Live-sawing and Five-part-sawing.

As shown in Table 2.7, for all of the four cutting bills and under both Live-sawing and Five-part-sawing, the average cutting length from Rip-first is longer than that from Crosscut-first at a high significant level of  $\alpha=0.01$ . If followed by Crosscut-first, Five-part-sawing results in higher average cutting length than Live-sawing at a high significant level of  $\alpha=0.01$  for all of the four cutting bills. If followed by Rip-first, however, Five-part-sawing results in higher average cutting length only for cutting bill #1 and #3 and at the significant level of  $\alpha=0.05$ , and the difference in the average cutting length between Live-sawing and Five-part-sawing is not significant for both cutting bill #2 and #4 at  $\alpha=0.05$  level. The distributions of individual cutting lengths resulted from the different combinations of the sawing patterns and cutting sequences are depicted in Figure 2.4 through Figure 2.7. These distributions will be

**Table 2.7 Paired T-test Results: Average cutting length**

|  |                   |                   |                   |                   |
|--|-------------------|-------------------|-------------------|-------------------|
| <p><b>Test: Live-Sawing Vs. Five-Part-Sawing</b></p> <p><math>H_0: L_{F-R} = L_{L-R}</math>                      <math>H_1: L_{F-R} &gt; L_{L-R}</math><br/> <math>L_{F-X} = L_{L-X}</math>                              <math>L_{F-X} &gt; L_{L-X}</math></p> |                   |                   |                   |                   |
| <b>Cutting Sequence</b>  | <b>CB#1</b>       | <b>CB#2</b>       | <b>CB#3</b>       | <b>CB#4</b>       |
| Rip-First  | S <sub>0.05</sub> | NS                | S <sub>0.05</sub> | NS                |
| Crosscut-First   | S <sub>0.01</sub> | S <sub>0.01</sub> | S <sub>0.01</sub> | S <sub>0.01</sub> |
| <p><b>Test: Rip-First Vs. Crosscut-First</b></p> <p><math>H_0: L_{L-R} = L_{L-X},</math>                      <math>H_1: L_{L-R} &gt; L_{L-X}</math><br/> <math>L_{F-R} = L_{F-X},</math>                              <math>L_{F-R} &gt; L_{F-X}</math></p>   |                   |                   |                   |                   |
| <b>Sawing Pattern</b>  | <b>CB#1</b>       | <b>CB#2</b>       | <b>CB#3</b>       | <b>CB#4</b>       |
| Live-Sawing  | S <sub>0.01</sub> | S <sub>0.01</sub> | S <sub>0.01</sub> | S <sub>0.01</sub> |
| Five-Part-Sawing   | S <sub>0.01</sub> | S <sub>0.01</sub> | S <sub>0.01</sub> | S <sub>0.01</sub> |

CB# - Cutting bill#.

L<sub>L-R</sub> - Average cutting length for the combination of Live-Sawing and Rip-First.

L<sub>L-X</sub> - Average cutting length for the combination of Live-Sawing and Crosscut-First.

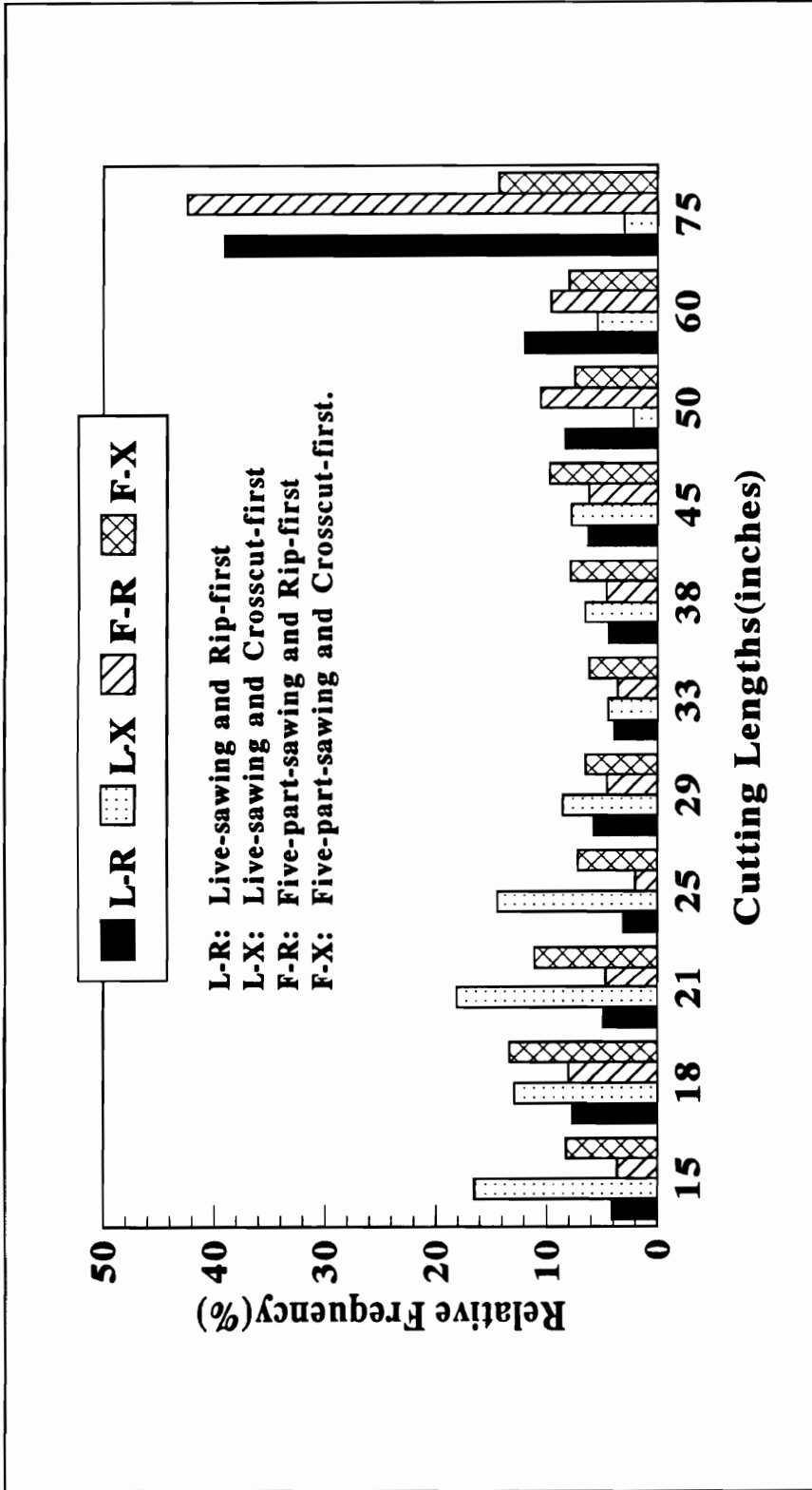
L<sub>F-R</sub> - Average cutting length for the combination of Five-Part-Sawing and Rip-First.

L<sub>F-X</sub> - Average cutting length for the combination of Five-Part-Sawing and Crosscut-First.

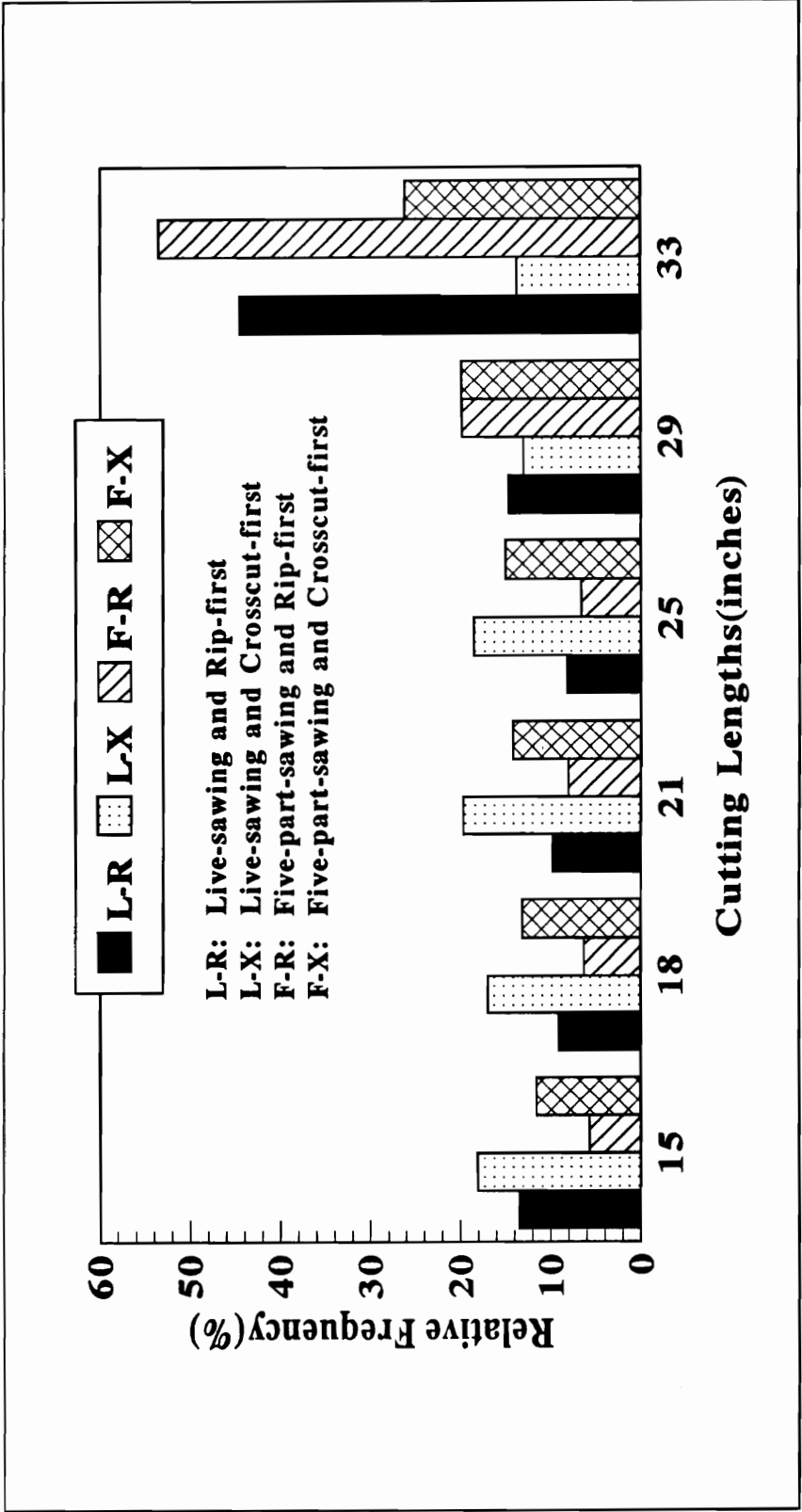
S<sub>0.05</sub> - Significantly different at  $\alpha=0.05$  level.

S<sub>0.01</sub> - Significantly different at  $\alpha=0.01$  level.

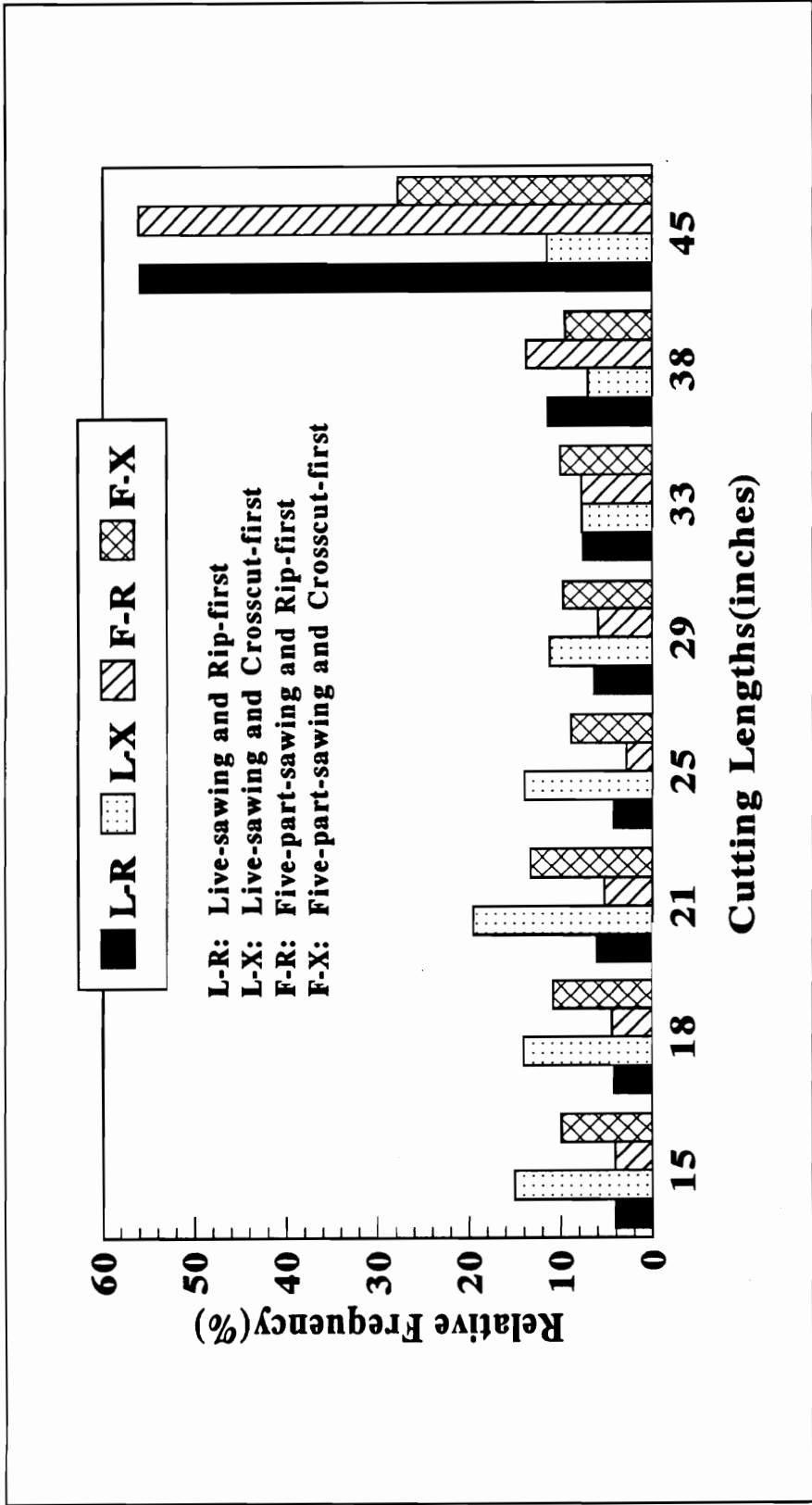
NS - Not Significantly different at  $\alpha=0.05$  level.



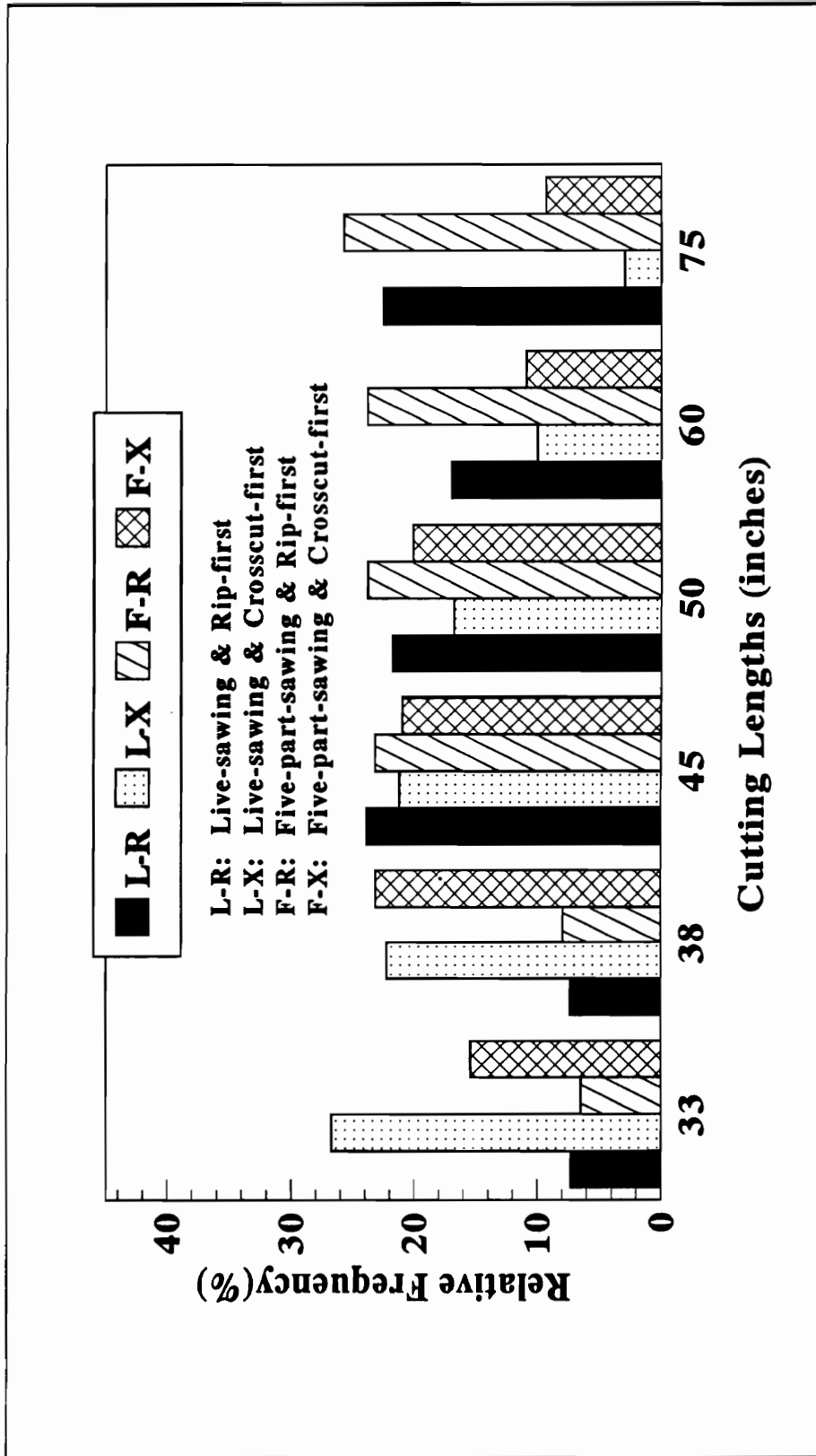
**Figure 2.4 Distribution of rough part lengths for cutting bill #1**  
 (Cutting lengths: 15, 18, 21, 25, 29, 33, 38, 45, 50, 60, 75 inches)



**Figure 2.5** Distribution of rough part length for cutting bill #2  
 (Cutting lengths: 15, 18, 21, 25, 29, 33 inches)



**Figure 2.6** Distribution of rough part lengths for cutting bill #3  
 (Cutting lengths: 15, 18, 21, 25, 29, 33, 38, 45 inches)



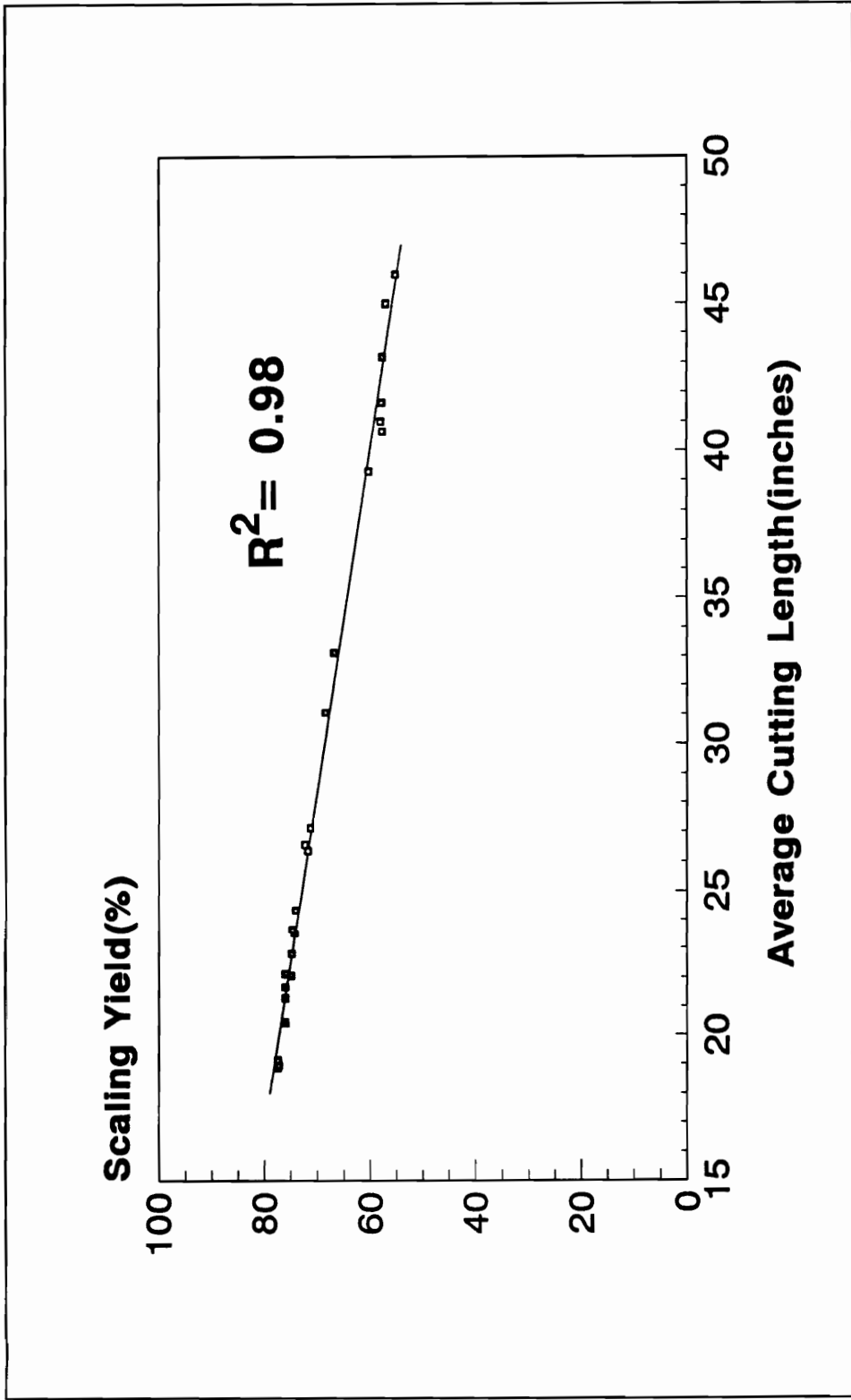
**Figure 2.7** Distribution of rough part lengths for cutting bill #4  
 (Cutting lengths: 33, 38, 45, 50, 60, 75 inches)



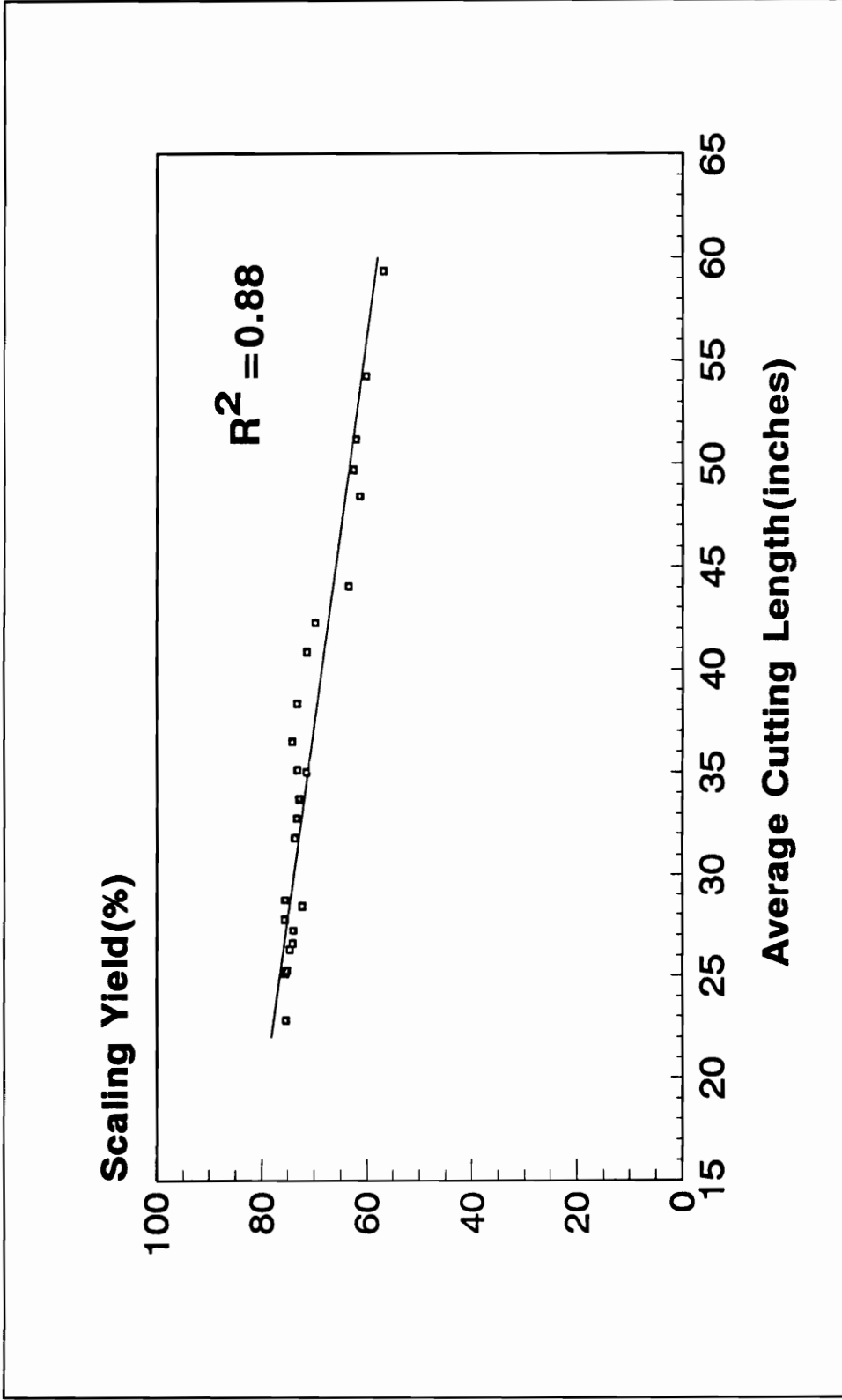
used as inputs of the system simulation models in Section 3. As shown in Figure 2.4 through 2.7, there are two general trends that Five-part-sawing produces more longer cuttings than Live-sawing and Rip-first produces more longer cutting than Crosscut-first. The only exception is that for the cutting bill containing only short cuttings (Cutting bill #2) and the cutting bill containing no short cuttings (cutting bill #4), the first trend is not significant if Rip-first is used.

#### **5.1.4 The Association Between Cutting Yield and Average Cutting Length**

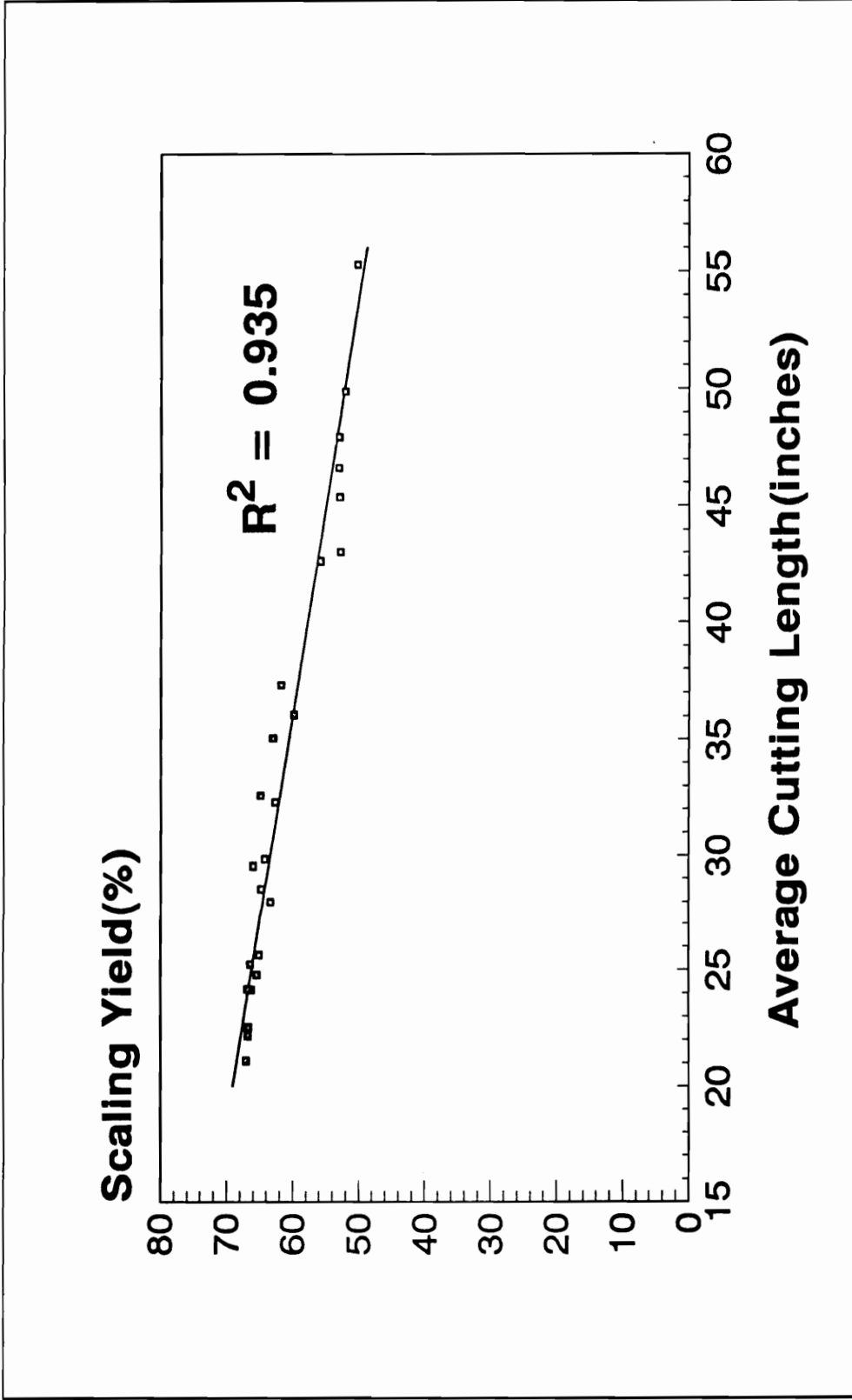
Since there appeared a trend that the cutting yield could be higher for a short cutting bill and lower for a longer cutting bill as shown in Table 2.2 and Table 2.3, the relationship between the scaling yield and the average cutting length was examined. Simple linear regression analysis was used to detect the degree of association between the scaling yield and the average cutting length within each combination of the two sawing patterns and the two cutting sequences. The data of the average cutting lengths and the corresponding scaling yields used in this regression analysis were obtained through running the program CORY for the four cutting bills listed in Table 2.1 under the weighting factors of 1.0, 1.1, 1.2, 1.3, 1.5 and 2.0. The results are demonstrated in Figure 2.8 through Figure 2.11. These results indicate that there is a negative linear association between the scaling yield and the average cutting length and this relationship is highly significant. The strong linear relationship is indicated by the high R-square value of the regressions, which varies from 0.83 to 0.98, depending on the combinations of the sawing patterns and the cutting sequences.



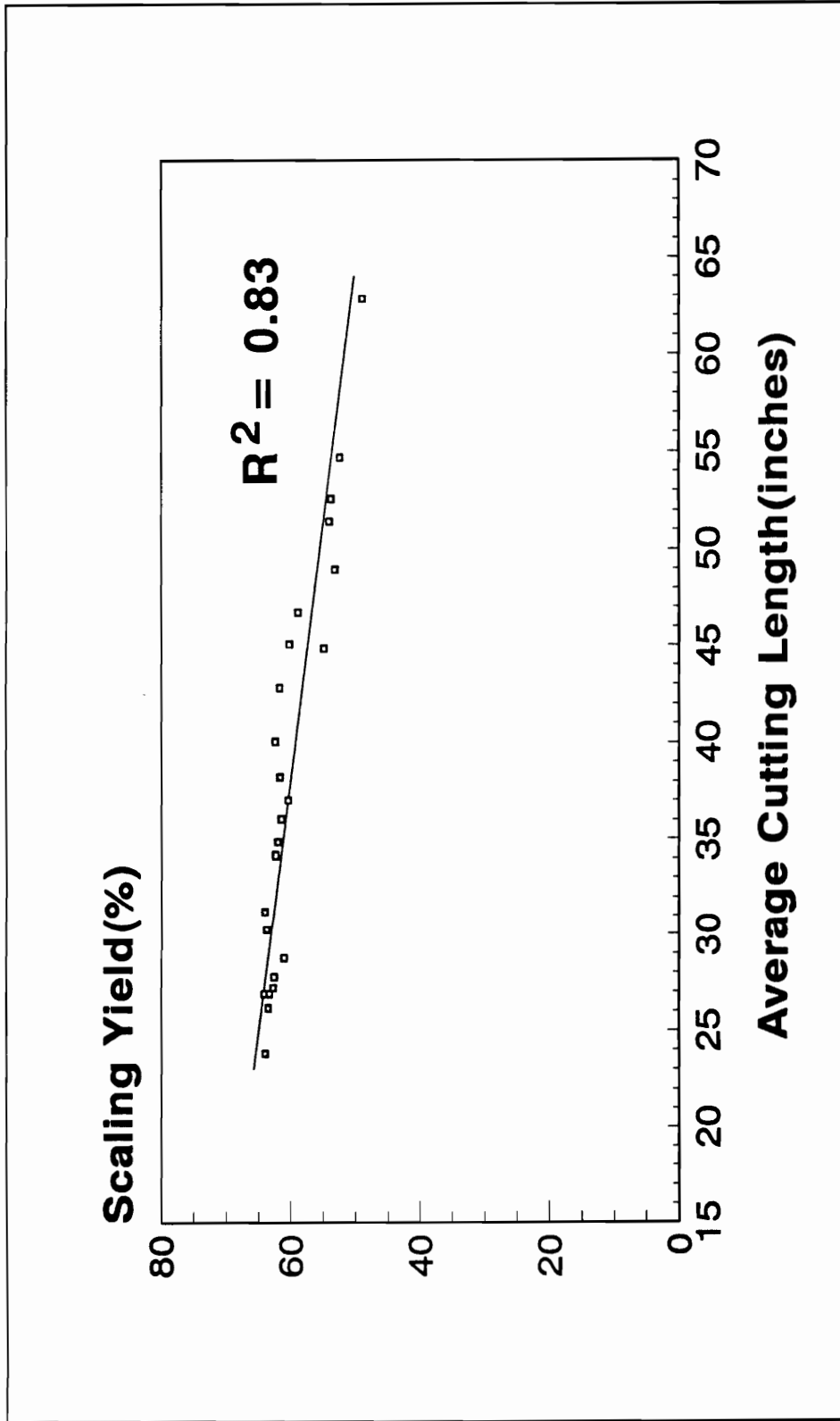
**Figure 2.8** Linear regression between scaling yield and average cutting length for the combination of Live-sawing and Crosscut-first



**Figure 2.9** Linear regression between scaling yield and average cutting length for the combination of Live-sawing and Rip-first



**Figure 2.10** Linear regression between scaling yield and average cutting length for the combination of Five-part-sawing and Crosscut-first



**Figure 2.11** Linear regression between scaling yield and average cutting length for the combination of Five-part-sawing and Rip-first

### 5.1.5 Adjusted Scaling Yield

Since an association between the scaling yield and the average cutting length was detected, scaling yields were adjusted to length and then compared for different sawing patterns and cutting sequences. The purpose of this adjustment was to see how the yield differences would change if the different processing methods are required to produce the similar cutting bills. The adjusted yield data were obtained by running the program CORY using different weighting factors. In these CORY runs, different weighting factors were chosen to force the four combinations of the sawing patterns and cutting sequences to have the similar average cutting length within each cutting bill. The adjusted scaling yields, along with the average cutting length and the weighting factors used in each CORY run are listed in Table 2.8.

Paired T-tests were performed for comparing the adjusted scaling yield between Live-sawing and Five-part-sawing and between Rip-first and Crosscut-first. The results of these tests are compiled in Table 2.9. If followed by Rip-first, the adjusted scaling yield from Live-sawing is significantly higher than that from Five-part-sawing for all of the four cutting bills at  $\alpha=0.01$  level. However, if followed by Crosscut-first, the difference in the adjusted scaling yield between Live-sawing and Five-part-sawing is no longer significant for cutting bill #1 and #4, even though it is still significant for cutting bill #2 and #3.

The difference in the adjusted scaling yield between Rip-first and Crosscut-first is not significant at  $\alpha=0.05$  level if logs are sawn in Five-part-sawing. However, if logs are sawn in Live-sawing, the difference in the adjusted scaling yield between Rip-first and Crosscut-first is significant for cutting bill #1, #3, and #4, and not significant for cutting bill #2 at  $\alpha=0.05$  level. Compared to the tests for the non-adjusted yields, the

**Table 2.8 Adjusted scaling yield\***

| Cutting Bill# | Processing Method | Scaling Yield(%) | Average Cutting Length (inches) | Weighting Factor |
|---------------|-------------------|------------------|---------------------------------|------------------|
| #1            | L - X             | 68.54            | 31.06                           | 1.50             |
|               | L - R             | 75.55            | 30.62                           | 1.05             |
|               | F - X             | 65.46            | 31.39                           | 1.15             |
|               | F - R             | 64.04            | 31.22                           | 1.00             |
| #2            | L - X             | 74.41            | 23.51                           | 1.50             |
|               | L - R             | 75.62            | 23.76                           | 1.05             |
|               | F - X             | 66.62            | 23.44                           | 1.15             |
|               | F - R             | 63.96            | 23.80                           | 1.00             |
| #3            | L - X             | 71.42            | 27.13                           | 1.50             |
|               | L - R             | 75.56            | 26.37                           | 1.05             |
|               | F - X             | 66.02            | 26.50                           | 1.15             |
|               | F - R             | 64.12            | 26.87                           | 1.00             |
| #4            | L - X             | 57.03            | 44.98                           | 1.50             |
|               | L - R             | 63.39            | 44.40                           | 1.05             |
|               | F - X             | 53.13            | 43.74                           | 1.05             |
|               | F - R             | 54.91            | 44.84                           | 1.00             |

\* Scaling yield was defined as the ratio of the board footages of the rough green dimension parts to the International 1/4-inch scaling board footages of the input logs.

- L-R: Live-Sawing followed by Rip-First.
- L-X: Live-Sawing followed by Crosscut-First.
- F-R: Five-Part-Sawing followed by Rip-First.
- F-X: Five-Part-Sawing followed by Crosscut-First.

**Table 2.9 Paired T-test Results: Adjusted scaling yield**

|  |                   |                   |                   |                   |
|--|-------------------|-------------------|-------------------|-------------------|
| <p><b>Test: Live-Sawing Vs. Five-Part-Sawing</b></p> <p><math>H_0: Y_{L-R} = Y_{F-R},</math>                      <math>H_1: Y_{L-R} &gt; Y_{F-R}</math><br/> <math>Y_{L-X} = Y_{F-X},</math>                              <math>Y_{L-X} &gt; Y_{F-X}</math></p> |                   |                   |                   |                   |
| Cutting Sequence   | CB#1              | CB#2              | CB#3              | CB#4              |
| Rip-First  | S <sub>0.01</sub> | S <sub>0.01</sub> | S <sub>0.01</sub> | S <sub>0.01</sub> |
| Crosscut-First   | NS                | S <sub>0.01</sub> | S <sub>0.05</sub> | NS                |
| <p><b>Test: Rip-First Vs. Crosscut-First</b></p> <p><math>H_0: Y_{L-R} = Y_{L-X},</math>                      <math>H_1: Y_{L-R} &gt; Y_{L-X}</math><br/> <math>Y_{F-R} = Y_{F-X},</math>                              <math>Y_{F-R} &gt; Y_{F-X}</math></p>     |                   |                   |                   |                   |
| Sawing Pattern   | CB#1              | CB#2              | CB#3              | CB#4              |
| Live-Sawing  | S <sub>0.01</sub> | NS                | S <sub>0.05</sub> | S <sub>0.01</sub> |
| Five-Part-Sawing   | NS                | NS                | NS                | NS                |

- CB# - Cutting bill #.
- Y<sub>L-R</sub> - Scaling yield for the combination of Live-Sawing and Rip-First.
- Y<sub>L-X</sub> - Scaling Yield for the combination of Live-Sawing and Crosscut-First.
- Y<sub>F-R</sub> - Scaling Yield for the combination of Five-Part-Sawing and Rip-First.
- Y<sub>F-X</sub> - Scaling Yield for the combination of Five-Part-Sawing and Crosscut-First.
- S<sub>0.05</sub> - Significantly different at α=0.05 level.
- S<sub>0.01</sub> - Significantly different at α=0.01 level.
- NS - Not Significantly different at α=0.05 level.



tests for adjusted yields have following two changes: (1) the adjusted scaling yields from Live-sawing and from Five-part-sawing are no longer significant for cutting bill #1 and #4 under Crosscut-first, and (2) Rip-first results in significantly higher yield than Crosscut-first for cutting bill #1, #3, and #4 under Live-sawing.

## **5.2 Dollar Value Recovery from No.3 Grade Red Oak Logs**

In comparing the dimension yields, only the yields of dimension parts were considered and the volume of the cants cut from Five-part-sawing was not considered in the dimension yields. However, these cants have value. In estimating the dollar value recovery from logs, both the value of dimension parts and cants are included.

The estimation and comparisons of dollar value recovered from No.3 red oak logs were conducted under two different assumptions: (1) all part lengths have equal value of per board foot, and (2) longer parts have higher value than shorter parts with a weighting factor of 1.3 for part length. In both cases, the average price of dimension parts was assumed to be \$2,200 per thousand board feet and the price for the 4"x4" cants from Five-part-sawing was assumed to be \$190 per thousand board feet. Two-way ANOVA was used to test the effects of sawing pattern and cutting sequence on the dollar value recovery from per board foot log input. It was hypothesized that both sawing pattern and the cutting sequence have significant influence on the dollar value recovery from No.3 grade red oak logs for both of the two assumptions mentioned above.

### **5.2.1 The Dollar Value Recovery When All Part Lengths Have Equal Value**

Table 2.10 lists the average dollar value (including the value of both dimension parts and the cants) recovered from per board foot log input by using the different sawing patterns and cutting sequences when all part lengths have equal value. The ANOVA results, as shown in Table 2.11, indicate that sawing pattern has significant effects on the dollar value recovery when all part lengths have equal value. However, cutting sequence has no significant effects on dollar value recovery. Since only two levels of sawing patterns were involved in the tests and no interactions were detected between the sawing patterns and cutting sequences, it can be concluded from Tables 2.10 and 2.11 that Live-sawing results in significantly higher dollar value recovery than Five-part-sawing if all part lengths have equal value.

### **5.2.2 The Dollar Value Recovery When The Longer Dimension Parts Have Higher Value With A Weighting Factor of 1.3 for Part Length**

The average dollar value (including the value of dimension parts and cants) recovered from per board foot log input when the longer dimension parts have higher value than shorter parts are listed in Table 2.12. The ANOVA results (see Table 2.13) show that sawing pattern has significant effects on dollar value recovery for cutting bill #1 through #3; however, it appears to have no significant effects on dollar value recovery for cutting bill #4. The results also indicate that cutting sequence significantly affect dollar value recovery for cutting bills #1, #3 and #4; however, the effect of cutting sequence on dollar value recovery is not significant for cutting bill #2.

**Table 2.10****Dollar value recovery from per board foot log input  
when all part lengths have equal value\***

| Cutting Bill | Processing Method |        |        |        |
|--------------|-------------------|--------|--------|--------|
|              | L-X               | L-R    | F-X    | F-R    |
| #1           | \$1.27            | \$1.28 | \$1.15 | \$1.11 |
| #2           | \$1.32            | \$1.29 | \$1.19 | \$1.14 |
| #3           | \$1.31            | \$1.28 | \$1.17 | \$1.12 |
| #4           | \$1.04            | \$1.08 | \$0.97 | \$0.98 |

\* The dollar values listed in this table include the values of both the dimension parts and the cants.

L - X : Live-sawing followed by Crosscut-first cutting.

L - R : Live-sawing followed by Rip-first cutting.

F - X : Five-part-sawing followed by Crosscut-first cutting.

F - R : Five-part-sawing followed by Rip-first cutting.

**Table 2.11 Analysis of variance for dollar value recovery per board foot log input  
Results 1: When all part lengths have equal value**

| Cutting Bill | Source            | Significance<br>at alpha=0.05 | P-value<br>(Pr > F) |
|--------------|-------------------|-------------------------------|---------------------|
| #1           | Sawing Patterns   | S                             | 0.0001              |
|              | Cutting Sequences | NS                            | 0.5786              |
|              | Interaction       | NS                            | 0.5063              |
| #2           | Sawing Patterns   | S                             | 0.0001              |
|              | Cutting Sequences | NS                            | 0.2132              |
|              | Interaction       | NS                            | 0.6584              |
| #3           | Sawing Patterns   | S                             | 0.0001              |
|              | Cutting Sequences | NS                            | 0.2710              |
|              | Interaction       | NS                            | 0.7185              |
| #4           | Sawing Patterns   | S                             | 0.0435              |
|              | Cutting Sequences | NS                            | 0.3460              |
|              | Interaction       | NS                            | 0.4774              |

S: Significant at  $\alpha=0.05$  level.

NS: Not significant at  $\alpha=0.05$  level.

**Table 2.12 Dollar value recovery from per board foot log input when longer parts have higher value with a weighting factor of 1.3**

| Cutting Bill | Processing Method |        |        |        |
|--------------|-------------------|--------|--------|--------|
|              | L-X               | L-R    | F-X    | F-R    |
| #1           | \$1.20            | \$1.43 | \$1.17 | \$1.25 |
| #2           | \$1.18            | \$1.22 | \$1.10 | \$1.08 |
| #3           | \$1.20            | \$1.32 | \$1.13 | \$1.16 |
| #4           | \$1.09            | \$1.24 | \$1.07 | \$1.12 |

\* The dollar values listed in this table include the values of both the dimension parts and the cants.

- L - X: Live-sawing followed by Crosscut-first cutting.
- L - R: Live-sawing followed by Rip-first cutting.
- F - X: Five-part-sawing followed by Crosscut-first cutting.
- F - R: Five-part-sawing followed by Rip-first cutting.

**Table 2.13 Analysis of variance for dollar value recovery per BF log input  
Results 2: When longer parts have higher value**

| Cutting Bill | Source            | Significance<br>at alpha=0.05 | P-value<br>(Pr > F) |
|--------------|-------------------|-------------------------------|---------------------|
| #1           | Sawing Patterns   | S                             | 0.0198              |
|              | Cutting Sequences | S                             | 0.0004              |
|              | Interaction       | S                             | 0.0461              |
| #2           | Sawing Patterns   | S                             | 0.0014              |
|              | Cutting Sequences | NS                            | 0.4979              |
|              | Interaction       | NS                            | 0.3070              |
| #3           | Sawing Patterns   | S                             | 0.0014              |
|              | Cutting Sequences | S                             | 0.0369              |
|              | Interaction       | S                             | 0.0268              |
| #4           | Sawing Patterns   | NS                            | 0.1175              |
|              | Cutting Sequences | S                             | 0.0267              |
|              | Interaction       | S                             | 0.0437              |

\* With weighting factor for part lengths equal to 1.3

S: Significant at  $\alpha=0.05$  level.

NS: Not significant  $\alpha=0.05$  level.

Since interactions between sawing patterns and the cutting sequences in affecting the dollar value recovery were detected for cutting bills #1, #3 and #4, further tests to determine the magnitude and direction of one main effect depending upon which level of the other main effect were necessary. Paired T-tests were used for pairwise comparisons of dollar value recovery between the two sawing patterns and between the two cutting sequences. The results of these tests are shown in Table 2.14.

If combined with Rip-first, Live-sawing results in significantly higher dollar value recovery than Five-part-sawing for all of the four cutting bills at  $\alpha=0.05$  level. If combined with Crosscut-first, Live-sawing results in significant higher dollar value recovery than Five-part-sawing for cutting bill #2 and #3 at  $\alpha=0.05$  level, but no significant difference for cutting bill #1 and #4.

The combination of Live-sawing and Rip-first produces significantly higher dollar value recovery than the combination of Live-sawing and Crosscut-first for cutting bills #1, #3 and #4 at  $\alpha=0.01$  level; however, the difference in the dollar value recovery is not significant for cutting bill #2. The combination of Five-part-sawing and Rip-first produces significantly higher dollar value recovery than the combination of Five-part-sawing and Crosscut-first for cutting bills #1 and #4, however, there is no significant difference in the dollar value recovery between Rip-first and Crosscut-first for cutting bill #2 and #3.

**Table 2.14 Paired T-test Results:  
Dollar value recovery per board foot log input \***

|  |                   |                   |                   |                   |
|--|-------------------|-------------------|-------------------|-------------------|
| <b>Test: Live-Sawing Vs. Five-Part-Sawing</b><br>$H_0: V_{L-R} = V_{F-R}, V_{L-X} = V_{F-X}$ $H_1: V_{L-R} \neq V_{F-R}, V_{L-X} \neq V_{F-X}$ |                   |                   |                   |                   |
| Cutting Sequence   | CB#1              | CB#2              | CB#3              | CB#4              |
| Rip-First  | S <sub>0.01</sub> | S <sub>0.01</sub> | S <sub>0.01</sub> | S <sub>0.05</sub> |
| Crosscut-First   | NS                | S <sub>0.05</sub> | S <sub>0.05</sub> | NS                |
| <b>Test: Rip-First Vs. Crosscut-First</b><br>$H_0: V_{L-R} = V_{L-X}, V_{F-R} = V_{F-X}$ $H_1: V_{L-R} \neq V_{L-X}, V_{F-R} \neq V_{F-X}$     |                   |                   |                   |                   |
| Sawing Pattern   | CB#1              | CB#2              | CB#3              | CB#4              |
| Live-Sawing  | S <sub>0.01</sub> | NS                | S <sub>0.01</sub> | S <sub>0.01</sub> |
| Five-Part-Sawing   | S <sub>0.01</sub> | NS                | NS                | S <sub>0.05</sub> |

- \* - It was assumed that longer parts have higher value than shorter parts with the weighting factor of 1.3 for part length
- CB# - Cutting bill #.
- V<sub>L-R</sub> - Part value resulted from Live-Sawing followed by Rip-First.
- V<sub>L-X</sub> - Part value resulted from Live-Sawing followed by Crosscut-First.
- V<sub>F-R</sub> - Part value resulted from Five-Part-Sawing followed by Rip-First.
- V<sub>F-X</sub> - Part value resulted from Five-Part-Sawing followed by Crosscut-First.
- S<sub>0.05</sub> - Significantly different at  $\alpha=0.05$  level.
- S<sub>0.01</sub> - Significantly different at  $\alpha=0.01$  level.
- NS - Not Significantly different at  $\alpha=0.05$  level.

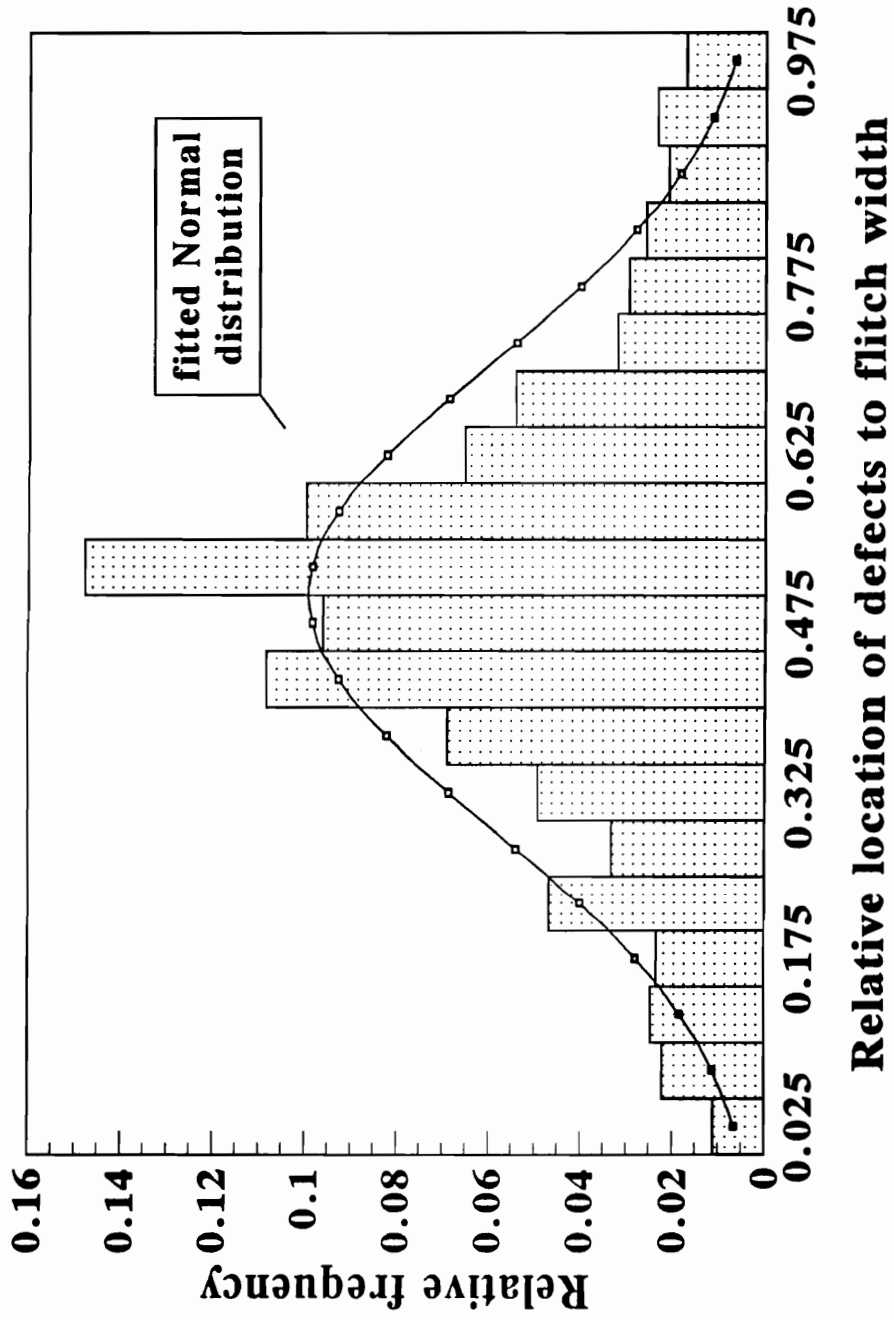


### **6.1 The Effects of Sawing Pattern and Cutting Sequence on Dimension Yield and Cutting Length from No.3 Red Oak Logs**

If the logs are cut into dimension parts based on maximizing the value of dimension parts, Live-sawing results in higher dimension yield (scaling yield) than Five-part-sawing for both Rip-first and Crosscut-first, independent of cutting bills. This is very obvious because a 4"x4" cant was cut from each log and the volume of the cant was not taken account in the dimension yields. The results also indicate that the dimension yields from Rip-first and Crosscut-first are not significantly different, which is consistent with the results obtained by Lucas and Araman (1975), Hall et al. (1980) and Brunner et al. (1989) in cutting standard grade lumber into dimension parts.

The average cutting length of dimension parts from Five-part-sawing is significantly higher than Live-sawing in most cases (for all of the four cutting bills under Crosscut-first and for cutting bills #1 and #3 under Rip-first) (see Table 2.7 and Figure 2.4 through 2.7). This could be attributed to the fact that the center of a log is the most defective area in a log and this area is removed in Five-part-sawing as a cant instead of being cut into dimension parts; therefore, more longer cuttings can be obtained from less defective Five-part-sawing flitches than from more defective Live-sawing flitches. It can be seen from Figure 2.12 that the distribution of defects across the width of Live-sawing flitches is a well-fitted truncated normal distribution.

The results of this study also show that the average cutting length from Five-part-sawing and from Live-Sawing is not significantly different for cutting bills #2 and #4 under Rip-first (Table 2.6). Cutting bill #2 contains only cuttings no longer than 33"



**Figure 2.12** Location of defects across the width of Live-sawing flitches

while cutting bill #4 contains only cuttings not shorter than 33". For the cutting bill containing only cuttings not longer than 33", the more defective strips ripped from Live-sawing flitches can still generate most of the cuttings contained in the cutting bill, and for the cutting bill containing only cuttings not shorter than 33", not many cuttings can be made from the most defective strips ripped from Live-sawing flitches; therefore, the average cutting lengths from Live-sawing and from Five-part-sawing show no significant difference in these two extreme cases.

For all of the four cutting bills and under both Live-sawing and Five-part-sawing, Rip-first results in more longer cuttings than Crosscut-first (see Table 2.7 and Figure 2.4 through 2.7). This result is consistent with those obtained by Lucas and Araman (1975), Hall et al. (1980) and Brunner et al. (1989) in cutting standard grade lumber into dimension parts. The consistency in the results of the influence of cutting sequence on dimension yield and cutting length implies that, in choosing cutting sequence, cutting flitches is similar to cutting standard grade lumber. Some rules used in selecting cutting sequence for cutting standard grade lumber into dimension parts can be used in cutting flitches into dimension parts too.

A strong linear relationship was detected between the scaling yield and the average cutting length within each combination of the two sawing patterns and two cutting sequences (Figure 2.8 through Figure 2.11). This relationship can be used to predict the yield change when cutting bill is changed (including the change of cutting lengths and the required percentage of each individual length). However, it should be pointed out that because the average cutting length does not reflect the detailed information of a cutting bill, the linear regression between the scaling yield and average cutting length is only a rough estimation of the relationship between yield and cutting bill.

When the logs are cut to fulfill a given order of dimension parts, the adjusted yields are more comparable than the unadjusted yields. After the scaling yields were adjusted to average cutting length, some of the conclusions derived from the unadjusted scaling yield data are no longer true (Table 2.8 and Table 2.9), for example: (1) the adjusted scaling yields from Live-sawing and Five-part-sawing are not significant for cutting bills #1 and #4 under Crosscut-first, and (2) Rip-first results in significantly higher yield than Crosscut-first for cutting bills #1, #3 and #4 under Live-sawing. These changes can be attributed to the following two reasons: (1) Five-part-sawing and Rip-first produce more longer cuttings than Live-sawing and Crosscut-first, and (2) there is a negative linear relationship between the scaling yield and the average cutting length.

## **6.2 The Effects of Sawing Pattern and Cutting Sequence on Dollar Value Recovery**

In this study, dollar value recovery was estimated under two different part-valuation scenarios. One assumed that all part lengths have equal value, and the other assumed that longer parts have more value and the weighting factor for part length is 1.3.

When all part lengths have equal value, the results (Table 2.11) indicate that Live-sawing recovers more dollar value from per board foot log input than Five-part-sawing, and the dollar value recovery from Rip-first and Crosscut-first shows no significant difference.

When the longer parts have more value than shorter parts with a weighting factor of 1.3, the effects of sawing pattern and cutting sequence on the dollar value recovery

are quite complex (see Table 2.13 and 2.14). Live-sawing has significantly higher dollar value recovery than Five-part-sawing in most cases, except for cutting bills #1 (whole range of cutting length) and #4 (medium to long cuttings) under Crosscut-first in which no significant difference in dollar value recovery between Live-sawing and Five-part-sawing exists. Although in most cases Live-sawing results in more dollar value recovery than Five-part-sawing, Five-part-sawing produces more flat-grain while Live-sawing produced more edge-grain cuttings.

When the longer parts have more value than shorter parts with a weighting factor of 1.3, the effects of cutting sequence on dollar value recovery depend on the cutting bill and the sawing pattern used. For cutting bills #1 and #4 which contain cuttings longer than 45", Rip-first recovers significantly higher dollar value than Crosscut-first under both Live-sawing and Five-part-sawing. However, for cutting bill #2, the one contains no cuttings longer than 33", the dollar value recovery from the two cutting sequences has no significant difference under both Live-sawing and Five-part-sawing. For cutting bill #3, Rip-first results in more dollar value recovery than Crosscut-first under Live-sawing, but no significant dollar value difference under Five-part-sawing. These results indicate that in terms of dollar value recovery the choice of cutting sequence is more important under Live-sawing than under Five-part-sawing and is more important for cutting long parts than for cutting short parts.

### **6.3 The Limitations of This Study**

The yield data obtained in this study should be used with caution. First, the yield data in this study were obtained under "optimal" cutting (cutting flitches into dimension parts). In real mill operation, the actual yields may be less than the "optimal" yield.

Second, the yield data obtained in this study are the yields of dimension parts in green status. After drying, the yields of dry dimension parts could be substantially lower than the green yields due to shrinkage and drying degradation (volume loss in after-drying recutting).

In this study the dollar value data of dimension parts and cants were estimated under certain assumptions. First, the dollar value estimated in this study was realized under "optimal cutting". The actual dollar value could be lower than these numbers. Second, the average price (the price for 33" long parts) of 4/4" red oak, clear-two-face dimension parts was assumed to be \$2,200 per thousand board feet and the price for the 4 by 4 cants was assumed to be \$190 per thousand board feet. These assumed prices are close to current market prices, however, the market prices change over time and estimated dollar value recovery will change as the prices for red oak dimension parts and cants change. Third, it was assumed that the degradation of drying 4/4 red oak dimension parts is 15 percent. In real mills, it can be higher or lower, depending on the practice of a particular mill. Finally, as mentioned early, the dollar values were estimated under two different part-valuation assumptions.

The dollar value recovery only indicates how much value was added to the input raw material. It is not the index of profit. If the increase in dollar value recovery is achieved through intensive machining activities that results in high machining and labor costs, the increase in dollar value recovery may be offset by the increasing machining and labor costs. Therefore, further studies to develop the mill designs for the various processing options discussed in this section and to estimate their operational and economic performance are necessary. These studies will be discussed in the next two sections, Section 3 and Section 4.

The objectives of this section were (1) to estimate the cutting yields of dimension parts and dollar value recovery from No.3 red oak logs for the various sawing patterns and cutting sequences, (2) to obtain cutting details of converting No.3 grade red oak logs in to rough dimension parts, and (3) to test the effects of sawing pattern and cutting sequence on the cutting yield and dollar value recovery.

The cutting yields of green dimension parts were obtained by sawing logs into flitches actually and "cutting" flitches into parts using a computer simulation program CORY. Two sawing patterns (Live-sawing and Five-part-sawing) and two cutting sequences (Rip-first and Crosscut-first) with four cutting bills were tested for their effects on the dimension yield, cutting length and dollar value recovery.

Depending on the cutting bill used, the average scaling yield of green dimension parts ranges from 62.2 to 74.2 percent for the processing option of Live-sawing followed by Rip-first, from 57.7 to 75 percent for the processing option of Live-sawing followed by Crosscut-first, from 53.8 to 62.8 percent for the processing option of Five-part-sawing followed by Rip-first, and from 53 to 65.4 percent for the processing option of Five-part-sawing followed by Crosscut-first. The yield data obtained from this section will be used in estimating the potential revenue of a direct processing system in the final section of this dissertation. The cutting details of cutting flitches into rough dimension parts obtained in this section will be used as inputs to the system simulation models in Section 3 of this dissertation.

If the same cutting length priority was used, Live-sawing resulted in significantly higher dimension yield than Five-part-sawing. Rip-first and Crosscut-first had no significant difference in dimension yields, however, Rip-first produced more longer cuttings than Crosscut-first. If followed by Crosscut-first, Five-part-sawing produced

more longer cuttings than Live-sawing. However, if followed by Rip-first, the effects of sawing pattern on the cutting length depended on the cutting bill used.

If different cutting length priorities were used to force the different combinations of the sawing patterns and cutting sequences to have similar average cutting lengths, the combination of Live-sawing and Rip-first gave significantly higher dimension yield than the combination of Five-part-sawing and Rip-first. However, if followed by Crosscut-first, the effect of the sawing pattern on the dimension yield depended on the cutting bill used. It was significant for two of the four cutting bills tested, but not for the other two. Rip-first resulted in notably higher dimension yield than Crosscut-first under Live-sawing for three of the four cutting bills used, except for the cutting bill that contains only cuttings no longer than 33". Under Five-part-sawing, no significant difference in dimension yield was detected between Rip-first and Crosscut-first.

If all part lengths have equal value, the results showed that Live-sawing recovered more dollar value than Five-part-sawing and cutting sequence had no significant effect on the dollar value recovery, independent of cutting bills.

If longer parts have more value, Live-sawing resulted more dollar value recovery than Five-part-sawing under Rip-first. However, the effect of sawing pattern on the dollar value recovery under Crosscut-first depended on the cutting bill. The difference in value recovery between Live-sawing and Five-part-sawing was not significant for the two cutting bills containing no parts longer than 45 inches (Cutting bill #2 and #3). The influence of cutting sequence on the dollar value recovery depended on the previous log sawing pattern and the cutting bill. Under Live-sawing, Rip-first produced significantly higher dollar value recovery than Crosscut-first for three of the four cutting bills, except for the cutting bill containing only short parts (Cutting bill #2). Under Five-part-sawing, Rip-first produced higher dollar value recovery than Crosscut-first only



for the two cutting bills containing cuttings longer than 45 inches (Cutting bill #1 and #4). These results suggested that in terms of dollar value recovery, the choice of cutting sequence is more important under Live-sawing than under Five-part-Sawing and is more important for cutting longer parts than for cutting short parts.

A strong negative linear relationship was detected between the cutting yield and the average cutting length within each combination of the sawing patterns and cutting sequences. This relationship can be used to roughly predict the change in dimension yield when cutting bill is changed.

This section only deals with the yield and value recovery issues with which value added can be determined. However, this section did not address issues such as the designs of the mills for the various sawing patterns and cutting sequences and the economic performance of these designs. These issues will be addressed in the next two sections.

- Araman, P.A., C.J. Gatchell, and H.W. Reynolds. 1982. Meeting the solid wood needs of the furniture and cabinet industries: Standard-size hardwood blanks. USDA Forest Service Research Paper NE-494, Northeastern Experiment Station, Broomall, PA, 27 pp.
- Brunner, C. C., M.S. White, F.M. Lamb, and J.G. Schroeder. 1989. CORY: A computer program for determining dimension stock yields. *Forest Products Journal* 39(2):23-24.
- Dunmire, D. E., E. F. Landt, R. E. Bodkin. 1972. Logging residue is a source of valuable black walnut dimension. *Forest Products Journal* 22(1):14-17.
- Gatchell, C. J. 1987. Impact of rough mill practices on yields. In White, J. L., ed. *Eastern hardwoods: the resource, the industry, and the market: Proceedings of the symposium, 1985 September 9-11, Harrisburg, PA.* Forest Products Research Society, 146-156.
- Hall, S. P., E. M. Wengert, R. A. Wysk and M. H. Agee. 1980. Yield distributions and cost comparisons of a crosscut-first and a gang-rip-first rough mill producing hardwood dimension stair parts. *Forest Products Journal* 30(5):34-39.
- Hanks, L.F., G.L. Gammon, R.L. Brisbin, and E.D. Rast. 1980. Hardwood log grades and lumber grade yields for factory lumber logs. USDA Forest Service Research Paper NE-468, Northeastern Experiment Station, Broomall, PA.
- Hoff, K. G., E. L. Adams, and E. S. Walker. 1991a. GR-1ST: PC Program for evaluating gang-rip-first board cut-up procedures. USDA Forest Service, Northeastern Experiment Station, General Technical Report NE-150, Radnor, PA, 16 pp.
- \_\_\_\_\_. 1991b. GR-1ST User's Guide. USDA Forest Service, Northeastern Experiment Station, General Technical Report NE-156, Radnor, PA, 14 pp.
- \_\_\_\_\_. 1992. Computer optimization of hardwood parts yield using gang-rip-first procedures. *Forest Products Journal* 42(3):57-59.
- Lucas, E.L. and P.A. Araman. 1975. Manufacturing interior furniture parts: a new look at an old problem. USDA Forest Service, Northeastern Experimental Station, Research Paper NE-334, Princeton, WV.
- Neilson, R. W., D. W. Bousquet, and S. M. Pnevmaticos. 1970. Sawing pattern effect on the yield of furniture components from high quality hard maple logs. *Forest Products Journal* 20(9):92-98.

Pnevmaticos, S. M. and D. W. Bousquist. 1972. Sawing pattern effect on the yield of lumber and furniture components from medium and low grade hard maple logs. *Forest Products Journal* 22(3):34-41.

Rast, E.D., D.L. Sonderman, and G.L. Gammon. 1973. A guide to hardwood log grading. USDA Forest Service General Technical Report NE-1, Northeastern Experiment Station, Broomall, PA, 31 pp.

Robichaud, Y, F. J. Petro, and M. C. Kingsley. 1974. Aspen lumber and dimension stock recovery in relation to sawing pattern. *Forest Products Journal* 24(3): 26-30.

Rosen, H. N., H. A. Stewart, and D. J. Polak. 1980. Dimension yields from short logs of low-quality hardwood trees. USDA Forest Service, Forest Products Lab., Research Paper FPL-184, Madison, WI, 21 pp.

SAS. 1988. SAS/STAT User's Guide. Release 6.3 Edition. SAS Institute Inc., 1028 pp.

Weston, J.F and T.E.Copeland. 1986. *Managerial Finance*. 5th Edition. The Dryden Press, Chicago, New York, 1035 pp.

Wiedenbeck, J. K. 1992. The potential for short length lumber in the furniture and cabinet industries. Ph.D Dissertation, Virginia Polytechnic Institute and State University, 260 pp.

Yun, L.Y. 1989. The margin for yield improvement for No.1 Common 5/4 red oak in a conventional rough mill. Master's thesis, Virginia Polytechnic Institute and State University, 87 pp.

## Section 3

### **DIRECT PROCESSING SYSTEM: SYSTEM DESIGN, SIMULATION, AND EVALUATION**

#### **1. ABSTRACT**

The objectives of this section were: (1) to develop the mill designs of the direct processing system for the various sawing patterns and cutting sequences, (2) to develop the computer simulation/animation models for the various mill designs, and (3) to investigate the dynamic performance of the designed mills and predict their production by using computer system simulation/animation techniques. Six initial mill designs were developed to carry out different sawing patterns and cutting sequences. System simulation models of these designs were developed using SIMAN IV. Animation models were also built using CINEMA for each mill design in conjunction with simulation model development to assist simulation model development, model verification and validation.

The dynamic performance of the direct processing systems was investigated. Based on simulation results, bottlenecks in the initial designs were identified and production lines were balanced. Three of the six initial designs were modified to balance production capacity. Before and after these three designs were modified, multiple comparisons of production rate and labor productivity between the six mill designs were conducted. Comparisons between the modified designs and initial designs were also carried out.

The production rates of the designed mills were estimated through simulation. Based on simulation results of the six final models, the direct processing system with one headrig saw can process from 17.8 to 20.5 MBF No.3 grade red oak logs and turn out 11 to 14.3 MBF Clear-two-face, 4/4 random width green dimension parts per shift. The production rate varies among the different mill designs.

The implementation of directly processing dimension parts from logs require a manufacturing system that can carry out the operations of converting logs into dimension parts. Since various sawing patterns and cutting sequences are can be used in the conversion of logs into dimension parts and different sawing patterns and cutting sequences require different mill layouts, there are many choices of the mill layouts for the direct processing system that converts logs into rough dimension parts.

In Section 2, the yields of dimension parts and dollar value recovery from No.3 red oak logs were estimated and compared for the various sawing patterns and cutting sequences. The yields of dimension parts and dollar value recovery provide important information for estimating the economic performance of the direct processing system. To predict the economic performance of the direct processing system under the different mill layouts, information on initial capital requirement, operating costs, and production rate are needed. The initial capital requirement, operating costs, and production rate are directly related to the design of the direct processing system. Therefore, it is necessary to develop and analyze the various mill designs in order to choose the design that yields the best economic performance. To achieve a better operational and economic performance, bottlenecks in the designed mills need to be identified and removed before they become real manufacturing systems.

Since real systems that processes hardwood logs directly into dimension parts are not available for direct experimentation, system simulation modeling appears to be a suitable tool for analyzing the various design alternatives of the direct processing system. System simulation modeling provides a means of indirect experimentation with a system that can not be directly experimented. System simulation modeling is a unique approach to capture the dynamic behavior of a system. As Kline et al. (1992) pointed

out, *"system simulation modeling links individual components of a processing system together so that the effect of a change in one element on the other elements and on the whole system can be assessed"*. Building a real mill can be very expensive and time consuming. With system simulation modeling, alternative designs can be thoroughly studied and bottlenecks in the systems can be identified and removed before their costly introduction into a real manufacturing system (Kline et al., 1992). Furthermore, many occurrences in a mill system such as machine's processing rate and operator's working speed are stochastic in nature. To estimate the operational performance of a mill system accurately, the stochastic nature of the system needs to be considered. Computer system simulation is a such tool that is capable of taking into consideration the stochastic nature of the system.

System simulation modeling has been used in sawmill design, modification and evaluation. A southern pine sawmill model (SPSM) was developed by Wagner and Taylor (1983) using a combined network and discrete-event model programmed in SLAM. In SPSM the SLAM network simulated log breakdown and the discrete-event simulation modeling described the systems involved in the processing of logs into lumber. Another sawmill simulation model, the design simulator (DESIM), was developed by Adams (1984a, 1984b, 1985) for designing and evaluating hardwood sawmills. It was programmed in GASP IV FORTRAN-based simulation language and capable of describing accurately the operating performance of various setups. According to a report (Adams 1988), DESIM could be used to realistically simulate the operations of relatively complex hardwood sawmills. However, the requirement for a large computer (a mainframe computer or a minicomputer) limited the flexibility of the application of DESIM. Meimban et al. (1992) integrated an economic performance measure into a processing simulation model for a chipper-canter sawmill. According to

Meimban et al., *"this integrated approach is capable of capturing the operational and cost behavior of the system over time by taking into consideration the effects of the stochastic occurrence of machine breakdowns and other processing delays"*.

The system simulation modeling techniques have also been used in designing and evaluating rough mills. Araman (1977) used system simulation in designing and evaluating a proposed rough mill for furniture interior parts and found that system simulation was very successful in identifying and removing production problems and bottlenecks before a mill is actually built. Anderson (1983) used systems simulation for evaluating the production costs of a Crosscut-first rough mill. Kline et al. (1992) developed a simulation/animation model for a Crosscut-first rough mill using object-oriented simulation techniques. This model was used to demonstrate the application and utility of the simulation/animation method applied to wood products manufacturing system. In a recent study, Wiedenbeck (1992) developed discrete-event systems simulation models for both a Crosscut-first and Rip-first rough mill. These models were used to evaluate the effect of lumber length on equipment utilization and on the volume and value of rough parts produced.

All of these system simulation models have either simulated the operations within a sawmill (from logs to lumber) or the operations within a rough mill (from lumber to furniture parts). No model that simulates an integrated system of a sawmill and a rough mill has been developed. Since the direct processing system is composed of both the operations of a sawmill and the operations of a rough mill, for studying the operational performance of such a system, the system simulation model needs to integrate both the operations of a sawmill and of a rough mill. System simulation models will be developed in this section to predict the dynamic operational response of the "whole direct processing system". These models will provide a detailed understanding of how

changes in cutting practices, machine resources, and labor resources affect the dynamic performance of the system. The distributions of cutting details and yield estimated from section 2 will provide important operational input into the models. Additional inputs including machine center information, conveyor and transporter information, and workers' working speed will also be required in this section.

### **3. OBJECTIVES**

The objectives of this section were: (1) to develop the various mill designs of the direct processing system for the various sawing patterns and cutting sequences discussed in section 2, (2) to develop computer simulation/animation models for the various mill designs, and (3) to investigate the dynamic performance of designed mills and predict their production rate by using computer simulation/animation tools.

### **4. METHODOLOGY**

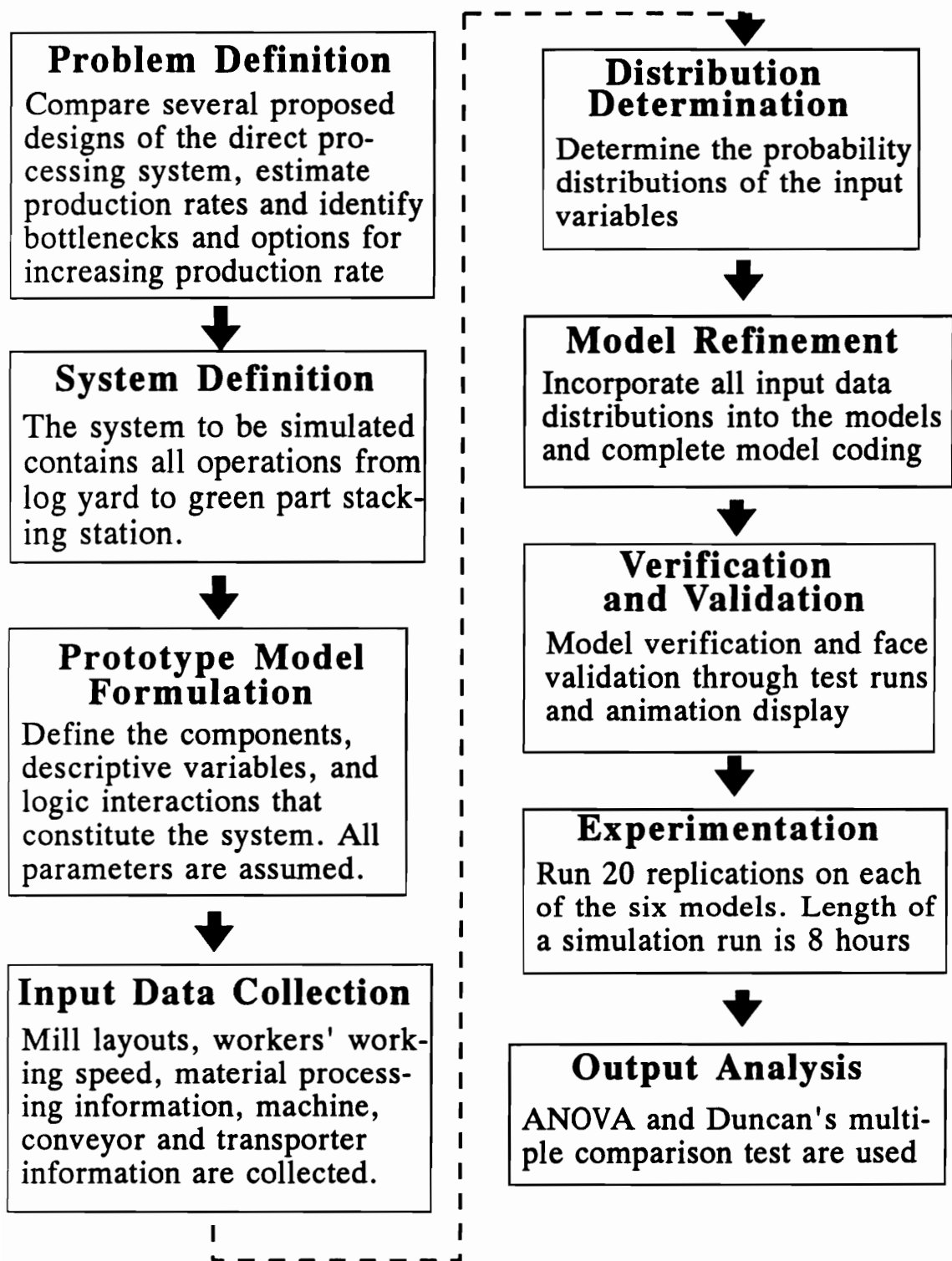
The direct processing system that converts hardwood logs directly into rough dimension parts is more complex than the system that cuts standard grade lumber into dimension parts. More machining activities and workers are involved in the direct processing system than in a rough mill. In designing a physical layout of the direct processing system, we need to determine the number and type of equipment to be included in the system to meet a production goal. For a proposed design of the system, we need to predict the operational performance of the system, such as production rate



and productivity, and to identify the location of the bottlenecks that restrict material flow through the system and the options for increasing production rate and productivity.

With the present high costs of construction and equipment, even minor modifications are costly. Systems simulation gives us the ability to experiment on the models rather than the real-world systems, thereby allowing us to have a thorough look at the operations of different designs of the system before actual installation. Simulation predicts the behavior of a manufacturing system by calculating the movement and interaction of system components. Physical layouts, equipment selection and operating procedures are evaluated by evaluating the flow of material through the machines and work stations and by examining the conflicting demands for limited resources.

Systems simulation is a powerful tool for designing and analyzing the different layouts of the direct processing system. SIMAN (Pegden et al. 1990), a FORTRAN-based simulation language, was chosen to develop the simulation models. It is capable of interfacing with user-written subroutines programmed in FORTRAN or C language. SIMAN contains a number of built-in features that make it particularly useful for modeling manufacturing and material handling systems. It provides the means of animating the simulated processes through CINEMA (SMC 1990). The animation feature can be used as a tool for model verification and validation, providing insights into dynamic interactions within the model, and presenting the model results (Pegden et al., 1990). Another important feature in SIMAN/CINEMA is its compatibility of mainframe, minicomputer, and microcomputer versions to permit movement between computer systems without modification (Pegden et al., 1990). A flowchart of simulation model development procedures is given in Figure 3.1.



**Figure 3.1 Simulation Model Development Procedures**  
(modified from Wiedenbeck, 1992)

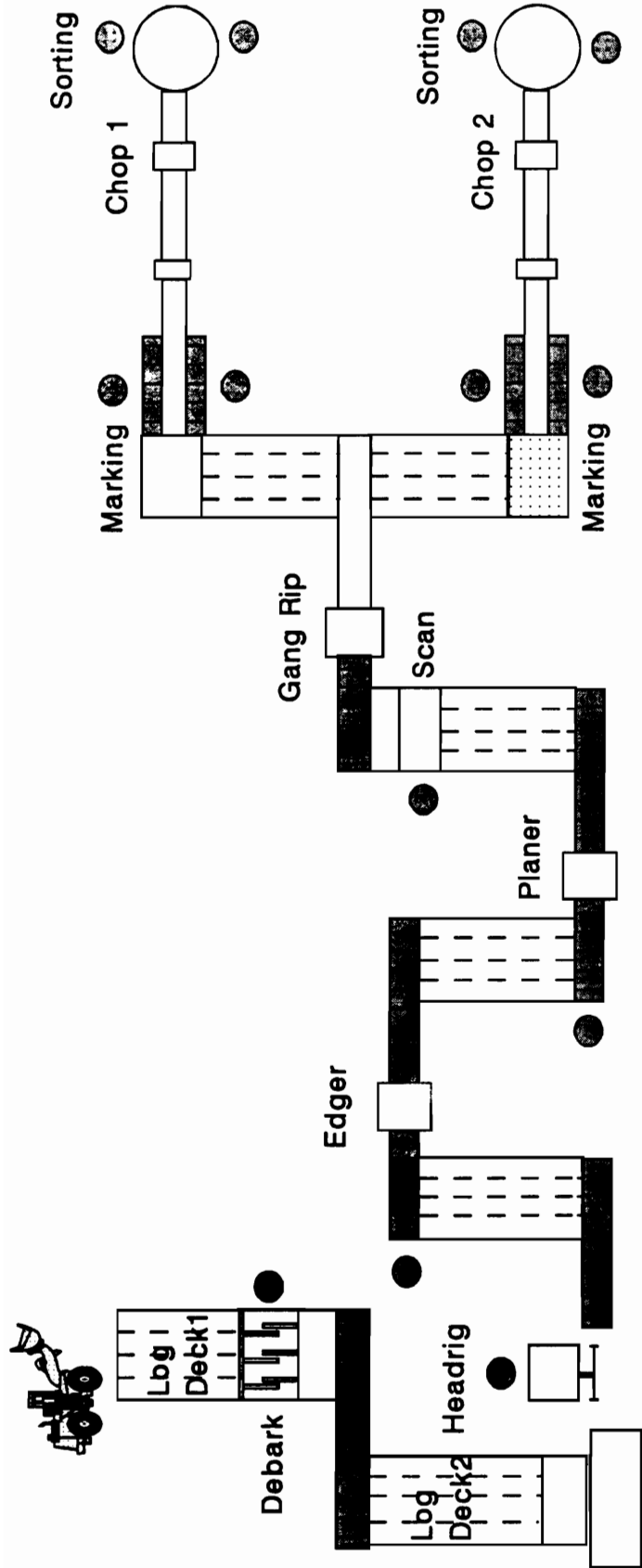
## 4.1 System Definition

The system to be simulated is the manufacturing system that converts hardwood logs directly into rough dimension parts. Because of the uncertainty in drying red oak dimension parts and the limitation of input data, only operations between log yard and green part stacking station, or the operations of green part manufacturing, were simulated. There are many designs that can be used to convert hardwood logs into rough dimension parts, To bring an end of the design work, this study only considers the designs that have one circular headrig saw. Six initial layout designs were created based on the information gathered from one sawmill, two rough mills and an automatic chop line in a mill-work plant. The six initial layout designs are shown in Figure 3.2 through Figure 3.7. These layouts were designed to use different sawing patterns and cutting sequences as well as different types of machines. The features of these designs are summarized in Table 3.1.

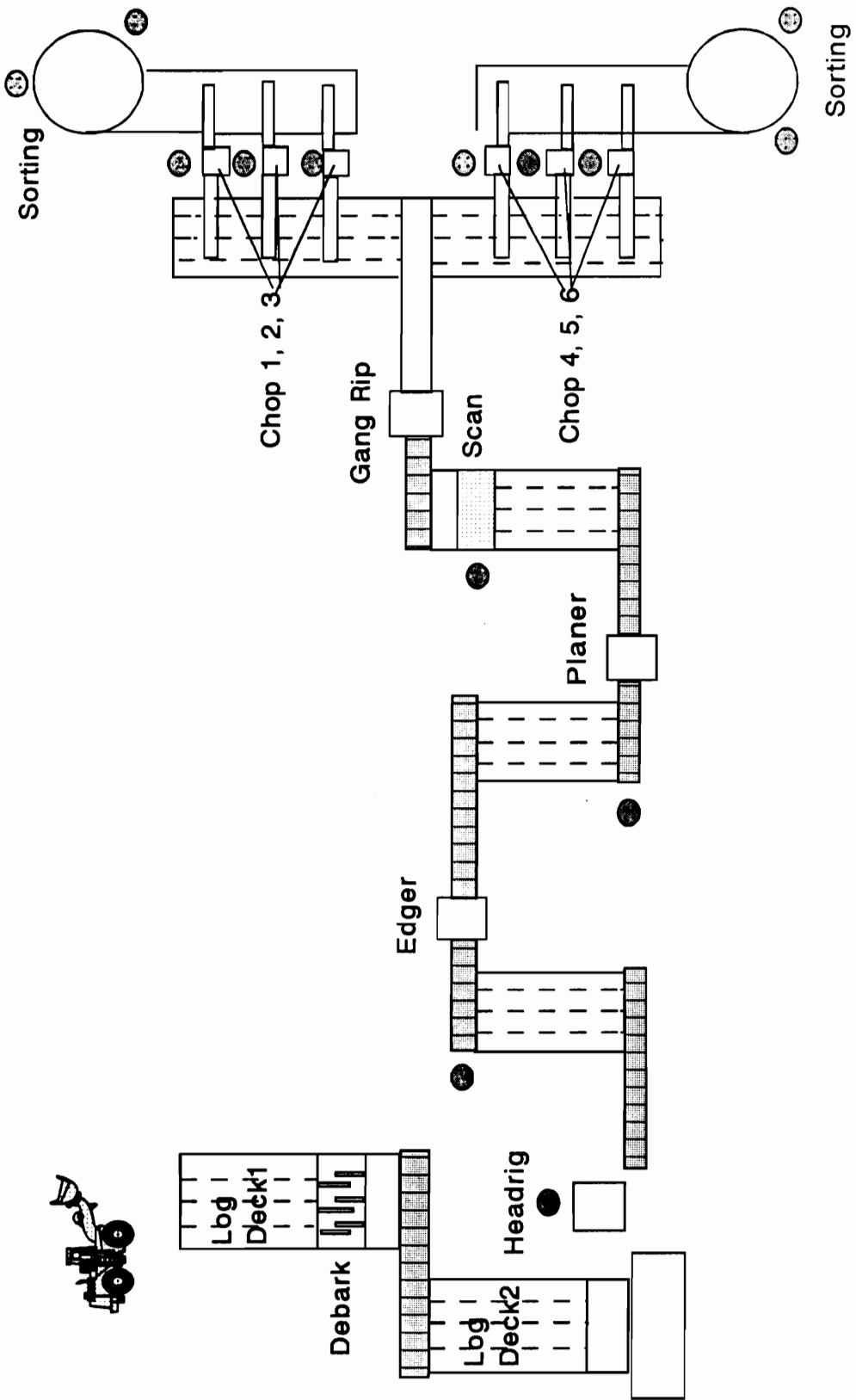
Designs 1 and 2 incorporate Live-sawing followed by Rip-first. In Design 1 one headrig saw is followed by one gang-rip saw and two automatic chop saws. And in Design 2 the headrig saw is followed by one gang-rip saw and six manual chop saws. Design 3 incorporate Live-sawing followed by Crosscut-first. In Design 3 one headrig saw is followed by three crosscut saws and five single line rip saws. Designs 4 and 5 incorporate Five-part-sawing followed by Rip-first. In Design 4 one headrig saw is followed by one gang resaw, one gang-rip saw and two automatic chop saws. The two automatic chop saws in Design 4 were replaced by six manual chop saws in Design 5. Design 6 incorporate Five-part-sawing followed by crosscut-first. In Design 6 one headrig saw is followed by one gang resaw, three crosscut saws and five single line rip saws.

**Table 3.1 Summary of the six initial mill designs**

| Design # | Sawing pattern   | Cutting sequence | Type of chop saws    |
|----------|------------------|------------------|----------------------|
| Design 1 | Live-sawing      | Gang-rip-first   | Automatic chop saws  |
| Design 2 | Live-sawing      | Gang-rip-first   | Manual chop saws     |
| Design 3 | Live-sawing      | Crosscut-first   | -----                |
| Design 4 | Five-part-sawing | Gang-rip-first   | Automatic chop saws. |
| Design 5 | Five-part-sawing | Gang-rip-first   | Manual chop saws     |
| Design 6 | Five-part-sawing | Crosscut-first   | -----                |



**Figure 3.2 Layout of mill design 1**



**Figure 3.3 layout of mill design 2**

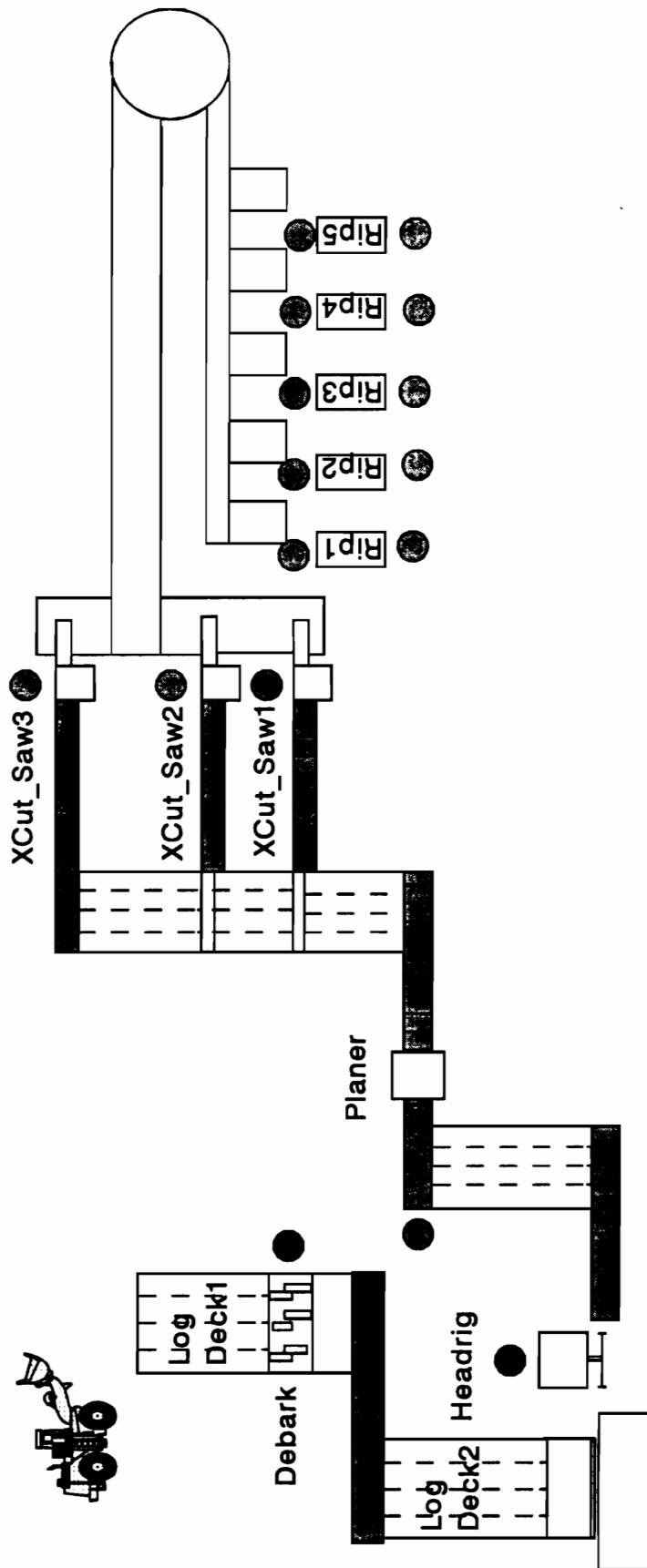


Figure 3.4 Layout of mill design 3

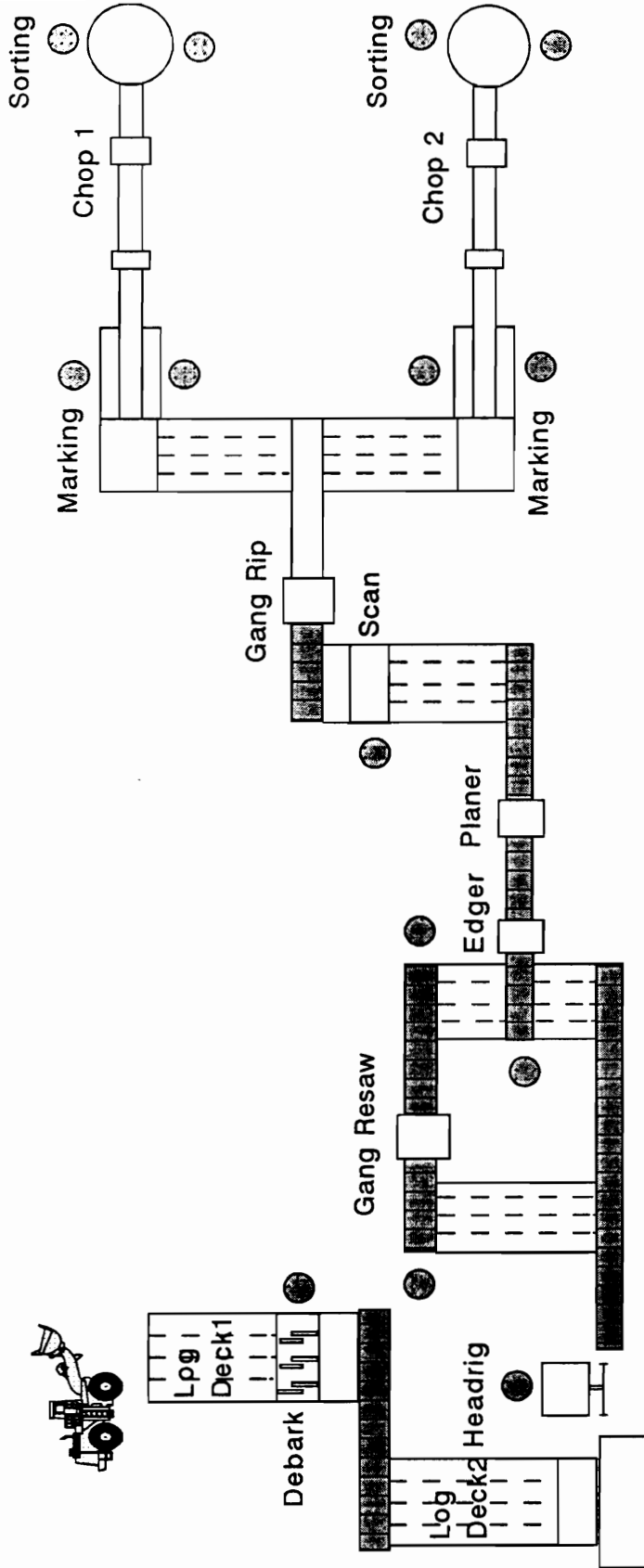
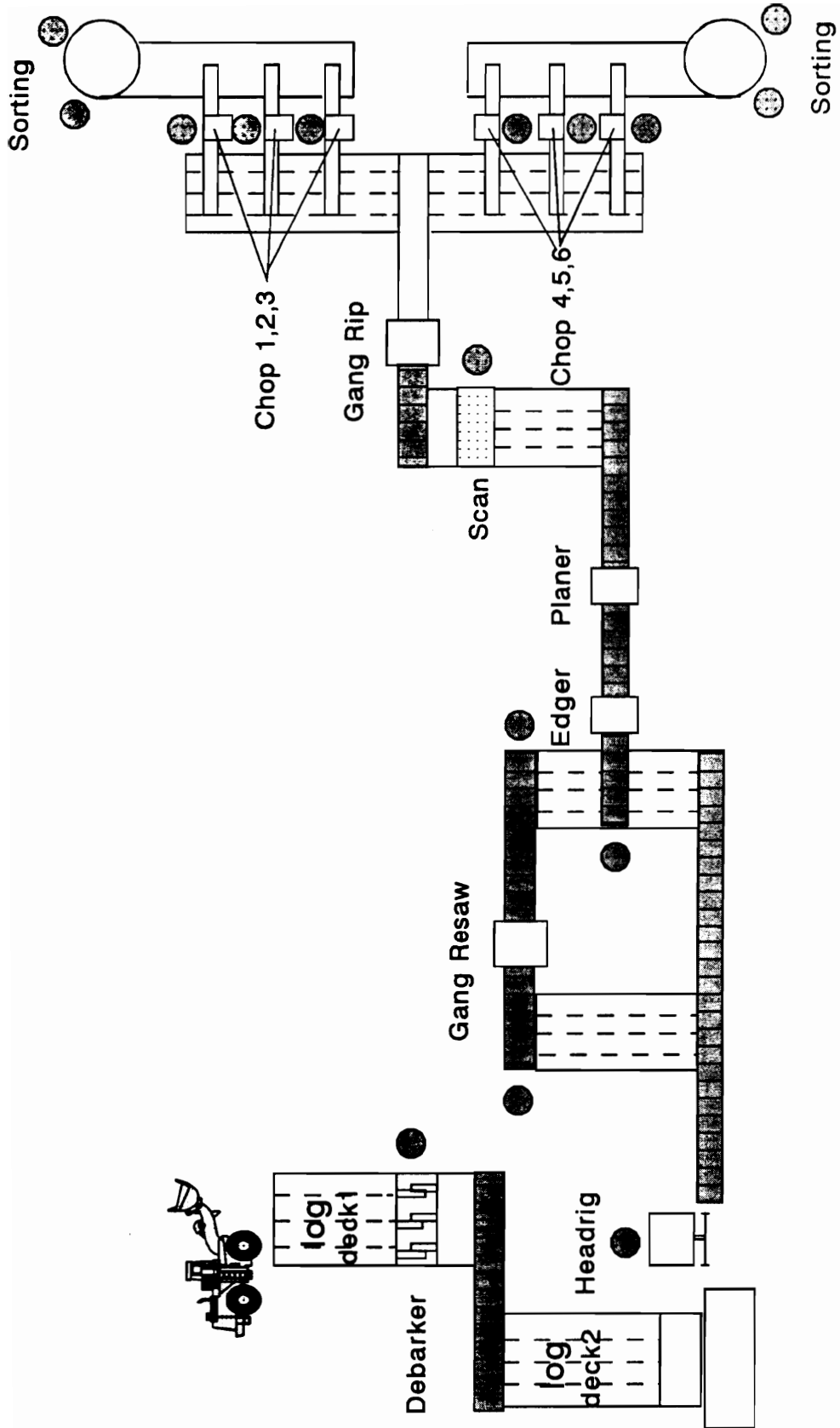


Figure 3.5 Layout of mill design 4





**Figure 3.6** Layout of mill design 5

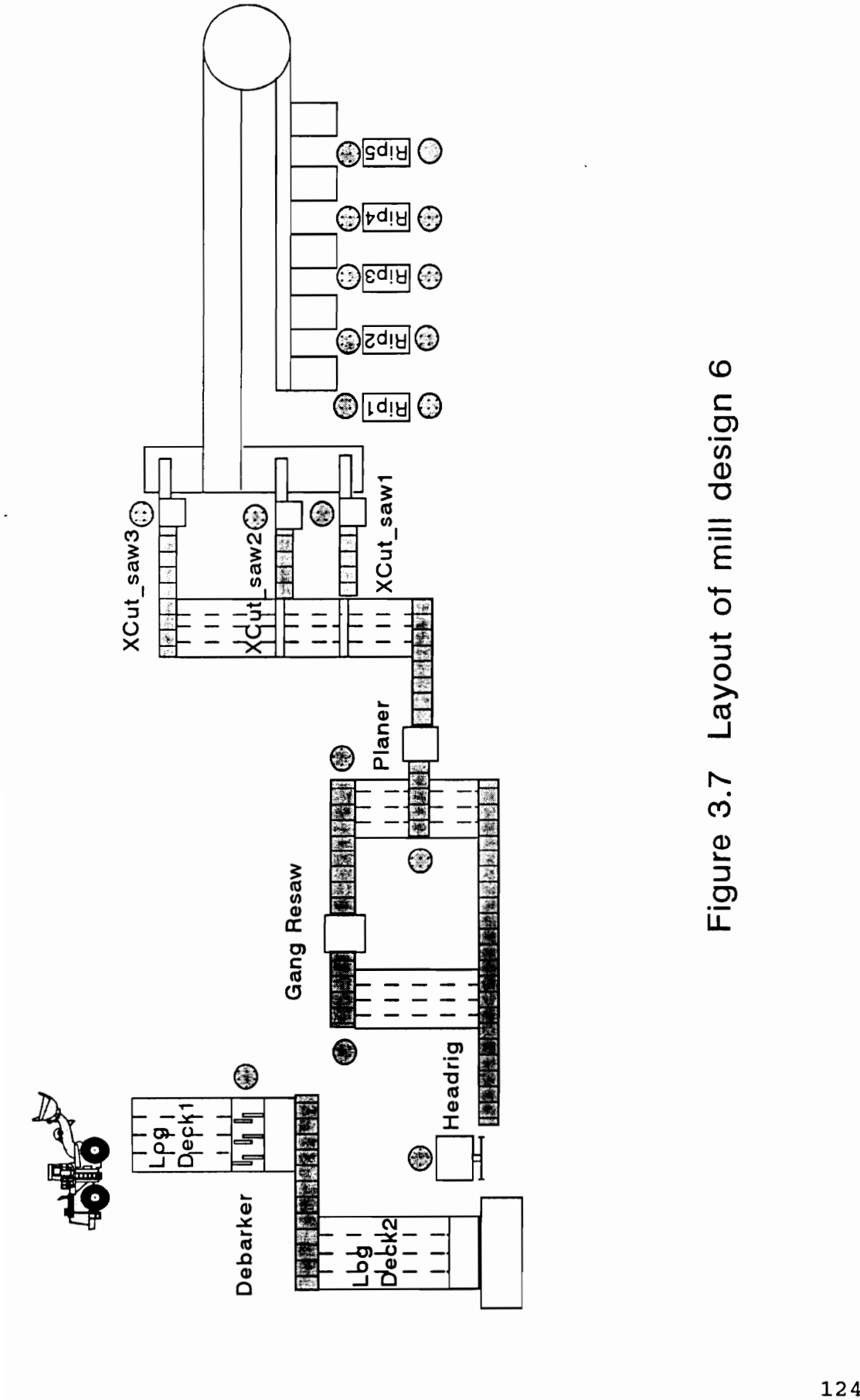


Figure 3.7 Layout of mill design 6

## 4.2 Input Data Collection

The data required as the input into the simulation models include: (1) material processing information (the number of operations in each step of processing a log into rough dimension parts), (2) machine center information (machine loading and unloading rate, machine processing rate and machine down time), (3) worker information (workers' feeding and handling speed), and (4) conveyor and transporter information (capacity and moving speed).

The first category of data was obtained from the detailed CORY output which provides complete information on the number of sawlines and the location of each sawline for each individual board. For Rip-first cutting, the number of ripped strips from each flitch and the number of choppings for each strips were recorded. For Crosscut-first cutting, the number of crosscuts for each flitch and the number of rippings for each crosscut piece were recorded. The other three categories of data were collected through in-mill timing studies. One sawmill, two rough mills (one rip-first and the other crosscut-first) and one automatic chop line in a mill-work plant were selected for in-mill timing study. Data for log fork, debarker, carriage, headrig saw, gang resaw, edging saw, and associated operators with these machines were obtained from the sawmill. Data for crosscut-saws, single line rips saws and associated operators were obtained from the Crosscut-first rough mill. Data for gang rip saw, rip saw laser scan, manual chop saws and associated operators were obtained from the Rip-first rough mill. Data for automatic chop saws and defect marking were collected from the automatic chop line in a mill-work plant. The defect marking speed could be slower for more defective material than for less defective material. The data for crosscut saws, manual chop saws, and single line rip saws operators were gathered on multiple

machines/operators. All data were collected when the studied mills processed red oak logs (in the sawmill) or 4/4 red oak lumber (in the rough mills).

Since the size and defect distributions of the flitches generated by Five-part-sawing are different from those generated by Live-sawing, the processing requirements and processing time for some operations, for example the number of strips ripped and the number Xcut-pieces cut off from each flitch, are different for different types of flitches. Some of the Five-part-sawing flitches are sawn by the gang resaw instead of directly coming out from the headrig saw. Those flitches coming out of the gang resaw are narrow (4" wide), rectangular pieces for which the processing time on the rip saw laser scan and crosscut saw stations can be much less than that for other flitches. Observations of processing some narrow boards (less than 6" wide) on rip saw laser scan and crosscut saws were recorded and used as the processing and handling time of the narrow flitches coming out of gang resaw. For convenience of description, all Live-sawing flitches are classified as Type 1 flitches. Those Five-part-sawing flitches that directly come out of the headrig saw are classified as Type 2 flitches. And those Five-part-sawing flitches that come out of gang resaw are classified as Type 3 flitches.

The timing data taken from the mills studies have several limitations: (1) for some of the operations only one machine or operator was timed, (2) the number of observations recorded for each operation was limited, and (3) the two rough mills were processing dry lumber rather than green unedged flitches. To take account of the difference between processing green flitches and processing dry lumber, a conservative assumption was made. It was assumed that 20 percent more time is needed for handling a piece of green unedged flitch than a piece of dry rectangular lumber on rip saw laser scan (rip-first) and crosscut saw (crosscut-first) stations.

### 4.3 Distribution Determination

Since the majority of the input data were random variables, the probability distributions of these input variables had to be specified. During simulation process, the values of input random variables will be taken from the appropriate distribution. Following the procedures described by Law and Kelton (1991), the probability distributions of the input variables were fitted and tested for goodness-of-fit. First, a family of distributions was selected based on the point statistics Standard Deviation/Mean, data histograms (line graphs for discrete variables) and probability plots. Then the parameters of each distribution were estimated by using the Maximum-likelihood method. Finally Chi-square tests were used to determine whether the fitted distribution was in agreement with observed data. The acceptable  $\alpha$  level was 0.1. For some variables, two or three families of distributions were tested to obtain an acceptably good fit. For those variables that had insufficient observations such as the laser scan rate and crosscut rate of the narrow boards coming out of the gang resaw, triangular distributions were used. The minimum and maximum points (parameter a and b) for a triangular distribution were chosen from the observations, and the shape parameter (parameter c) was determined through the equation  $(a+b+c)/3 = \text{mean}$ . For those discrete variables without an appropriate distribution fit, such as the number of operations in each of the processing steps, discrete distributions were empirically defined using original data. Some distributions such as Weibull and Lognormal distributions can generate any real number larger than 0, and other distributions such as Normal distribution can generate any real number. However, it is impossible for the actual data to be  $+\infty$  or  $-\infty$ . Hence, all Weibull, Normal and Lognormal distributions were truncated. The truncating points were determined based on the observed data that

were used for fitting these distributions. The distributions used in the final simulation models are listed in Table 3.2. These distributions are defined as follows:

(1) **Weibull**( $\alpha$ ,  $\beta$ ,  $\tau$ )

Where,  $\alpha$  = shape parameter ( $\alpha > 0$ ),  $\beta$  = scale parameter ( $\beta > 0$ )

$\tau$  = location parameter

(2) **Normal**( $\mu$ ,  $\sigma^2$ )

Where,  $\mu$  = mean,  $\sigma$  = standard deviation

(3) **Lognormal**( $\mu$ ,  $\sigma^2$ )

Where,  $\mu$  = lognormal mean,  $\sigma$  = lognormal standard deviation

(4) **Triangular**(a, b, c)

Where, a = minimum, b = maximum, c = mode or shape parameter

(5) **Discrete**( $p_1, v_1, p_2, v_2, p_3, v_3, \dots$ )

Where,  $v_i$  = associated cumulative probabilities,  $i = 1, 2, \dots$

$p_i$  = values of the random variable,  $i = 1, 2, \dots$

#### 4.4 Model Programming

Six prototype simulation models were built based on the six initial layout designs before extensive input data collection was conducted. In the prototype models, components, descriptive variables, and logic interactions that constitute the system were defined. All parameters, however, were simply assumed. Extensive data would be collected in later stages of model development to more adequately represent the operations of the real system.

**Table 3.2 Listing of the more important distributions incorporated into the simulation models**

| Parameters  | Distribution  | Truncation            |
|---|---|-----------------------|
| Number of logs per load                                       | DISCRETE(0.23,3,0.52,4,0.74,5,0.87,6,0.94,7,0.98,8,1,9) |                       |
| Log fork loading time (sec./load)                             | WEIBULL(7.15, 1.55, 3)                                  | $X \leq 50$           |
| Log fork unloading time (sec./load)                           | WEIBULL(14, 1.4, 3)                                     | $X \leq 50$           |
| Debarker loading time (sec./log)                              | WEIBULL(1.33, 1.8, 1)                                   | $X \leq 4.5$          |
| Debarking time(sec./log)                                      | WEIBULL(12.4, 1.72, 6)                                  | $X \leq 45$           |
| Unloading debarked log (sec./log)                             | WEIBULL(2.1, 2.3, 1.5)                                  | $X \leq 6.5$          |
| Loading and positioning a log on carriage (sec./log)          | LOGNORMAL(3.5, 1.83)+1.5                                | $X \leq 10$           |
| Log turnig time(sec.)   | WEIBULL(1.78, 1.36, 1.4)                                | $X \leq 8$            |
| Gang Rip laser scan rate for Type 1 and 2 flitch(sec./flitch) | WEIBULL(1.95, 3.4, 2.5)                                 | $X \leq 10$           |
| Gang Rip saw networks Delay (sec.)                            | NORMAL(4.5, 0.3)  | $3.5 \leq X \leq 6$   |
| Defect marking rate(sec./strip)                               | NORMAL(5.75, 1.25)                                      | $3.2 \leq X \leq 9.5$ |
| Chop rate of automatic chop saws(sec./cut)                    | NORMAL(1.0, 0.16)                                       | $0.8 \leq X \leq 1.2$ |
| Chop rate of manual chop saws (sec./cut)                      | LOGNORMAL(1.88, 0.15)                                   | $1.2 \leq X \leq 3.4$ |
| Number of strips ripped from per Type 1 flitch                | DISCRETE(0.18, 2, 0.53,3,0.85, 4, 1, 5)                 |                       |
| Number of chops per strip ripped from Type 1 flitches         | DISCRETE(0.03,2,0.32,3,0.56,4,0.78,5,0.9,6,0.98,7,1,8)  |                       |

**Table 3.2 Listing of the more important distributions incorporated into the simulation models (continued)**

|  |  |           |
|--|--|-----------|
| Rip saw laser scan rate for Type 3 flitches (sec./flitch)    | TRIANGULAR(2.5, 4, 6)                            |           |
| Number of strips per Type 2 flitch                           | DISCRETE(0.1,1,0.26,2,0.67,3,0.96,4,1,5)         |           |
| Number of strips per Type 3 flitch                           | DISCRETE(0.6,1,0.95,2,1,3)                       |           |
| Number of chops per strip ripped from Type 2 and 3 flitches  | DISCRETE(0.07,2,0.28,3,0.55,4,0.78,5,0.94,6,1,7) |           |
| Time of picking up a piece of Type 1 and 2 flitch pre-XCut   | LOGNORMAL(2.88,1.73)+2                           | X ≤ 9     |
| Time of picking up a piece of Type 3 flitch pre-XCut         | TRIANGULAR(2,3.6,6)                              |           |
| Number of Xcuts per piece of Type 1 flitch                   | DISCRETE(0.14,3,0.43,4,0.73,5,0.9,6,1,7)         |           |
| Number of Xcuts per piece of Type 2 and Type 3 flitch        | DISCRETE(0.25,3,0.55,4,0.77,5,0.93,6,1,7)        |           |
| Xcut rate for Type 1 and Type 2 flitches (sec./cut)          | NORMAL(3.8,0.5)                                  | 2 ≤ X ≤ 7 |
| Xcut rate for Type 3 flitches (sec./cut)                     | TRIANGULAR(1.4,2.75,5)                           |           |
| Number of rip operations per Xcut piece from Type 1 flitches | DISCRETE(0.05,2,0.28,3,0.54,4,0.78,5,0.93,6,1,7) |           |
| Number of rip operations per Xcut piece from Type 2 flitches | DISCRETE(0.15,2,0.45,3,0.74,4,0.9,5,0.98,6,1,7)  |           |
| Number of rip operations per Xcut piece from Type 3 flitches | DISCRETE(0.14,0,0.44,1,0.88,2,1,3)               |           |
| Rip_feeding rate of Xcut pieces at Rip saws                  | WEIBULL(1.44,1.8,1,5)                            | X ≤ 6     |



A SIMAN simulation program consists of a model frame and an experiment frame. Appendix 1 shows the computer code of both model frame and experiment frame for one mill design. The model frame is a functional description of the system's components and their interactions. The experiment frame, on the other hand, defines the experimental conditions (run length, initial status, and resource capacity etc.). The prototype models were developed block by block following the sequence of operations through which entities (logs, flitches and parts etc.) move from one station to next station.

After all input data were collected and fitted in appropriate distributions, they were then incorporated into the prototype models. Some of the model components were changed in accordance with real operations observed in real mills. The capacities of various resources and buffer stations were determined at this stage.

After observing the operations in real mills, it was found that some machine operations were misrepresented in the prototype models. For example, for the automatic chop saw it was assumed in the prototype model that ripped strips can be continuously fed into the automatic chop saw as long as the infeed conveyor between the chop scan unit and saw unit has enough space. However, while observing the real operation of the automatic saw, it was found that no more than one strip could be conveyed on the infeed conveyor between the chop scan unit and saw unit; otherwise, it would jam and the automatic chop saw would stop working. During model development it was also found that some variables assumed in the prototype models were not adequate in representing actual activities. For example, the processing rates of the crosscut saws and chop saws were more appropriate to be collected in seconds per cut rather than seconds per piece of lumber, because the number of operations required for the lumber processed in the observed rough mills are different from those required

for the flitches cut from No.3 grade red oak logs. In these cases some re-timing work was carried out to collect more adequate data.

In the final models, it was assumed that there is a ten minute break every four hours and the change of saw blade of the headrig saw is carried out during each break. It was also assumed the system will not shut down during one shift because of log supply shortage. In the economic analysis section (Section 4) of this dissertation, it is assumed that only 90% of capacity will be used due to unexpected machine down and possible log shortage.

#### **4.5 Model Verification and Validation**

Verification seeks to show that the computer simulation program performs as expected and intended, thus providing a correct logical representation of the model. Validation, on the other hand, determines how accurately the conceptual simulation model represents the real-world system being simulated.

The verification process consists of isolating and correcting unintentional errors in the models. The computer program of each model was debugged in two subprograms, one represents the operations from logs to flitches and the other represents the operations from flitches to rough dimension parts. Then, the logic connection between the two subprograms was checked and corrected. Model verification was carried out in parallel with model development by testing the models stage by stage. Entity trace and interactive debugger facilities were used in the process of model verification to check the changes in resource status, values of global variables, and attributes of entities. Animation models were developed for each of the simulation models and used in model verification. Animation displays the information

of all model components simultaneously. The simultaneous display makes it easier to follow the complex interactions occurring within the model. Animation proved to be a very powerful in checking material flow and in identifying blockages and deadlocks in the model.

Since the proposed designs of the direct processing system have yet to be built, no direct experimentation could be made for validating the model. In case that the referent system does not exist, logically it is almost impossible to validate a model of a proposed system, therefore, the validation remained in the level of face validity. With the aid of the animation, the reasonableness of the models and their behavior were checked by persons knowledgeable about the referent system. The similarity in the amount of logs processed between the simulated system that processed by the real sawmill in which part of the input data was collected partially validated the simulation models. The sawmill that was used for collecting data processes about 20 MBF red oak logs (mixture of No.2 grade and No.3 grade) per 8 hour shift if no breakdown and log supply shortage happen. This number is very close to the production rate of the simulated mills when the headrig saw is fully utilized. The change in production rate caused by removing and adding machines/operators in three of the six models appeared reasonable. The results of these changes will be discussed in the **Results and Discussion** section.

## **4.6 Experimentation and Analysis**

In running the simulation models, the system was treated as a terminating system. The simulation started in the beginning of one shift and ended at the end of the shift. The length of each simulation run was 8 hours. It was assumed that the system is idle

and empty at the beginning of each simulation run. Statistics were collected from the beginning to the end of each simulation run. Twenty replications were run for each of the simulation models. The summary values displayed in the SIMAN Summary Report for each replication rather than the individual observations within each replication were used for analysis. Thus, each replication produced a single observation; hence the total number of observations was the number of replications of the model run. Many standard statistical procedures require observations to be independent. As long as different random-number seeds were used for each replication, the observations across replications are independent (Pegden etc. 1990). The REPLICATE element was used to make multiple replications in which different random-number seeds were automatically used for each replication. Thus the observations from the 20 replications can be considered to be independent. Many standard statistical procedures also require that the observations have a normal distribution. Because the summary values displayed in the SIMAN Summary Report are typically the average of many individual observations within the replication, it is reasonable to assume, based on the Central Limit Theorem, that they have a normal distribution.

One-way ANOVA was performed using the SAS statistical software package to determine whether there was any significant difference in production rate among the six initial designs of the direct processing system. In cases where the ANOVA test showed a significant difference in production rate, multiple comparisons were conducted using Duncan's multiple range test to determine which means differed from each other.

## 5.

## RESULTS AND DISCUSSION

### 5.1 Simulation Results of Initial Designs

The mean daily (one shift) production rates along with several other output variables for the six initial designs of the direct processing system are given in Table 3.3. The variability of the production rate among the different designs was very large. In terms of daily log volume processed, the production rate ranged from a low of 10154 BF for Design 1 to a high of 20585 BF for Design 6. And in terms of daily volume of green parts output, the production rate ranged from 7453 BF for Design 1 to 14279 BF for Design 2. ANOVA results show that both in terms of daily log volume processed and daily volume output of green parts at least one of the six initial designs differs from the rest with the p-value equal to 0.0001. Duncan's multiple comparison tests further indicate that for daily volume of logs processed only Design 2 and Design 3 are not significantly different. And for daily volume of green parts produced only Design 1 and Design 4 are not significantly different (Table 3.4). The labor productivity in terms of green parts output (BF) per direct worker per day varies greatly among the six initial designs. Duncan's multiple comparison tests show that the mean values of labor productivity in terms of green part output (BF) per direct worker per day for each of the six designs differs significantly (Table 3.4).

The labor productivity and overall machine and labor utilization of Design 1 and Design 4 appear to be much lower than that of other designs (Table 3.3). And the time in system for Design 1 and Design 4 are much higher than that for other designs (Table 3.3). The lower productivity and lower machine and labor utilization as well as longer

**Table 3.3 Summary of simulation results for the six initial designs**

| Output Variable  | Design # |       |       |       |       |       |
|--|----------|-------|-------|-------|-------|-------|
|  | D1       | D2    | D3    | D4    | D5    | D6    |
| Log processed (BF/day)                                       | 10154    | 19454 | 19449 | 12053 | 17823 | 20585 |
| Green Part Output (BF/day)                                   | 7453     | 14279 | 14062 | 7436  | 10997 | 12989 |
| Labor Productivity (BF green part output per worker per day) | 532.4    | 892.4 | 827.2 | 499.8 | 646.9 | 683.6 |
| Time in System (min)   | 45.2     | 21.7  | 20.5  | 42.5  | 23.4  | 31.3  |
| Machine Uti.(%)  | 45.89    | 58.15 | 66.31 | 49.70 | 51.40 | 67.06 |
| Labor Uti.(%)  | 34.05    | 64.98 | 64.59 | 31.80 | 48.47 | 62.90 |

- D1 - Design 1 (Live-sawing, Gang-rip-first, two automatic chop saws).
- D2 - Design 2 (Live-sawing, Gang-rip-first, six manual chop saws).
- D3 - Design 3 (Live-sawing, Crosscut-first).
- D4 - Design 4 (Five-part-sawing, Gang-rip-first, two automatic chop saws).
- D5 - Design 5 (Five-part-sawing, Gang-rip-first, six manual chop saws).
- D6 - Design 6 (Five-part-sawing, Crosscut-first).

**Table 3.4 Production rate and productivity of the six initial designs  
- Confidence intervals and Duncan's multiple comparison results**

| Output Variables   | Design # | Mean $\pm$ 95% CI | Grouping* |
|--|----------|-------------------|-----------|
| Log Processed<br>(BF per day)  | D1       | 10154 $\pm$ 251   | A         |
|  | D2       | 19454 $\pm$ 323   | B         |
|  | D3       | 19450 $\pm$ 333   | B         |
|  | D4       | 12153 $\pm$ 235   | C         |
|  | D5       | 17823 $\pm$ 145   | D         |
|  | D6       | 20585 $\pm$ 178   | E         |
| Green Parts Output<br>(BF per day)                                       | D1       | 7453 $\pm$ 184    | A         |
|  | D2       | 14279 $\pm$ 237   | B         |
|  | D3       | 14062 $\pm$ 241   | C         |
|  | D4       | 7497 $\pm$ 145    | A         |
|  | D5       | 10997 $\pm$ 90    | D         |
|  | D6       | 12989 $\pm$ 112   | E         |
| Labor Productivity<br>(BF of green part<br>output per worker<br>per day) | D1       | 523.4 $\pm$ 13.1  | A         |
|  | D2       | 892.4 $\pm$ 14.8  | B         |
|  | D3       | 827.2 $\pm$ 14.2  | C         |
|  | D4       | 499.8 $\pm$ 9.7   | D         |
|  | D5       | 646.9 $\pm$ 5.3   | E         |
|  | D6       | 683.6 $\pm$ 5.9   | F         |

\* Means with the same letter are not significantly different at  $\alpha=0.05$  level.

- D1 - Design 1 (Live-sawing, Gang-rip-first, two automatic chop saws).
- D2 - Design 2 (Live-sawing, Gang-rip-first, six manual chop saws).
- D3 - Design 3 (Live-sawing, Crosscut-first).
- D4 - Design 4 (Five-part-sawing, Gang-rip-first, two automatic chop saws).
- D5 - Design 5 (Five-part-sawing, Gang-rip-first, six manual chop saws).
- D6 - Design 6 (Five-part-sawing, Crosscut-first).

time in system indicate that Designs 1 and 4 will run inefficiently if they are to be built and some bottlenecks may exist in these two designs.

For the purpose of identifying bottlenecks in the system, data for individual machine and labor utilization is more helpful than data for overall machine and labor utilization. The bottlenecks in a particular design can be either a machine or a worker who operates a machine or performs an activity. If an operator can feed a machine faster than the machine's processing speed, the utilization of the machine will be higher than that of the operator and the possible bottleneck can be the machine. Otherwise, the utilization of the machine will be lower than that of the operator and the possible bottleneck can be the operator. The individual machine and labor utilization of the six initial designs obtained from simulation results are listed in Tables 3.5 and 3.6. Based on the individual machine and labor utilization, the location of bottlenecks in each of the six initial designs was identified. In Design 1 and Design 4, the automatic chop saws run at their full capacity while the utilization of other machines in the system is far below their full capacity. Therefore, it is the chopping capacity that constrains the production rate of these two designs. Adding additional chop saws may lead to increase in production rate for these two designs.

For Design 2 and Design 3, the bottleneck is located in the headrig saw. To increase production rate, another headrig saw needs to be added to the initial designs. However, since the direct processing system considered in this research is limited to containing only one headrig saw, the option of adding another headrig saw is not under consideration.

In Design 5, the capacity of the gang-rip saw restricts the throughput of the whole system. Adding another gang-rip saw may increase production rate. However, since the usage of headrig saw and edging saw is higher too, any increase in production



**Table 3.5 Individual machine utilization(%)**

| Machines             | Design # |       |       |       |       |       |
|----------------------|----------|-------|-------|-------|-------|-------|
|                      | D1       | D2    | D3    | D4    | D5    | D6    |
| Log Fork             | 12.41    | 22.42 | 22.34 | 14.50 | 21.31 | 24.36 |
| Debarker             | 14.99    | 28.19 | 27.60 | 17.47 | 25.65 | 29.24 |
| Headrig Saw          | 52.09    | 99.55 | 99.49 | 51.31 | 75.84 | 87.36 |
| Gang Resaw           | -----    | ----- | ----- | 12.16 | 18.15 | 20.84 |
| Planer               | 29.79    | 57.19 | 57.31 | 46.42 | 71.94 | 77.71 |
| Edging Saw           | 35.73    | 68.70 | ----- | 55.76 | 86.56 | ----- |
| Rip Scanner          | 30.71    | 63.95 | ----- | 40.61 | 63.78 | ----- |
| Gang-Rip Saw         | 39.63    | 77.22 | ----- | 62.35 | 96.26 | ----- |
| Auto Chop saws       | 98.82    | ----- | ----- | 98.22 | ----- | ----- |
| Manual Chop Saws     | -----    | 56.45 | ----- | ----- | 43.36 | ----- |
| Crosscut Saws        | -----    | ----- | 69.61 | ----- | ----- | 76.64 |
| Single Line Rip Saws | -----    | ----- | 76.03 | ----- | ----- | 80.47 |

- D1 - Design 1 (Live-sawing, Gang-rip-first, two automatic chop saws).
- D2 - Design 2 (Live-sawing, Gang-rip-first, six manual chop saws).
- D3 - Design 3 (Live-sawing, Crosscut-first).
- D4 - Design 4 (Five-part-sawing, Gang-rip-first, two automatic chop saws).
- D5 - Design 5 (Five-part-sawing, Gang-rip-first, six manual chop saws).
- D6 - Design 6 (Five-part-sawing, Crosscut-first).

**Table 3.6 Individual labor utilization(%)**

|  | Design # |       |       |       |       |       |
|--|----------|-------|-------|-------|-------|-------|
|  | D1       | D2    | D3    | D4    | D5    | D6    |
| Operators                              |          |       |       |       |       |       |
| Log Fork Driver                        | 12.41    | 22.42 | 22.34 | 14.50 | 21.31 | 24.36 |
| Debarking Oper.                        | 14.99    | 28.17 | 27.6  | 17.47 | 25.65 | 29.24 |
| Headrig Oper.                          | 52.09    | 99.55 | 99.49 | 51.31 | 75.84 | 87.36 |
| Gang Resaw Oper.                       | -----    | ----- | ----- | 6.02  | 9.19  | 10.55 |
| After Gang Resaw<br>Material Separator | -----    | ----- | ----- | 8.02  | 11.92 | 12.85 |
| Planer Oper.                           | 29.66    | 57.15 | 22.88 | ----- | ----- | ----- |
| Edging Oper.                           | 23.73    | 45.72 | ----- | 30.18 | 43.89 | ----- |
| Rip Scan Oper.                         | 30.71    | 63.95 | ----- | 40.61 | 63.78 | ----- |
| Defect Markers                         | 28.85    | ----- | ----- | 28.81 | ----- | ----- |
| Manual Chop<br>Saws Operators          | -----    | 62.21 | ----- | ----- | 48.63 | ----- |
| Crosscut Saws<br>Operators             | -----    | ----- | 87.45 | ----- | ----- | 94.45 |
| Single Line Rip<br>Infeed Opers.       | -----    | ----- | 70.65 | ----- | ----- | 75.14 |
| Single Line Rip<br>Outfeed Opers.      | -----    | ----- | 62.04 | ----- | ----- | 61.75 |
| Part Sorters                           | 49.43    | 87.36 | ----- | 48.41 | 70.14 | ----- |

- D1 - Design 1 (Live-sawing, Gang-rip-first, two automatic chop saws).
- D2 - Design 2 (Live-sawing, Gang-rip-first, six manual chop saws).
- D3 - Design 3 (Live-sawing, Crosscut-first).
- D4 - Design 4 (Five-part-sawing, Gang-rip-first, two automatic chop saws).
- D5 - Design 5 (Five-part-sawing, Gang-rip-first, six manual chop saws).
- D6 - Design 6 (Five-part-sawing, Crosscut-first).

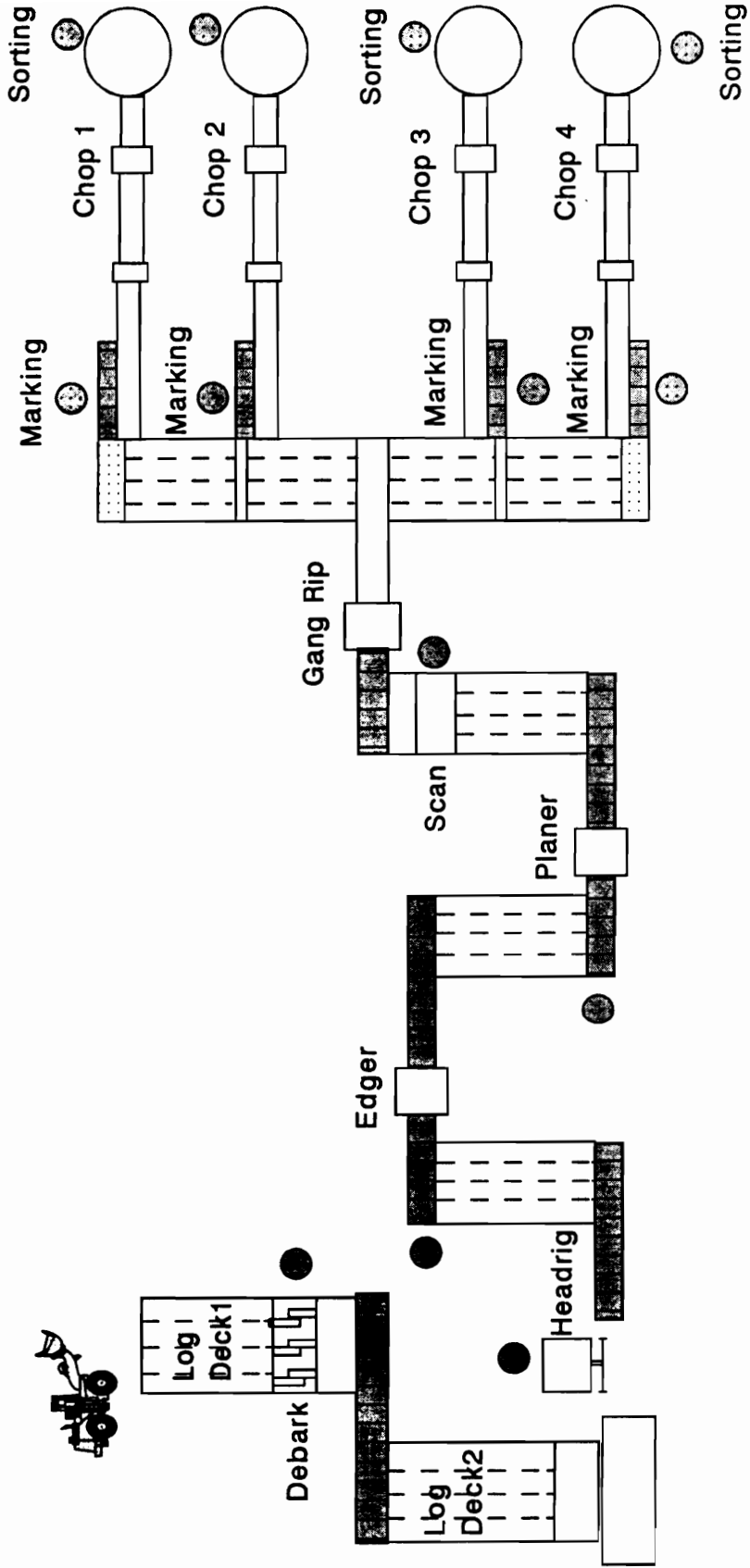
rate through adding another gang-rip saw would be limited if no additional headrig saw and edging saw are added. On the other hand, the utilization of chop saws in Design 5 appears to be low. Since multiple chop saws are used in Design 5, there is a chance to reduce the number of the chop saws in this design.

For Design 6, the bottleneck appears to be in the crosscutting station. The utilization of the crosscut saw operators is near to their full capacity. To remove the bottleneck, additional crosscut saws are needed. However, since the use of the headrig saw is close to its full capacity (87 percent of its capacity), without adding additional headrig saw capacity the increase in production by adding an additional crosscut saw will be very limited.

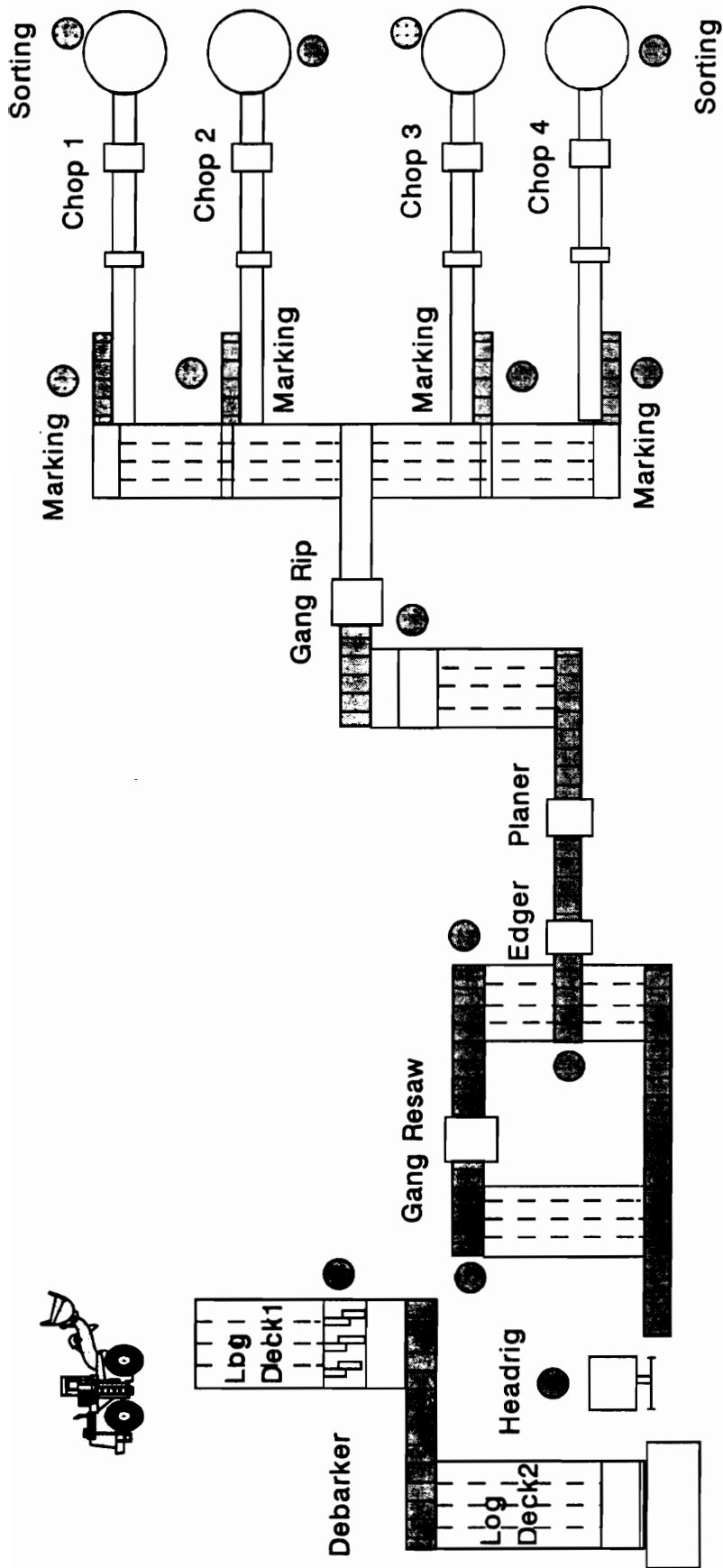
One alternate headrig saw could be a scragg mill headrig or chipper canter. This alternate headrig saw will make sawing logs into flitches more efficient. However, because this alternative headrig saw cuts a large slab containing material that can be cut into parts, the yield of dimension parts may be lower. Furthermore, as a whole system, the efficiency of a direct processing system is not determined by a single machine. The subsequent operations followed the headrig saw have to be considered when the headrig saw is changed. The performance of the direct processing system which uses alternate headrig saw can be investigated using the same methodology presented in this dissertation.

## **5.2 Simulation Results of Modified Designs**

Three of the six initial designs, Design 1, Design 4 and Design 5, were modified. In modified Design 1 and Design 4, two additional automatic chop saws were added to the initial designs (Figure 3.8 and 3.9). The number of defect markers and part sorters



**Figure 3.8** Layout of modified mill design 1



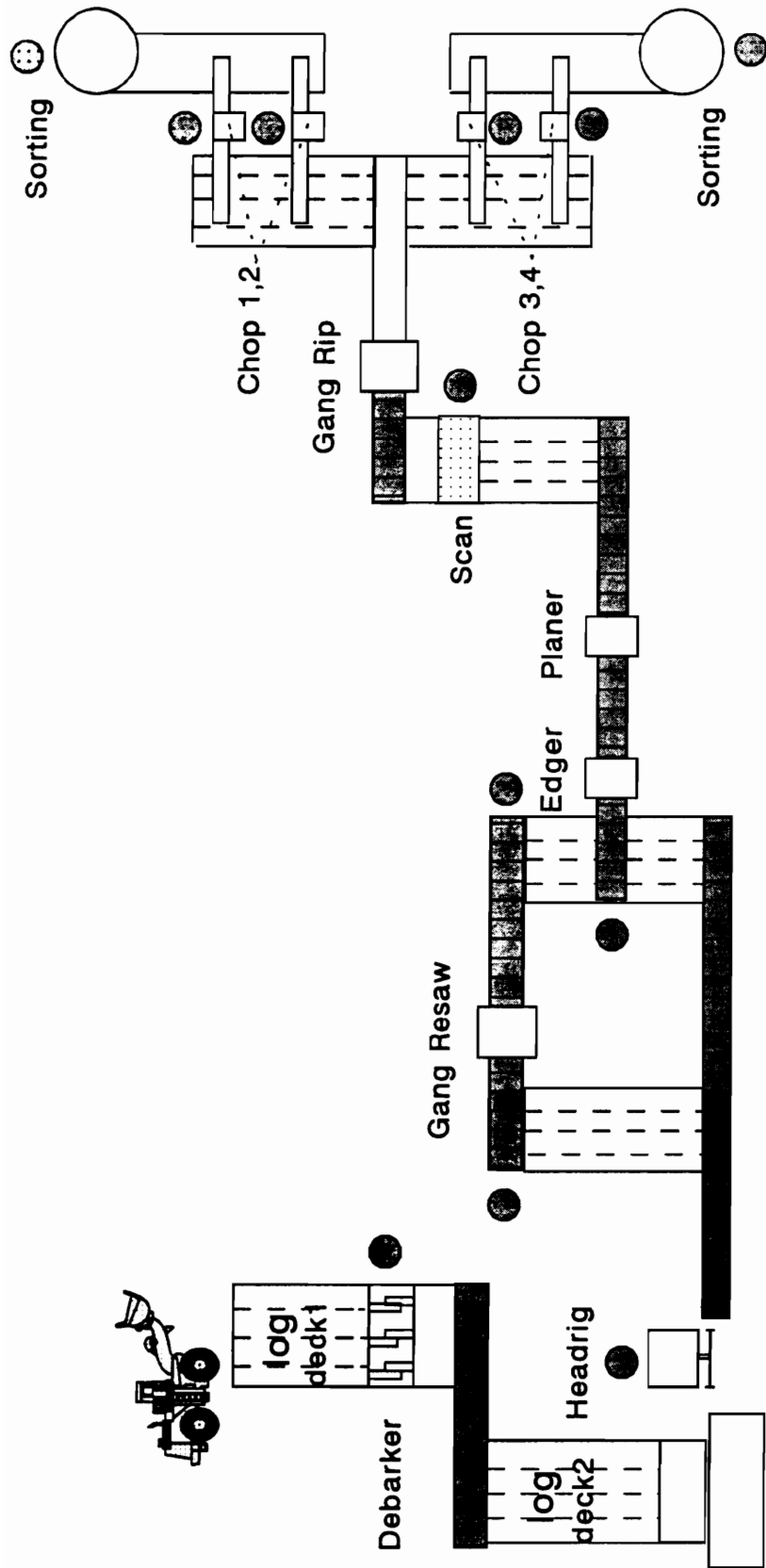
**Figure 3.9** Layout of modified mill design 4

in each automatic chop line was reduced from two to one in both modified Design 1 and 4. In modified Design 5, the number of chop saws was reduced from six to four and other components of the system remained unchanged (Figure 3.10).

A summary of the simulation results for the three modified models is given in Table 3.7. These modified designs are more efficient than their initial designs. After modification, the labor productivity in terms of green part output (BF) per direct worker per day has increased significantly for all of the three designs modified (Table 3.8). After adding two additional automatic chop saws, the production rate of Design 1 and 4 is almost doubled and the time in system has decreased to half as much as in their initial designs. Machine and labor utilization of modified Design 1 and 4 are also much higher than initial Designs 1 and 4. After two chop saws were removed, machine and labor utilization of modified Design 5 has increased, while the production rate and the time in system have not changed significantly.

T-tests were performed to determine whether the change in production rate was proportional to the number of chop saws added for Design 1 and Design 4 and if the production rate remains unchanged for Design 5 after two chop saws were removed. All these tests are two-side tests. As shown in Table 3.8, the results of these T-tests indicate that although the production rate of Design 1 and Design 4 has increased significantly after adding two automatic chop saws, the increase in production rate is not proportional to the number of the automatic chop saws added. The T-test results also show that the production rate of Design 5 remains unchanged after two chop saws were removed from the initial design (Table 3.8).

After the three designs were modified, new ANOVA tests were conducted among the six designs (three unmodified designs and three modified designs). The new ANOVA tests show that at least one of the six designs significantly differs from the rest



**Figure 3.10** Layout of modified mill design 5

**Table 3.7 Summary of simulation results for the three modified designs**

| Output Variable   | Design # |       |       |
|---|----------|-------|-------|
|   | MD1      | MD4   | MD5   |
| Log processed (BF/day)                                      | 19541    | 17835 | 17842 |
| Green Part Output (BF/day)                                  | 14343    | 11004 | 11008 |
| Labor Productivity (BF green part output per worker per dy) | 1024.5   | 733.6 | 733.9 |
| Time in System (min)  | 22.3     | 23.5  | 23.2  |
| Machine Uti.(%)   | 75.25    | 63.14 | 59.83 |
| Labor Uti.(%)   | 63.13    | 48.71 | 54.50 |

MD1 - Modified Design 1 (Live-sawing, Gang-rip-first, four automatic chop saws).

MD4 - Modified Design 4 (Five-part-sawing, Gang-rip-first, four automatic chop saws).

MD5 - Modified Design 5 (Five-part-sawing, Gang-rip-first, four manual chop saws).



**Table 3.8 T-Test results: modified designs vs. initial designs**

| Variables   | Test hypothesis   | $t_{obs}$ | Result*      |
|---|---|-----------|--------------|
| Daily log volume processed (BF/day)                             | $H_0: Y_{D1} = 2Y_{MD1}$<br>$H_1: Y_{D1} \neq 2Y_{MD1}$ | 11.407    | Reject $H_0$ |
|   | $H_0: Y_{D4} = 2Y_{MD4}$<br>$H_1: Y_{D4} \neq 2Y_{MD4}$ | 117.65    | Reject $H_0$ |
|   | $H_0: Y_{D5} = Y_{MD5}$<br>$H_1: Y_{D5} \neq Y_{MD5}$   | 0.7907    | Accept $H_0$ |
| Daily green part volume produced (BF/day)                       | $H_0: Y_{D1} = 2Y_{MD1}$<br>$H_1: Y_{D1} \neq 2Y_{MD1}$ | 11.374    | Reject $H_0$ |
|   | $H_0: Y_{D4} = 2Y_{MD4}$<br>$H_1: Y_{D4} \neq 2Y_{MD4}$ | 119.10    | Reject $H_0$ |
|   | $H_0: Y_{D5} = Y_{MD5}$<br>$H_1: Y_{D5} \neq Y_{MD5}$   | 0.4681    | Accept $H_0$ |
| Labor Productivity (BF of green part output per worker per day) | $H_0: Y_{MD1} = Y_{D1}$<br>$H_1: Y_{MD1} > Y_{D1}$      | 114.66    | Reject $H_0$ |
|   | $H_0: Y_{MD4} = Y_{D4}$<br>$H_1: Y_{MD4} > Y_{D4}$      | 83.58     | Reject $H_0$ |
|   | $H_0: Y_{MD5} = Y_{D5}$<br>$H_1: Y_{MD5} > Y_{D5}$      | 47.26     | Reject $H_0$ |

Notation:

- \* - Test results at  $\alpha$  level of 0.05
- $Y_{Di}$  - Mean value for initial design i
- $Y_{Mdi}$  - Mean value for modified design i

in both daily log volume processed and daily volume of green parts output with the p-value of 0.0001. Duncan's multiple comparison tests further indicate that for daily volume of log processed, there is no significant difference among modified Design 1, Design 2 and Design 3 and between modified Design 4 and modified Design 5 at  $\alpha=0.05$  level (Table 3.9). And the daily volume of green parts output are not significantly different between modified Design 1 and Design 2 and between modified Design 4 and modified Design 5 at  $\alpha=0.05$  level (Table 3.9).

### 5.3 Discussion

The production rate and other operational performances of the direct processing system can be estimated by using system simulation modeling techniques. Based on the simulation results of the six final models, the direct processing system with one headrig saw can process 17.8 to 20.5 MBF No.3 grade red oak logs and turn out 11 to 14.3 MBF 4"/4 rough green dimension parts of random width per shift (Table 3.9), depending on the system layout. The labor productivity of the direct processing system with one headrig saw can reach at 684 to 1025 MBF green part output per worker per day, which also depends on the layout designs of the system. The estimated production rate will be used in the economic analysis of the direct processing system in the **Section 4**.

Duncan's multiple comparison tests show that within a given sawing pattern, the labor productivity in terms of green part output per direct worker per day is significantly higher for Rip-first designs than that for Crosscut-first designs (Table 3.9). For example, the labor productivity of Modified Design 1 and Design 2 is higher than that of Design 3. And the labor productivity of Modified Design 4 and 5 is higher

**Table 3.9 Production rate and productivity of the six designs after modification - Confidence intervals and Duncan's multiple comparison results**

| Output Variables   | Design # | Mean $\pm$ 95% CI | Grouping* |
|--|----------|-------------------|-----------|
| Log Processed<br>(BF per day)  | MD1      | 19541 $\pm$ 276   | A         |
|  | D2       | 19454 $\pm$ 323   | A         |
|  | D3       | 19450 $\pm$ 333   | A         |
|  | MD4      | 17835 $\pm$ 192   | B         |
|  | MD5      | 17842 $\pm$ 153   | B         |
|  | D6       | 20585 $\pm$ 178   | C         |
| Green Parts Output<br>(BF per day)                                       | MD1      | 14343 $\pm$ 203   | A         |
|  | D2       | 14279 $\pm$ 237   | A         |
|  | D3       | 14062 $\pm$ 241   | B         |
|  | MD4      | 11004 $\pm$ 118   | C         |
|  | MD5      | 11008 $\pm$ 94    | C         |
|  | D6       | 12989 $\pm$ 112   | D         |
| Labor Productivity<br>(Bf of green part<br>output per worker<br>per day) | MD1      | 1024.5 $\pm$ 14.5 | A         |
|  | D2       | 892.4 $\pm$ 14.8  | B         |
|  | D3       | 827.2 $\pm$ 14.2  | C         |
|  | MD4      | 733.6 $\pm$ 7.9   | D         |
|  | MD5      | 733.9 $\pm$ 6.3   | D         |
|  | D6       | 683.6 $\pm$ 5.9   | E         |

\* Means with the same letter are not significantly different at  $\alpha=0.05$  level.

D2- Design 2 (Live-sawing, Gang-rip-first, six manual chop saws).

D3- Design 3 (Live-sawing, Crosscut-first).

D6- Design 6 (Five-part-sawing, Crosscut-first).

MD1- Modified Design 1 (Live-sawing, Gang-rip-first, four automatic chop saws).

MD4- Modified Design 4 (Five-part-sawing, Gang-rip-first, four automatic chop saws).

MD5- Modified Design 5 (Five-part-sawing, Gang-rip-first, four manual chop saws).

than that of Design 6. The result that Rip-first designs have higher labor productivity than Crosscut-first designs is similar to that obtained by Hall et al. (1980) in comparing Rip-first and Crosscut-first rough mills for producing hardwood dimension parts from No.1 Common red oak lumber.

For the designs that use Live-sawing followed by Rip-first (Modified Design 1 and Design 2), the use of automatic chop saws significantly increased the productivity of the system (Modified Design 1 has higher labor productivity than Design 2). For the designs that use Five-part-sawing followed by Rip-first (Modified Design 4 and 5), however, the labor productivity of Modified Design 4 and Modified Design 5 showed no significant difference. The reason is that the automatic chop saws were not used in full capacity in Modified Design 4 due to the restriction of gang-rip saw capacity,

Systems simulation modeling proved to be a very successful tool in identifying and removing bottlenecks in the layout designs of the direct processing systems. Based on the simulation results, the bottlenecks in the initial designs were identified successfully. After the bottlenecks were removed from initial designs, the productivity of the modified designs were improved significantly.

The bottleneck occurs in different locations in the layouts designed for using Live-sawing and those designed for using Five-part-sawing. This can be attributed to the fact that the number of flitches generated by Five-part-sawing is more than that generated by Live-sawing. The more flitches generated from a log, the more work the gang-rip saw (in Rip-first designs) and crosscut saws (in Crosscut-first designs) need to process. Thus, the gang-rip saw in Rip-first designs and the crosscut saws in Crosscut-first designs are more likely to become bottlenecks in the designs for using Five-part-sawing.

Since the sawing pattern and cutting sequence affect the production rate and labor productivity of the direct processing system, the selection of sawing pattern and cutting sequence should not only be based on the dimension yields and value recovery but also should consider the difference in production rate and productivity.

In Modified Design 1 and 4, the simulation results indicated that the increase in production rate is not proportional to the number of automatic chop saws added. This result reflects the interactive nature of the whole direct processing system. As a whole system, each design consists of many components which are dynamically interrelated. Any changes in one component can cause reactions of other components in the system. This interaction is easily captured by system simulation. For example, after the bottleneck in initial Design 1 was identified and removed by adding two additional automatic chop saws, the utilization of the headrig saw in Modified Design 1 has reached its capacity limit (Table 3.10), hence the increase in production rate of Modified Design 1 is restricted by the capacity of the headrig saw. Similarly in Design 4, after adding two additional automatic chop saws, chopping capacity is no longer a bottleneck, however, a new bottleneck emerges. In Modified Design 4, the capacity of the gang-rip saw reached its limit before the capacity of all automatic chop saws was fully utilized (Table 3.10). The capacity of gang-rip saw then became the new bottleneck and constrained the production rate increase.

In this study, the automatic chops used in Design 1 and 4, Modified Design 1 and 4 are not capable of continuously (or butt-to-butt) feeding. If these automatic chop saws are capable of continuously feeding, their capacity will increase, and the number of automatic chop saws required in Modified Design 1 and 4 can be reduced. Further study can be carried out for continuously-feeding automatic chop saws using the same methodology presented in this dissertation.

**Table 3.10 Machine and labor utilization of the three modified designs(%)**

|                              | Machine Utilization (%) |       |       | Labor Utilization (%) |       |       |
|------------------------------|-------------------------|-------|-------|-----------------------|-------|-------|
|                              | Design #                |       |       | Design #              |       |       |
| Machines/Oper.               | MD1                     | MD4   | MD5   | MD1                   | MD4   | MD5   |
| Log Fork                     | 21.87                   | 21.4  | 22.63 | 21.78                 | 21.40 | 22.63 |
| Debarker                     | 27.50                   | 26.14 | 25.62 | 27.50                 | 26.14 | 25.62 |
| Headrig Saw                  | 99.51                   | 75.28 | 75.86 | 99.51                 | 75.28 | 75.86 |
| Gang Resaw                   | -----                   | 17.94 | 18.09 | -----                 | 9.03  | 9.11  |
| After Resaw Mater. Separator | -----                   | ----- | ----- | -----                 | 11.82 | 11.95 |
| Planer                       | 57.32                   | 71.21 | 71.92 | 57.28                 | ----- | ----- |
| Edging Saw                   | 68.83                   | 85.66 | 86.51 | 45.73                 | 44.45 | 43.92 |
| Rip Scanner                  | 59.88                   | 62.84 | 63.64 | 59.88                 | 62.84 | 63.64 |
| Gang-Rip Saw                 | 77.36                   | 96.45 | 97.21 | -----                 | ----- | ----- |
| Defect Markers               | -----                   | ----- | ----- | 56.21                 | 44.87 | ----- |
| Auto Chop saws               | 95.63                   | 75.19 | ----- | -----                 | ----- | ----- |
| Manual Chop Saws             | -----                   | ----- | 64.12 | -----                 | ----- | 71.84 |
| Crosscut Saws                | -----                   | ----- | ----- | -----                 | ----- | ----- |
| Single Line Rip Saws         | -----                   | ----- | ----- | -----                 | ----- | ----- |
| Part Sorters                 | -----                   | ----- | ----- | 86.82                 | 75.04 | 69.34 |

MD1 - Modified Design 1 (Live-sawing, Gang-rip-first, four automatic chop saws).

MD4 - Modified Design 4 (Five-part-sawing, Gang-rip-first, four automatic chop saws).

MD5 - Modified Design 5 (Five-part-sawing, Gang-rip-first, four manual chop saws).

There are many possible design alternatives for the direct processing system. The six designs presented in this paper are just a small portion of them. Operationally, these six designs after modification appear to be reasonable. Their performance will be further judged based on their economic performance.

In this section, only the operations of green part manufacturing were addressed and the operations after green part manufacturing were not considered due to the uncertainty in the drying of dimension parts. The operations after green part manufacturing will be addressed in the next section.

## 6.

## SUMMARY

To implement the concept of directly processing hardwood logs into rough dimension parts, a manufacturing system that carries out the operations of converting logs into rough dimension parts need to be designed. To investigate the dynamic performance of the various mill designs that convert No.3 red oak logs into rough dimension parts, system simulation models for these designs need to be developed. To determine the economic feasibility and profitability of the designed manufacturing system, the production rate of the system needs to be estimated.

Six initial mill designs were developed to carry out the different sawing patterns and cutting sequences. System simulation models of these designs were developed using SIMAN IV. And animation models were also built using CINEMA for each mill design in conjunction with simulation model development to assist simulation model development, model verification and validation.

The dynamic performance of the direct processing systems was investigated. Based on simulation results, bottlenecks in the initial designs were identified and production lines were balanced. It was found that bottlenecks occurred in different locations in those designs for carrying out Live-sawing and those designs for carrying out Five-part-sawing. Three of the six initial designs were modified for balancing production capacity. The production rate and labor productivity of these modified designs were much higher than their initial designs. System simulation was proved to be a very powerful tool for capturing the dynamic performance of a "whole system" that can not be directly manipulated.

The production rates of the designed mills were estimated through simulation. Based on simulation results of the six final models, the direct processing system with



one headrig saw can process 17.8 to 20.5 MBF No.3 grade red oak logs and turn out 11 to 14.3 MBF, Clear-two-face, 4/4 rough green dimension parts of random width per shift. The production rate varies among the different mill designs. Production rate in both daily log volume processed and daily volume of green part output are significantly different between those designs for using Live-sawing and those for using Five-part-sawing. For the designs using the same sawing pattern, the productivity in terms of green parts output per worker per day for Rip-first designs is slightly higher than for crosscut-first designs. These results will be used in subsequent economic analysis of the direct processing system.

Because of the difference in production rate and productivity between the design alternatives for different processing methods, not only dimension yields and dollar value recovery but also the production rate and productivity should be considered in selecting sawing pattern and cutting sequence. The performance of the design alternatives for the direct processing system needs to be further judged by their economical performance.

- Adams, E. L. 1984a. DESIM: a system for designing and simulating hardwood sawmill systems. USDA Forest Service General Technical Report NE-89, USDA Forest Service, Northeastern Experiment Station, Broomall, PA, 10 pp.
- \_\_\_\_\_. 1984b. DESIM user's manual: a procedural guide for designing and simulating hardwood sawmill systems. USDA forest Service General Technical Report NE-94, USDA Forest Service, Northeastern Experiment Station, Broomall, PA, 58 pp.
- \_\_\_\_\_. 1985. DESIM data manual: a procedural guide for developing equipment processing and down time data. USDA Forest Service General Technical Report NE-102, USDA Forest Service, Northeastern Experiment Station, Broomall, PA, 23 pp.
- \_\_\_\_\_. 1988. Testing DESIM for designing and simulating the operation of hardwood sawmills. *Forest Products Journal* 38(7/8):41-45.
- Anderson, R. B. 1983. Furniture rough mill costs evaluated by computer simulation. USDA Forest Service Research Paper NE-518, USDA Forest Service, Northeastern Experiment Station, Princeton, WV, 11 pp.
- Araman, P. A. 1977. Use of computer simulation in designing and evaluating a proposed rough mill for furniture interior parts. USDA Forest Service Research Paper NE-361, USDA Forest Service, Northeastern Experiment Station, Upper Darby, PA.
- Hall, S.P., E.M. Wengert, R.A. Wysk and M.A. Agee. 1980. Yield distributions and cost comparisons of a crosscut-first and a gang-rip-first rough mill producing hardwood dimension stair parts. *Forest Products Journal* 30(5):34-39.
- Kline, D. E., J. K. Wiedenbeck, and P. A. Araman. 1992. Management of wood products manufacturing using simulation/animation. *Forest Products Journal* 42(2):45-52.
- Law, A. M. and W. D. Kelton. 1991. *Simulation Modeling and Analysis*. Second ed. McGraw-Hill Book Company, New York. 759 pp.
- Meimban, R.J., G.A. Mendoza, and H. Carino. 1992. Integrating economic performance and process simulation models in evaluating sawmill design alternatives. *Wood & Fiber Science* 24(1):68-72.
- Pegden, C. D., R. E. Shannon, and R. P. Sadowski. 1990. *Introduction to Simulation Using SIMAN*. McGraw-Hill, Inc., New York, N.Y. 615 pp.
- Systems Modeling Corp. (SMC). 1990. *CINEMA IV Reference Guide*. 504 Beaver Street, Sewickley, PA. 155 pp.
- Wagner, Jr., F. G. and F. W. Taylor. 1983. SPSM-A Southern Pine Sawmill Model. *Forest Products Journal* 33(4):37-42.

Wiedenbeck, J.K. 1992. The potential for short length lumber in the furniture and cabinet industries. Ph.D Dissertation, Virginia Polytechnic Institute and State University, 260 pp.

## Section 4

# **ECONOMIC EVALUATION OF THE DIRECT PROCESSING SYSTEM FOR CONVERTING NO.3 GRADE RED OAK LOGS INTO ROUGH DIMENSION PARTS**

## 1.

### **ABSTRACT**

A financial analysis using discounted cash flow methods was conducted to determine the economic feasibility of the direct processing system that processes No.3 grade red oak logs directly into rough dimension parts. Six design alternatives of the direct processing system were evaluated. Under the assumptions of this study, measured by both Net Present Value (NPV; discount rate = 12%) and Internal Rate of Return (IRR), all six designs are economically acceptable.

With the highest NPV of \$4,193,700 and the highest IRR of 29.6 percent, the design that uses Live-sawing and Gang-rip-first cutting with manual chop saws (design2) was found to be the most economically attractive design among the six design alternatives evaluated.

The profitability of the direct processing system, measured in Return on Sales (ROS), was estimated and compared with the profitability of the conventional processing system that processes standard grade lumber into dimension parts. The results showed that the direct processing systems are more profitable than the conventional processing system for making dimension parts.

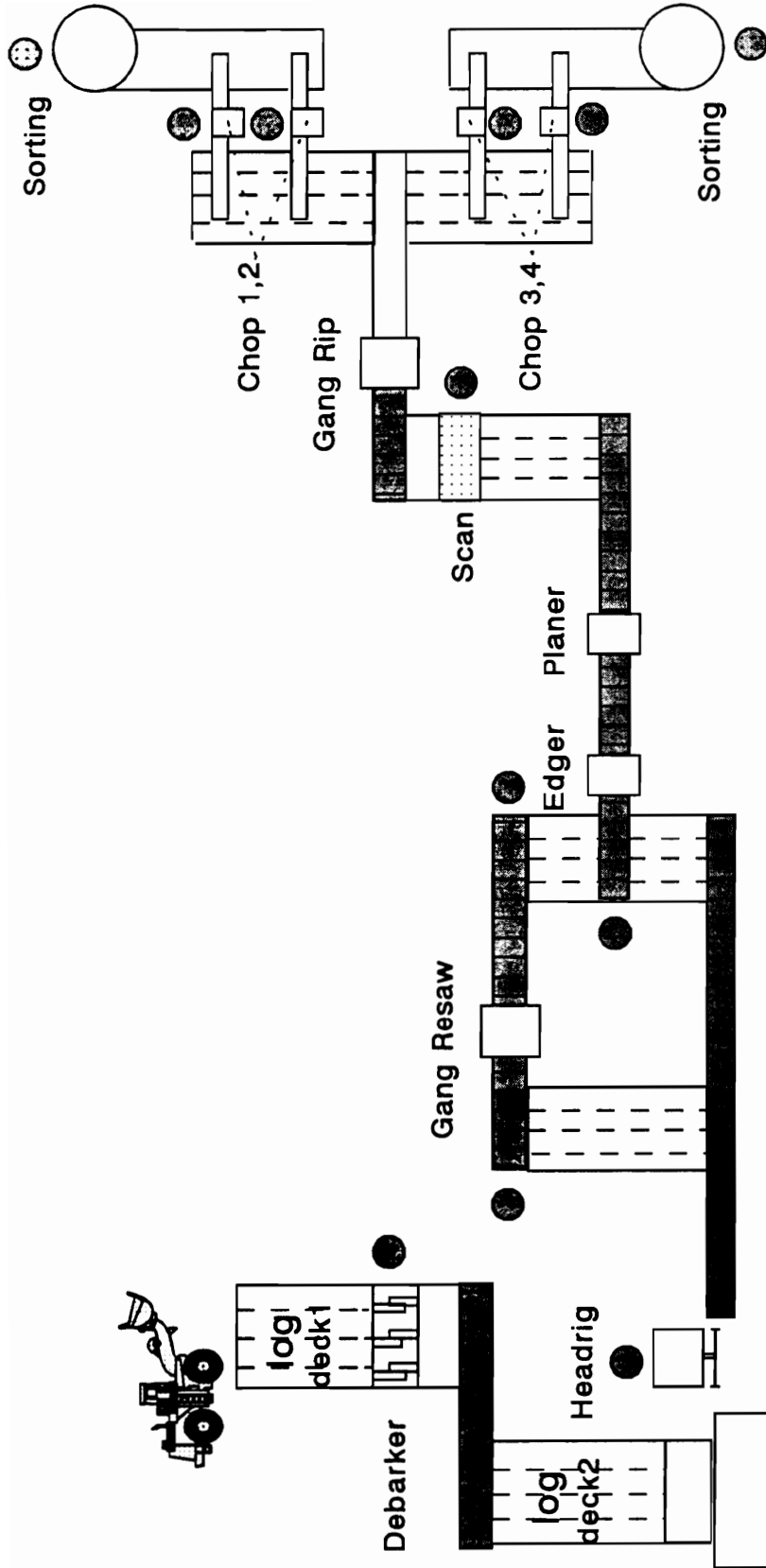
The sensitivity of NPV and ROS to the changes in dimension part price, log price, labor cost, overhead cost, initial capital investment, weighting factor for part lengths, green cutting yield, and drying and remanufacturing loss was analyzed. Dimension part price, green cutting yield, drying and remanufacturing loss were found to be the most important factors affecting the economic feasibility and profitability of the direct processing system.

in each automatic chop line was reduced from two to one in both modified Design 1 and 4. In modified Design 5, the number of chop saws was reduced from six to four and other components of the system remained unchanged (Figure 3.10).

A summary of the simulation results for the three modified models is given in Table 3.7. These modified designs are more efficient than their initial designs. After modification, the labor productivity in terms of green part output (BF) per direct worker per day has increased significantly for all of the three designs modified (Table 3.8). After adding two additional automatic chop saws, the production rate of Design 1 and 4 is almost doubled and the time in system has decreased to half as much as in their initial designs. Machine and labor utilization of modified Design 1 and 4 are also much higher than initial Designs 1 and 4. After two chop saws were removed, machine and labor utilization of modified Design 5 has increased, while the production rate and the time in system have not changed significantly.

T-tests were performed to determine whether the change in production rate was proportional to the number of chop saws added for Design 1 and Design 4 and if the production rate remains unchanged for Design 5 after two chop saws were removed. All these tests are two-side tests. As shown in Table 3.8, the results of these T-tests indicate that although the production rate of Design 1 and Design 4 has increased significantly after adding two automatic chop saws, the increase in production rate is not proportional to the number of the automatic chop saws added. The T-test results also show that the production rate of Design 5 remains unchanged after two chop saws were removed from the initial design (Table 3.8).

After the three designs were modified, new ANOVA tests were conducted among the six designs (three unmodified designs and three modified designs). The new ANOVA tests show that at least one of the six designs significantly differs from the rest



**Figure 3.10** Layout of modified mill design 5

**Table 3.7 Summary of simulation results for the three modified designs**

| Output Variable   | Design # |       |       |
|---|----------|-------|-------|
|   | MD1      | MD4   | MD5   |
| Log processed (BF/day)                                      | 19541    | 17835 | 17842 |
| Green Part Output (BF/day)                                  | 14343    | 11004 | 11008 |
| Labor Productivity (BF green part output per worker per dy) | 1024.5   | 733.6 | 733.9 |
| Time in System (min)  | 22.3     | 23.5  | 23.2  |
| Machine Uti.(%)   | 75.25    | 63.14 | 59.83 |
| Labor Uti.(%)   | 63.13    | 48.71 | 54.50 |

MD1 - Modified Design 1 (Live-sawing, Gang-rip-first, four automatic chop saws).

MD4 - Modified Design 4 (Five-part-sawing, Gang-rip-first, four automatic chop saws).

MD5 - Modified Design 5 (Five-part-sawing, Gang-rip-first, four manual chop saws).

**Table 3.8 T-Test results: modified designs vs. initial designs**

| Variables   | Test hypothesis   | $t_{obs}$ | Result*      |
|---|---|-----------|--------------|
| Daily log volume processed (BF/day)                             | $H_0: Y_{D1} = 2Y_{MD1}$<br>$H_1: Y_{D1} \neq 2Y_{MD1}$ | 11.407    | Reject $H_0$ |
|   | $H_0: Y_{D4} = 2Y_{MD4}$<br>$H_1: Y_{D4} \neq 2Y_{MD4}$ | 117.65    | Reject $H_0$ |
|   | $H_0: Y_{D5} = Y_{MD5}$<br>$H_1: Y_{D5} \neq Y_{MD5}$   | 0.7907    | Accept $H_0$ |
| Daily green part volume produced (BF/day)                       | $H_0: Y_{D1} = 2Y_{MD1}$<br>$H_1: Y_{D1} \neq 2Y_{MD1}$ | 11.374    | Reject $H_0$ |
|   | $H_0: Y_{D4} = 2Y_{MD4}$<br>$H_1: Y_{D4} \neq 2Y_{MD4}$ | 119.10    | Reject $H_0$ |
|   | $H_0: Y_{D5} = Y_{MD5}$<br>$H_1: Y_{D5} \neq Y_{MD5}$   | 0.4681    | Accept $H_0$ |
| Labor Productivity (BF of green part output per worker per day) | $H_0: Y_{MD1} = Y_{D1}$<br>$H_1: Y_{MD1} > Y_{D1}$      | 114.66    | Reject $H_0$ |
|   | $H_0: Y_{MD4} = Y_{D4}$<br>$H_1: Y_{MD4} > Y_{D4}$      | 83.58     | Reject $H_0$ |
|   | $H_0: Y_{MD5} = Y_{D5}$<br>$H_1: Y_{MD5} > Y_{D5}$      | 47.26     | Reject $H_0$ |

Notation:

\* - Test results at  $\alpha$  level of 0.05

$Y_{Di}$  - Mean value for initial design i

$Y_{Mdi}$  - Mean value for modified design i



in both daily log volume processed and daily volume of green parts output with the p-value of 0.0001. Duncan's multiple comparison tests further indicate that for daily volume of log processed, there is no significant difference among modified Design 1, Design 2 and Design 3 and between modified Design 4 and modified Design 5 at  $\alpha=0.05$  level (Table 3.9). And the daily volume of green parts output are not significantly different between modified Design 1 and Design 2 and between modified Design 4 and modified Design 5 at  $\alpha=0.05$  level (Table 3.9).

### 5.3 Discussion

The production rate and other operational performances of the direct processing system can be estimated by using system simulation modeling techniques. Based on the simulation results of the six final models, the direct processing system with one headrig saw can process 17.8 to 20.5 MBF No.3 grade red oak logs and turn out 11 to 14.3 MBF 4"/4 rough green dimension parts of random width per shift (Table 3.9), depending on the system layout. The labor productivity of the direct processing system with one headrig saw can reach at 684 to 1025 MBF green part output per worker per day, which also depends on the layout designs of the system. The estimated production rate will be used in the economic analysis of the direct processing system in the **Section 4**.

Duncan's multiple comparison tests show that within a given sawing pattern, the labor productivity in terms of green part output per direct worker per day is significantly higher for Rip-first designs than that for Crosscut-first designs (Table 3.9). For example, the labor productivity of Modified Design 1 and Design 2 is higher than that of Design 3. And the labor productivity of Modified Design 4 and 5 is higher

**Table 3.9 Production rate and productivity of the six designs after modification - Confidence intervals and Duncan's multiple comparison results**

| Output Variables   | Design # | Mean $\pm$ 95% CI | Grouping* |
|--|----------|-------------------|-----------|
| Log Processed<br>(BF per day)  | MD1      | 19541 $\pm$ 276   | A         |
|  | D2       | 19454 $\pm$ 323   | A         |
|  | D3       | 19450 $\pm$ 333   | A         |
|  | MD4      | 17835 $\pm$ 192   | B         |
|  | MD5      | 17842 $\pm$ 153   | B         |
|  | D6       | 20585 $\pm$ 178   | C         |
| Green Parts Output<br>(BF per day)                                       | MD1      | 14343 $\pm$ 203   | A         |
|  | D2       | 14279 $\pm$ 237   | A         |
|  | D3       | 14062 $\pm$ 241   | B         |
|  | MD4      | 11004 $\pm$ 118   | C         |
|  | MD5      | 11008 $\pm$ 94    | C         |
|  | D6       | 12989 $\pm$ 112   | D         |
| Labor Productivity<br>(Bf of green part<br>output per worker<br>per day) | MD1      | 1024.5 $\pm$ 14.5 | A         |
|  | D2       | 892.4 $\pm$ 14.8  | B         |
|  | D3       | 827.2 $\pm$ 14.2  | C         |
|  | MD4      | 733.6 $\pm$ 7.9   | D         |
|  | MD5      | 733.9 $\pm$ 6.3   | D         |
|  | D6       | 683.6 $\pm$ 5.9   | E         |

\* Means with the same letter are not significantly different at  $\alpha=0.05$  level.

D2- Design 2 (Live-sawing, Gang-rip-first, six manual chop saws).

D3- Design 3 (Live-sawing, Crosscut-first).

D6- Design 6 (Five-part-sawing, Crosscut-first).

MD1- Modified Design 1 (Live-sawing, Gang-rip-first, four automatic chop saws).

MD4- Modified Design 4 (Five-part-sawing, Gang-rip-first, four automatic chop saws).

MD5- Modified Design 5 (Five-part-sawing, Gang-rip-first, four manual chop saws).

than that of Design 6. The result that Rip-first designs have higher labor productivity than Crosscut-first designs is similar to that obtained by Hall et al. (1980) in comparing Rip-first and Crosscut-first rough mills for producing hardwood dimension parts from No.1 Common red oak lumber.

For the designs that use Live-sawing followed by Rip-first (Modified Design 1 and Design 2), the use of automatic chop saws significantly increased the productivity of the system (Modified Design 1 has higher labor productivity than Design 2). For the designs that use Five-part-sawing followed by Rip-first (Modified Design 4 and 5), however, the labor productivity of Modified Design 4 and Modified Design 5 showed no significant difference. The reason is that the automatic chop saws were not used in full capacity in Modified Design 4 due to the restriction of gang-rip saw capacity,

Systems simulation modeling proved to be a very successful tool in identifying and removing bottlenecks in the layout designs of the direct processing systems. Based on the simulation results, the bottlenecks in the initial designs were identified successfully. After the bottlenecks were removed from initial designs, the productivity of the modified designs were improved significantly.

The bottleneck occurs in different locations in the layouts designed for using Live-sawing and those designed for using Five-part-sawing. This can be attributed to the fact that the number of flitches generated by Five-part-sawing is more than that generated by Live-sawing. The more flitches generated from a log, the more work the gang-rip saw (in Rip-first designs) and crosscut saws (in Crosscut-first designs) need to process. Thus, the gang-rip saw in Rip-first designs and the crosscut saws in Crosscut-first designs are more likely to become bottlenecks in the designs for using Five-part-sawing.

Since the sawing pattern and cutting sequence affect the production rate and labor productivity of the direct processing system, the selection of sawing pattern and cutting sequence should not only be based on the dimension yields and value recovery but also should consider the difference in production rate and productivity.

In Modified Design 1 and 4, the simulation results indicated that the increase in production rate is not proportional to the number of automatic chop saws added. This result reflects the interactive nature of the whole direct processing system. As a whole system, each design consists of many components which are dynamically interrelated. Any changes in one component can cause reactions of other components in the system. This interaction is easily captured by system simulation. For example, after the bottleneck in initial Design 1 was identified and removed by adding two additional automatic chop saws, the utilization of the headrig saw in Modified Design 1 has reached its capacity limit (Table 3.10), hence the increase in production rate of Modified Design 1 is restricted by the capacity of the headrig saw. Similarly in Design 4, after adding two additional automatic chop saws, chopping capacity is no longer a bottleneck, however, a new bottleneck emerges. In Modified Design 4, the capacity of the gang-rip saw reached its limit before the capacity of all automatic chop saws was fully utilized (Table 3.10). The capacity of gang-rip saw then became the new bottleneck and constrained the production rate increase.

In this study, the automatic chops used in Design 1 and 4, Modified Design 1 and 4 are not capable of continuously (or butt-to-butt) feeding. If these automatic chop saws are capable of continuously feeding, their capacity will increase, and the number of automatic chop saws required in Modified Design 1 and 4 can be reduced. Further study can be carried out for continuously-feeding automatic chop saws using the same methodology presented in this dissertation.

**Table 3.10 Machine and labor utilization of the three modified designs(%)**

|                              | Machine Utilization (%) |       |       | Labor Utilization (%) |       |       |
|------------------------------|-------------------------|-------|-------|-----------------------|-------|-------|
|                              | Design #                |       |       | Design #              |       |       |
| Machines/Oper.               | MD1                     | MD4   | MD5   | MD1                   | MD4   | MD5   |
| Log Fork                     | 21.87                   | 21.4  | 22.63 | 21.78                 | 21.40 | 22.63 |
| Debarker                     | 27.50                   | 26.14 | 25.62 | 27.50                 | 26.14 | 25.62 |
| Headrig Saw                  | 99.51                   | 75.28 | 75.86 | 99.51                 | 75.28 | 75.86 |
| Gang Resaw                   | -----                   | 17.94 | 18.09 | -----                 | 9.03  | 9.11  |
| After Resaw Mater. Separator | -----                   | ----- | ----- | -----                 | 11.82 | 11.95 |
| Planer                       | 57.32                   | 71.21 | 71.92 | 57.28                 | ----- | ----- |
| Edging Saw                   | 68.83                   | 85.66 | 86.51 | 45.73                 | 44.45 | 43.92 |
| Rip Scanner                  | 59.88                   | 62.84 | 63.64 | 59.88                 | 62.84 | 63.64 |
| Gang-Rip Saw                 | 77.36                   | 96.45 | 97.21 | -----                 | ----- | ----- |
| Defect Markers               | -----                   | ----- | ----- | 56.21                 | 44.87 | ----- |
| Auto Chop saws               | 95.63                   | 75.19 | ----- | -----                 | ----- | ----- |
| Manual Chop Saws             | -----                   | ----- | 64.12 | -----                 | ----- | 71.84 |
| Crosscut Saws                | -----                   | ----- | ----- | -----                 | ----- | ----- |
| Single Line Rip Saws         | -----                   | ----- | ----- | -----                 | ----- | ----- |
| Part Sorters                 | -----                   | ----- | ----- | 86.82                 | 75.04 | 69.34 |

MD1 - Modified Design 1 (Live-sawing, Gang-rip-first, four automatic chop saws).

MD4 - Modified Design 4 (Five-part-sawing, Gang-rip-first, four automatic chop saws).

MD5 - Modified Design 5 (Five-part-sawing, Gang-rip-first, four manual chop saws).

There are many possible design alternatives for the direct processing system. The six designs presented in this paper are just a small portion of them. Operationally, these six designs after modification appear to be reasonable. Their performance will be further judged based on their economic performance.

In this section, only the operations of green part manufacturing were addressed and the operations after green part manufacturing were not considered due to the uncertainty in the drying of dimension parts. The operations after green part manufacturing will be addressed in the next section.

## 6.

## SUMMARY

To implement the concept of directly processing hardwood logs into rough dimension parts, a manufacturing system that carries out the operations of converting logs into rough dimension parts need to be designed. To investigate the dynamic performance of the various mill designs that convert No.3 red oak logs into rough dimension parts, system simulation models for these designs need to be developed. To determine the economic feasibility and profitability of the designed manufacturing system, the production rate of the system needs to be estimated.

Six initial mill designs were developed to carry out the different sawing patterns and cutting sequences. System simulation models of these designs were developed using SIMAN IV. And animation models were also built using CINEMA for each mill design in conjunction with simulation model development to assist simulation model development, model verification and validation.

The dynamic performance of the direct processing systems was investigated. Based on simulation results, bottlenecks in the initial designs were identified and production lines were balanced. It was found that bottlenecks occurred in different locations in those designs for carrying out Live-sawing and those designs for carrying out Five-part-sawing. Three of the six initial designs were modified for balancing production capacity. The production rate and labor productivity of these modified designs were much higher than their initial designs. System simulation was proved to be a very powerful tool for capturing the dynamic performance of a "whole system" that can not be directly manipulated.

The production rates of the designed mills were estimated through simulation. Based on simulation results of the six final models, the direct processing system with

one headrig saw can process 17.8 to 20.5 MBF No.3 grade red oak logs and turn out 11 to 14.3 MBF, Clear-two-face, 4/4 rough green dimension parts of random width per shift. The production rate varies among the different mill designs. Production rate in both daily log volume processed and daily volume of green part output are significantly different between those designs for using Live-sawing and those for using Five-part-sawing. For the designs using the same sawing pattern, the productivity in terms of green parts output per worker per day for Rip-first designs is slightly higher than for crosscut-first designs. These results will be used in subsequent economic analysis of the direct processing system.

Because of the difference in production rate and productivity between the design alternatives for different processing methods, not only dimension yields and dollar value recovery but also the production rate and productivity should be considered in selecting sawing pattern and cutting sequence. The performance of the design alternatives for the direct processing system needs to be further judged by their economical performance.



## 7.

## REFERENCES

- Adams, E. L. 1984a. DESIM: a system for designing and simulating hardwood sawmill systems. USDA Forest Service General Technical Report NE-89, USDA Forest Service, Northeastern Experiment Station, Broomall, PA, 10 pp.
- \_\_\_\_\_. 1984b. DESIM user's manual: a procedural guide for designing and simulating hardwood sawmill systems. USDA forest Service General Technical Report NE-94, USDA Forest Service, Northeastern Experiment Station, Broomall, PA, 58 pp.
- \_\_\_\_\_. 1985. DESIM data manual: a procedural guide for developing equipment processing and down time data. USDA Forest Service General Technical Report NE-102, USDA Forest Service, Northeastern Experiment Station, Broomall, PA, 23 pp.
- \_\_\_\_\_. 1988. Testing DESIM for designing and simulating the operation of hardwood sawmills. *Forest Products Journal* 38(7/8):41-45.
- Anderson, R. B. 1983. Furniture rough mill costs evaluated by computer simulation. USDA Forest Service Research Paper NE-518, USDA Forest Service, Northeastern Experiment Station, Princeton, WV, 11 pp.
- Araman, P. A. 1977. Use of computer simulation in designing and evaluating a proposed rough mill for furniture interior parts. USDA Forest Service Research Paper NE-361, USDA Forest Service, Northeastern Experiment Station, Upper Darby, PA.
- Hall, S.P., E.M. Wengert, R.A. Wysk and M.A. Agee. 1980. Yield distributions and cost comparisons of a crosscut-first and a gang-rip-first rough mill producing hardwood dimension stair parts. *Forest Products Journal* 30(5):34-39.
- Kline, D. E., J. K. Wiedenbeck, and P. A. Araman. 1992. Management of wood products manufacturing using simulation/animation. *Forest Products Journal* 42(2):45-52.
- Law, A. M. and W. D. Kelton. 1991. *Simulation Modeling and Analysis*. Second ed. McGraw-Hill Book Company, New York. 759 pp.
- Meimban, R.J., G.A. Mendoza, and H. Carino. 1992. Integrating economic performance and process simulation models in evaluating sawmill design alternatives. *Wood & Fiber Science* 24(1):68-72.
- Pegden, C. D., R. E. Shannon, and R. P. Sadowski. 1990. *Introduction to Simulation Using SIMAN*. McGraw-Hill, Inc., New York, N.Y. 615 pp.
- Systems Modeling Corp. (SMC). 1990. *CINEMA IV Reference Guide*. 504 Beaver Street, Sewickley, PA. 155 pp.
- Wagner, Jr., F. G. and F. W. Taylor. 1983. SPSM-A Southern Pine Sawmill Model. *Forest Products Journal* 33(4):37-42.

Wiedenbeck, J.K. 1992. The potential for short length lumber in the furniture and cabinet industries. Ph.D Dissertation, Virginia Polytechnic Institute and State University, 260 pp.

## Section 4

# **ECONOMIC EVALUATION OF THE DIRECT PROCESSING SYSTEM FOR CONVERTING NO.3 GRADE RED OAK LOGS INTO ROUGH DIMENSION PARTS**

## **1. ABSTRACT**

A financial analysis using discounted cash flow methods was conducted to determine the economic feasibility of the direct processing system that processes No.3 grade red oak logs directly into rough dimension parts. Six design alternatives of the direct processing system were evaluated. Under the assumptions of this study, measured by both Net Present Value (NPV; discount rate = 12%) and Internal Rate of Return (IRR), all six designs are economically acceptable.

With the highest NPV of \$4,193,700 and the highest IRR of 29.6 percent, the design that uses Live-sawing and Gang-rip-first cutting with manual chop saws (design2) was found to be the most economically attractive design among the six design alternatives evaluated.

The profitability of the direct processing system, measured in Return on Sales (ROS), was estimated and compared with the profitability of the conventional processing system that processes standard grade lumber into dimension parts. The results showed that the direct processing systems are more profitable than the conventional processing system for making dimension parts.

The sensitivity of NPV and ROS to the changes in dimension part price, log price, labor cost, overhead cost, initial capital investment, weighting factor for part lengths, green cutting yield, and drying and remanufacturing loss was analyzed. Dimension part price, green cutting yield, drying and remanufacturing loss were found to be the most important factors affecting the economic feasibility and profitability of the direct processing system.

The direct processing system has been used in Japan and Europe (Araman, 1987), and there is a trend toward processing dimension parts from logs in the United States (Lawser 1991, Southern Lumberman 1992). However, several technical and economic problems remain unsolved. These problems include the uncertainty of cutting yield and value recovery from different grades and sizes of logs, the uncertainty of operational and economic performance. Before dimension manufacturers will accept the direct processing system that produces rough dimension parts directly from logs, these problems must be solved. In Section 2 the cutting yield and value recovery from No.3 red oak logs were estimated. And in Section 3, the operational performance of several designs of the direct processing system was evaluated. However, the economic performance of the direct processing system is still unknown. If the proposed direct processing system has a poor economic return, such a manufacturing system would not be a wise investment. If the direct processing system can not generate more profit than current conventional processing systems, dimension manufacturers will not shift to direct processing system. Therefore, two major concerns for the new processing system are whether it is economically feasible and whether it can be more profitable than the conventional processing system that processes standard grade lumber into dimension parts.

Among the many methods for evaluating the economic feasibility of proposed projects, NPV and IRR are the two most commonly used economic analysis tools. Both NPV and IRR are discounted cash flow techniques which take into account the time value of money. NPV is defined as the present value of expected future cash flows discounted at the appropriate cost of capital, minus the cost of the investment (Weston

& Copeland 1986). If the net present value is positive, the project earns more than the required rate of return, thus, the project should be an acceptable alternative. If the net present value is negative, the alternative should be rejected (Weston & Copeland 1986). IRR is defined as the interest rate that equates the present value of the expected future cash flows to the initial cost outlay (Weston & Copeland). If IRR is greater than the cost of capital (interest rate of capital), the project should be accepted; otherwise, it should be rejected (Weston & Copeland 1986).

NPV and IRR are frequently used in analyzing investment opportunities in wood product manufacturing. Araman and Hansen (1983) used NPV and IRR as evaluation criteria in an economic feasibility study of a conventional processing system of standard-size edge-glued blanks for furniture and cabinet parts. They used the cash flow computer program developed by Harpole (1978) to obtain IRR and NPV values in their study. IRR was also used in evaluating System 6 for making kitchen cabinet Clear-two-face blanks from small-diameter, low-grade red oak logs (Reynolds et al. 1983) and for making black cherry blanks (Reynolds & Hansen 1986). Stewart et al. (1982) applied IRR and NPV methods in determining the economic feasibility and comparison of different processing systems for producing dimension products from short logs of black walnut, black cherry, and yellow-popular. Recently, Huber et al. (1989) used IRR and NPV in an economic analysis of cutting hardwood dimension parts with an automated processing system.

Profitability is the most important criteria for evaluating a firm's performance. Usually, profitability can be measured in one of three ways (Weston & Copeland 1986). One measurement is the return on sales (or profit margin on sales) which is

defined as the ratio of the net profit to the sales. Another measurement of profitability is the return on net worth which is defined as the ratio of the net profit to the net worth, it measures the rate of return on the stockholders' investment. The other measurement of profitability is return on assets (or return on investment) which is defined as the ratio of the net profit to the total assets of the firm. Dun and Bradstreet (Dun & Bradstreet Yearly Report) provides profitability data for over 800 different lines of business as defined by the U.S. Standard Industrial Classification (SIC) code number, including the hardwood dimension and flooring industry, classified (SIC 2426).

### **3. OBJECTIVE**

This section brings the results together from Section 2 and 3 to assess the economic viability of the direct processing system. Therefore, the objective of this section was to determine the economic feasibility of the direct processing system for converting No.3 red oak logs into rough dimension parts and to compare the profitability of the direct processing system with that of the conventional processing system.

## **4.**

## **METHODS**

### **4.1 Estimation of the Operations after Green Parts Manufacturing**

In Section 3, operations after green part manufacturing were not considered due to the uncertainty in the drying red oak dimension parts. However, green parts are not the final products to be sold in market. In this study, the final products of the direct processing system are assumed to be standard-size edge-glued panels and cut-to-size dimension parts. To completely estimate the economic performance of the direct processing system, those operations required after green parts are produced must be considered. The operations after green parts manufacturing include stacking and sticking, drying, resawing (cutting off drying defects and getting edge-glue quality parts), edge-gluing to panels, and cutting panels into parts. Six designs described in Section 3 (modified design 1, design 2, design 3, modified design 4, modified design 5 and design 6) were expanded to include the operations after green parts manufacturing. The complete facility layouts of the six design alternatives used in the economic analysis are illustrated in Figures 4.1 through 4.6.

At the end of the green parts production line, random width green parts are sticker-stacked on skids. These green part stacks are then moved into a predrier and continuously cycled through the predrier. At about 25 percent moisture content, the parts are moved to a conventional kiln drier and dried to the final moisture content of 6 percent. Average time in the predrier was assumed to be 5 weeks. The required predrier capacity was calculated based on the assumption that the required drying time in predrier will be 5 weeks. The required drying capacity was then multiplied by a factor of 1.25 to provide excess capacity to allow for possible drying problems or

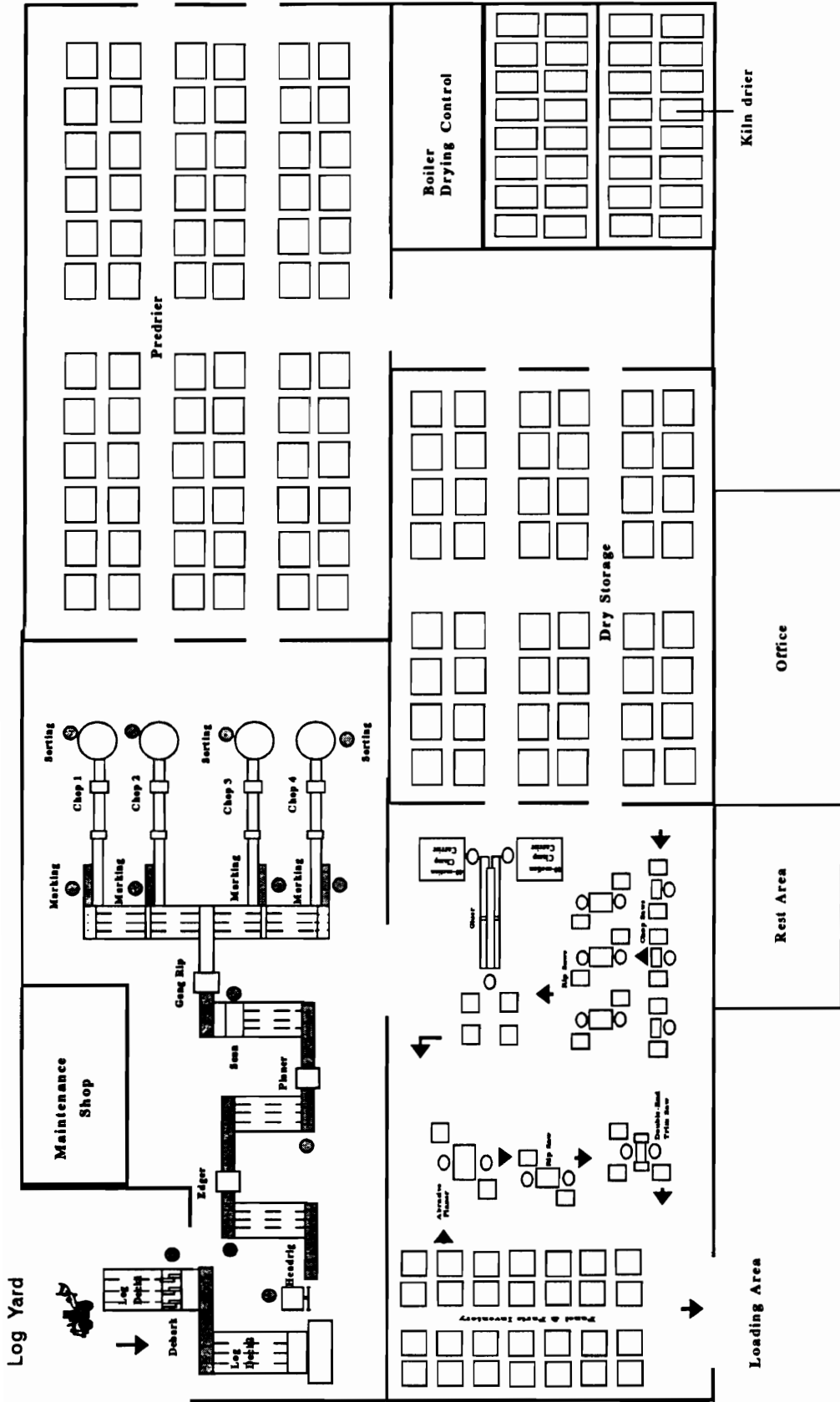


Figure 4.1 Complete layout of modified design 1



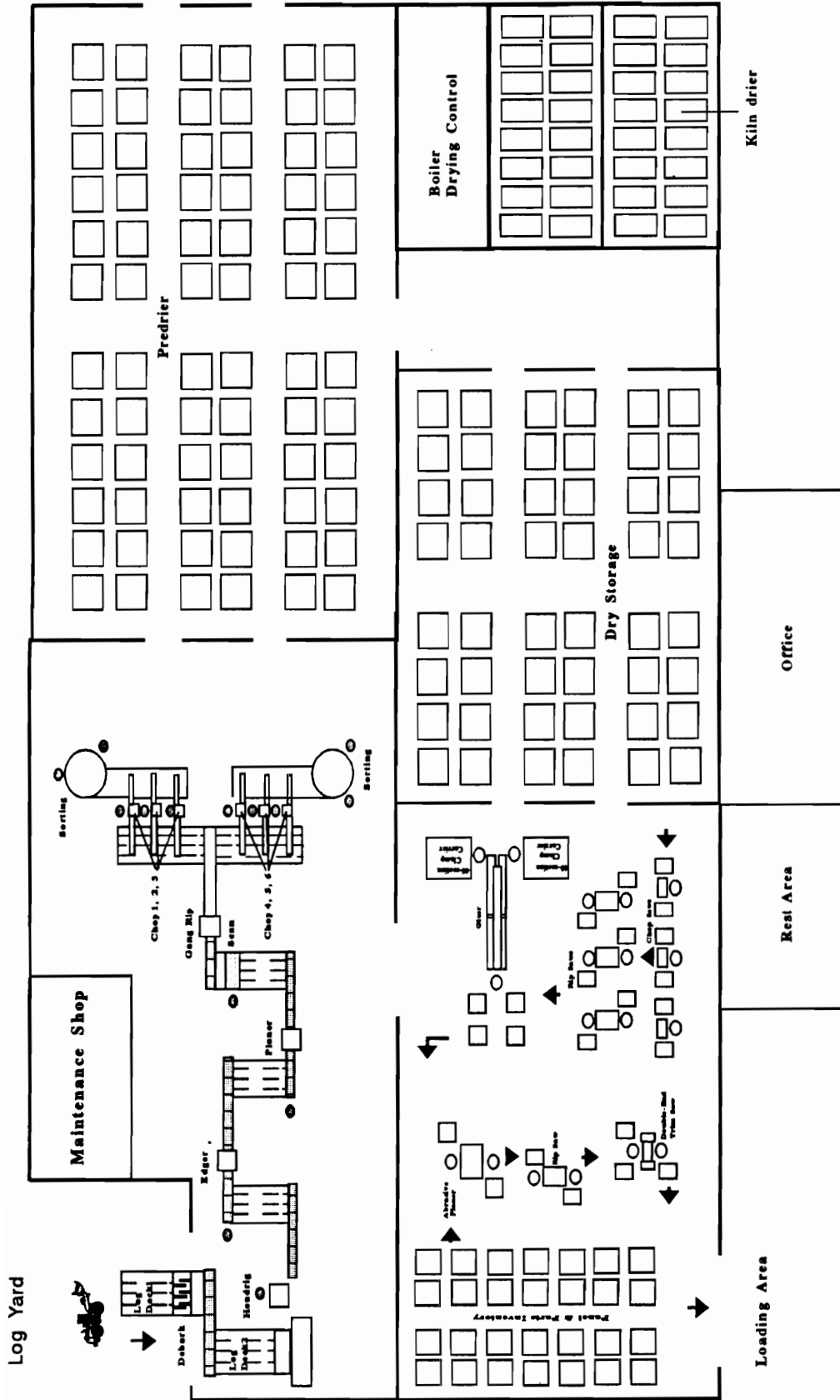
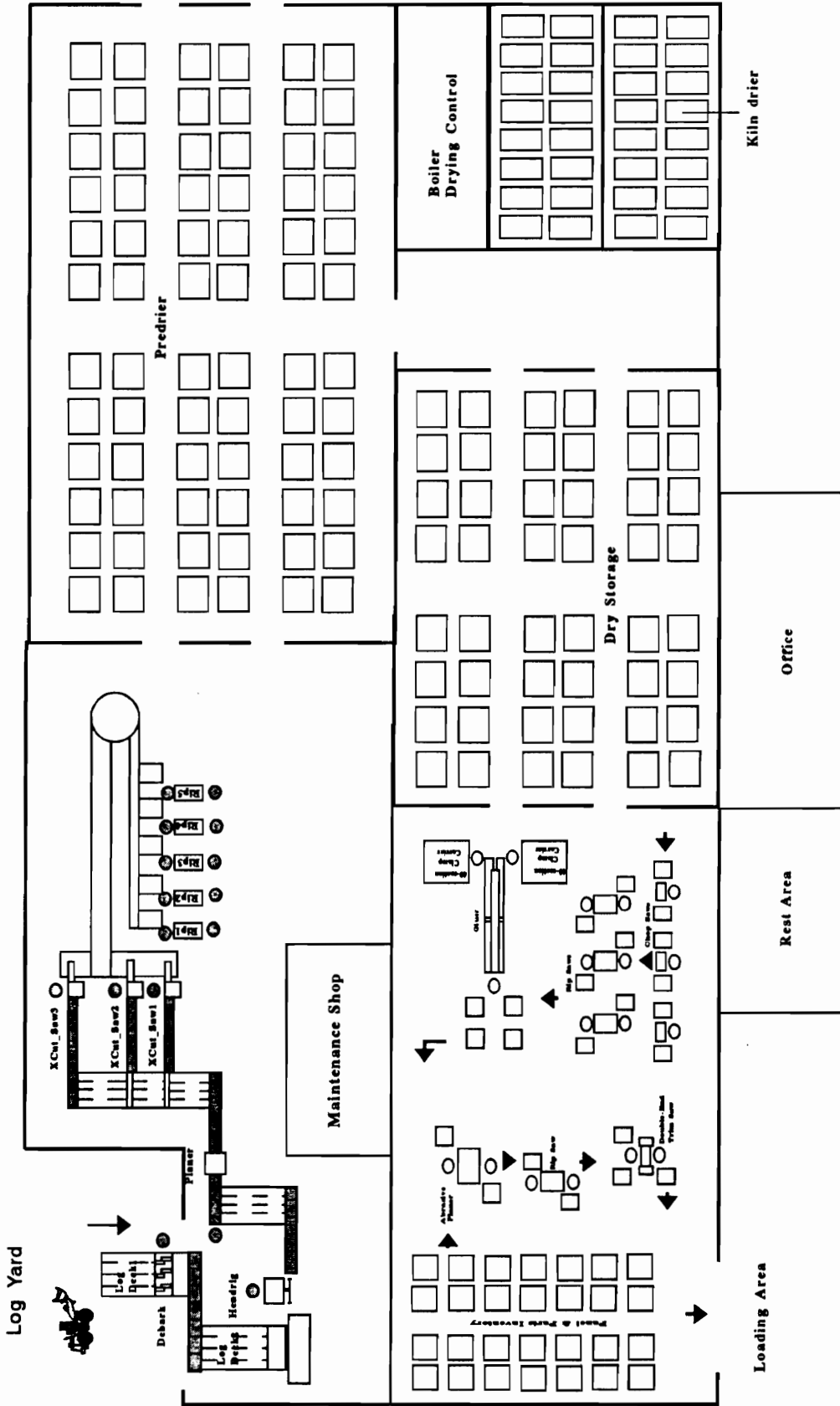


Figure 4.2 Complete Layout of Design 2



**Figure 4.3 Complete Layout of Design 3**

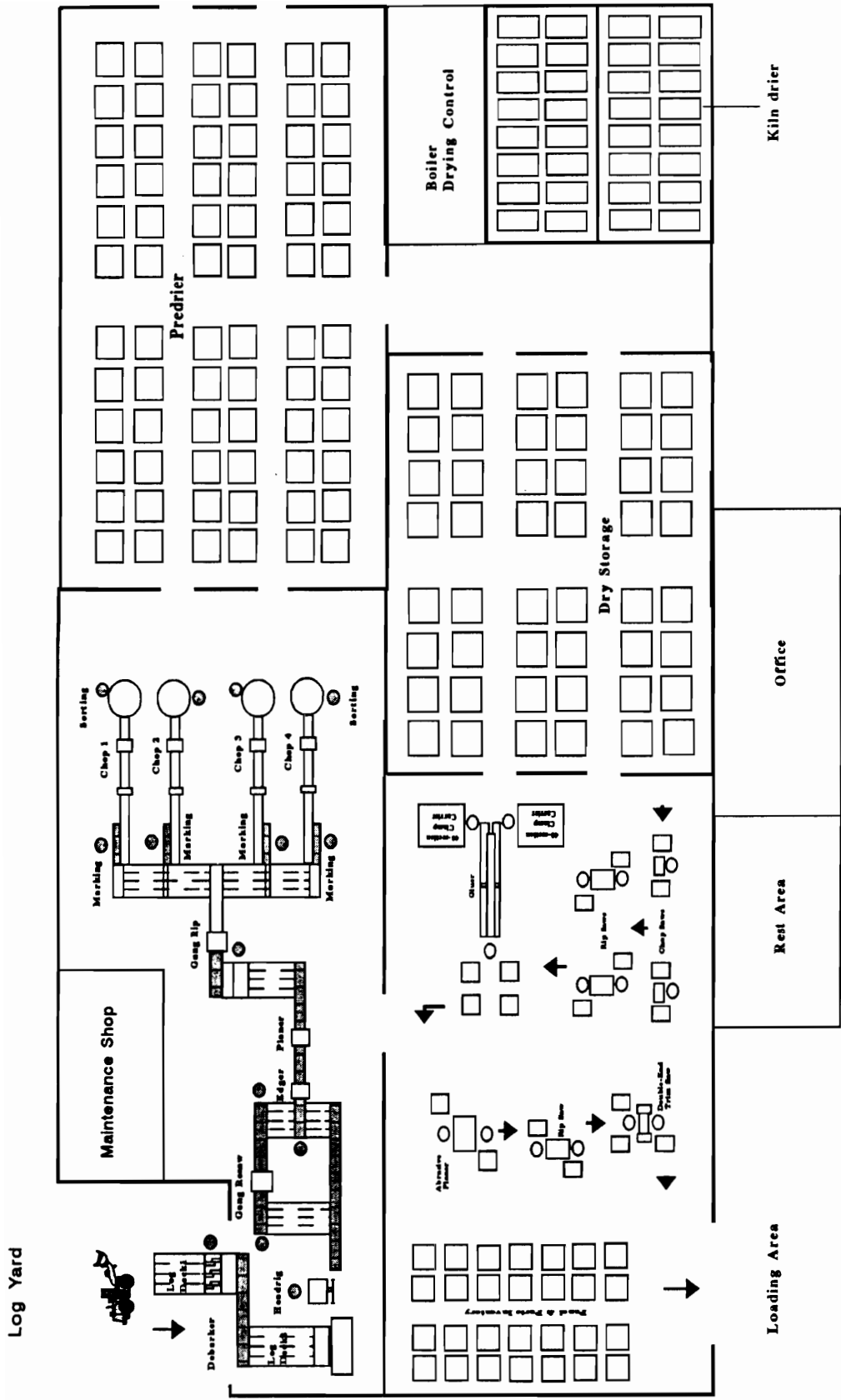


Figure 4.4 Complete layout of modified design 4



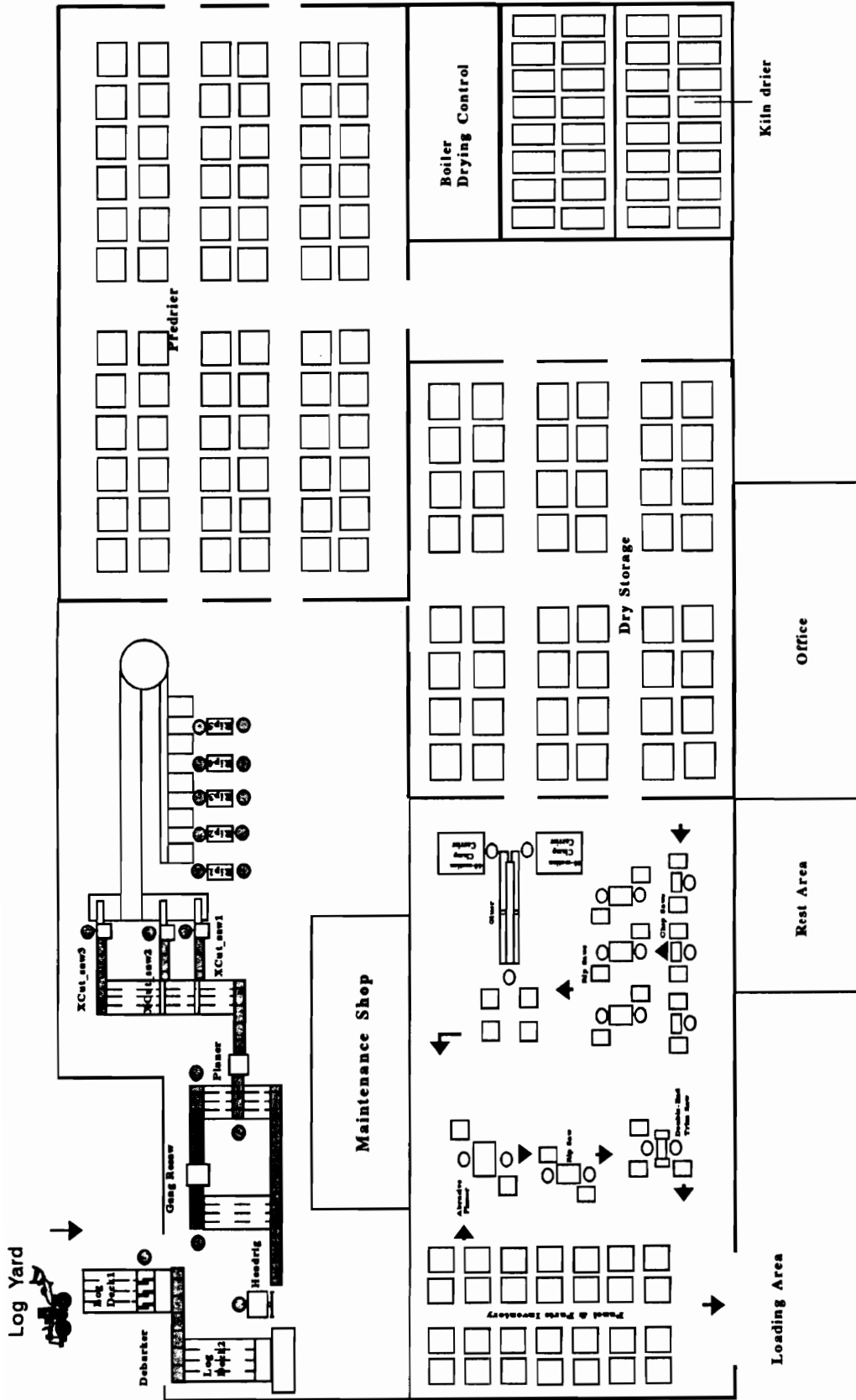


Figure 4.6 Complete Layout of Design 6

delays. The average drying time in the conventional kilns was assumed to be one week. The required kiln drier capacity was calculated based on this assumption. As with the predrier, the required drying capacity was then multiplied by a factor of 1.25 as the designed drying capacity to provide excess drying capacity.

After drying, parts are moved into a storage area where dried parts cool down and are maintained at their new moisture content. This storage area can store about two weeks of material supply to remanufacturing area and provides a buffer between part drying and remanufacturing should one of the kiln driers break down.

In the remanufacturing area, some of the dried parts are remanufactured to cut off drying defects and obtain edge-gluing quality. If required, some customer-size parts may be cut from the dried random-width parts. Those parts that are still in random width are matched for color and grain into panel sets. These panel sets are then edge-glued in a 40-section automatic clamp carrier. After a 24 hour period to allow for proper glue bonding, the panels are abrasively planed to  $7/8$ ". Further cutting edge-glued panels to fixed-width parts can be carried out by one single-arbor rip saw and one double-end trim saw. The remanufacturing capacity was sized such that it would not limit the capacity of the whole system. Three straight-line rip saws and three chop saws were used in resawing in modified design 1, design 2, design 3 and design 6, and two straight-line rip saws and two chop saws were used in modified design 4 and 5. The number of glue applicators and clamp carriers was estimated based on the data provided by the machine manufacturer. Two glue applicators and two 40-section clamp carriers are used in all of the six designs.

## 4.2 Estimation of Economic Performance

Two measurements of investment performance, NPV and IRR were used in evaluating the economic feasibility of the direct processing system. ROS was used as the measurement of profitability in comparing the direct processing system and conventional processing system. NPV, IRR and ROS were estimated for all of the six design alternatives. The following assumptions were used in the initial analysis:

1. The final products of the direct processing system will be standard edge-glued panels and cut-to-size dimension parts.
2. All final products produced by the proposed direct processing mill will be sold.
3. The proposed direct processing mill will be totally new.
4. The proposed direct processing mill will be fully equity financed.
5. The minimum attractive return rate will be 12%.
6. The mill will operate 250 days a year and one shift per day.
7. The mill will process only No.3 red oak logs and produce 4/4 clear-two-face quality dimension parts.
8. The mill will operate at 30% of its full capacity in the first year and 70% in the second year. Starting from the third year, the mill will enter normal operation, running at 90% of its capacity due to some unforeseeable events such as absence of workers, log shortage, and machines down etc.
9. The profitability of current dimension manufacturers provided by Dun and Bradstreet is a representative sampling of all hardwood dimension manufacturers who are currently using the conventional processing system.
10. The proposed direct processing dimension mill will be located in Wise County, Virginia.

11. The life of the proposed direct processing mill will be ten years.
12. A combination method of predrying and conventional kiln drying will be used to dry 4/4 red oak dimension parts.
13. The drying and remanufacturing loss of dimension parts will be 15 percent.

#### **4.2.1 Estimation of Initial Investment**

First, the requirement for initial investment was estimated. Initial investment is the sum of the capital for building, equipment, land, and working capital for starting the operation.

The cost of building was estimated based on the data provided by local construction contractors. Pre-engineered superstructure with a concrete slab was chosen for the building of the proposed manufacturing plant. The unit cost of this type of building is about \$18 per square foot. The cost of office building is about \$40 per square foot. The costs of the predrier and kiln driers were estimated on the basis of the designed drying capacity. It was assumed that the cost of the predrier is \$1,000 per MBF capacity and the cost of kiln driers is \$3,500 per MBF capacity. The itemized building costs for the six designs are listed in Appendices 2.1 through 2.6.

The capital requirement for purchasing equipment was estimated based on the price of each piece of equipment provided by equipment manufacturers. The installation cost of equipment was assumed to be 10 percent of equipment expenditures, excepting the expenditures of log loaders, fork lifts, factory trucks and furniture. The itemized equipment costs for the six designs are listed in Appendices 3.1 through 3.6.

It was estimated that 8 acres of land would be needed to build the proposed direct processing dimension plant (for all of the six design alternatives). The information provided by the local economic planning commission indicated that the cost of per acre



of land is \$10,000 in Wise County, Virginia. Adding \$20,000 for site preparation and improvement, the total cost of land will be \$100,000.

The amount of working capital needed for starting operation was estimated based on the capital requirement covering the first two month's operating costs. This included the cost of carrying out two month's log supply inventory and a certain amount of maintenance supply inventory, first two month's wage, first two month's administration costs, first two month's selling expense, and first two month's utility costs and insurance costs. Table 4.1 lists the initial investment requirements for the six design alternatives.

#### 4.2.2 Estimation of Annual Revenue

It was assumed that the proposed direct processing dimension plant would produce cutting bill #1 which has 11 cutting lengths ranging from 15" to 75" (see Table 2.1 in Section 2). The dimension yield used in estimating revenue is the dimension yield obtained through running the computer program CORY in Section 2 minus 5 percent. The cutting yield obtained from CORY was 73.4 percent. The cutting yield used in estimating revenue is 68.4 percent. This 5 percent deduction can be regarded as the yield difference between computer-simulated cutting and actual cutting. The part length distribution used in estimating revenue was directly taken from the results generated by CORY. The yield obtained in Section 2 was the yield of green parts. To convert the yield of green parts to the yield of dry parts, it was assumed that there will be a 7 percent width shrinkage from green to the final moisture content of 6 percent and an additional 15 percent loss in volume during post-drying remanufacturing.

If the relative values of different part lengths are determined by values of **Width X Length<sup>wf</sup>**, the prices for different part lengths can be determined by following

**Table 4.1 Estimated initial investment requirements**

| Design # | Item        |             |           |                 | Total       |
|----------|-------------|-------------|-----------|-----------------|-------------|
|          | Building    | Equipment   | Land      | Working Capital |             |
| Design 1 | \$1,921,400 | \$2,223,800 | \$100,000 | \$475,000       | \$4,720,200 |
| Design 2 | \$1,903,400 | \$1,884,600 | \$100,000 | \$484,000       | \$4,372,000 |
| Design 3 | \$1,903,400 | \$1,814,800 | \$100,000 | \$475,000       | \$4,293,200 |
| Design 4 | \$1,773,400 | \$2,348,800 | \$100,000 | \$441,000       | \$4,663,200 |
| Design 5 | \$1,755,400 | \$2,009,800 | \$100,000 | \$441,000       | \$4,306,200 |
| Design 6 | \$1,846,400 | \$1,968,000 | \$100,000 | \$488,000       | \$4,402,400 |

equation:

$$P_L = P_{33} * (L/33)^{(wf-1)} \quad (\$/MBF) \quad (4.1)$$

Where,  $P_L$  = price for L inches long parts (\$/MBF).

$P_{33}$  = price for 33 inches long parts (\$/MBF).

L = part length in inches.

wf = Weighting factor for part valuation.

Based on the data provided by several companies, the price for 33" long, Clear-two-face, 4/4 red oak dimension parts is about \$2,200/MBF. To be conservative, this price was reduced by \$200 to \$2,000/MBF. In the initial analysis, a weighting factor of 1.3 for part valuation was used, therefore, the prices of other lengths were determined based on the following price-length relationship:

$$P_L = 2000 * (L/33)^{0.3} \quad (\$/MBF) \quad (4.2)$$

The part valuation (or the relationship between part length and price) may have significant effect on revenue. This effect will be assessed in sensitivity analysis. For those designs using Five-part-sawing, 4"X4" cants are produced. The price for 4"X4" cants was assumed to be at \$190 per MBF which is the current average price for 4"X4" red oak cants for pallets. The value of residue was conservatively estimated at \$5.00 per ton. The production rate obtained in Section 3 through computer simulation was used in estimating revenue. The estimated annual revenue of the six design alternatives is listed in Table 4.2.

#### **4.2.3 Estimation of Operating Costs**

The operating costs include raw material costs, labor costs, utility costs, selling expenses, maintenance costs, administrative costs and insurance costs. The raw material cost listed in Table 4.3 includes the cost of logs, glue and packaging material. The

**Table 4.2 Estimated annual revenue\***

| Design alternative | Item            | Year 1      | Year 2      | Year 3 - 10 |
|--------------------|-----------------|-------------|-------------|-------------|
| Modified Design 1  | dimension parts | \$1,774,400 | \$4,140,200 | \$5,323,000 |
|                    | residue         | \$12,000    | \$28,000    | \$36,000    |
|                    | <b>Total:</b>   | \$1,786,400 | \$4,168,200 | \$5,359,000 |
| Design 2           | dimension parts | \$1,766,600 | \$4,122,200 | \$5,299,700 |
|                    | residue         | \$12,000    | \$28,000    | \$36,000    |
|                    | <b>Total:</b>   | \$1,778,600 | \$4,150,000 | \$5,335,700 |
| Design 3           | dimension parts | \$1,475,800 | \$3,443,500 | \$4,427,400 |
|                    | residue         | \$12,000    | \$28,000    | \$36,000    |
|                    | <b>Total:</b>   | \$1,487,800 | \$3,471,500 | \$4,463,400 |
| Modified Design 4  | dimension parts | \$1,354,200 | \$3,159,800 | \$4,062,600 |
|                    | 4X4 cants       | \$57,000    | \$133,000   | \$171,000   |
|                    | residue         | \$9,000     | \$21,000    | \$27,000    |
|                    | <b>Total:</b>   | \$1,420,200 | \$3,313,800 | \$4,260,600 |
| Modified Design 5  | dimension parts | \$1,354,200 | \$3,159,800 | \$4,062,600 |
|                    | 4X4 cants       | \$57,000    | \$133,000   | \$171,000   |
|                    | residue         | \$9,000     | \$21,000    | \$27,000    |
|                    | <b>Total:</b>   | \$1,420,200 | \$3,313,800 | \$4,260,600 |
| Design 6           | dimension parts | \$1,447,400 | \$3,377,300 | \$4,342,300 |
|                    | 4X4 cants       | \$66,300    | \$154,700   | \$198,900   |
|                    | residue         | \$12,000    | \$28,000    | \$36,000    |
|                    | <b>Total:</b>   | \$1,525,700 | \$3,560,000 | \$4,577,200 |

\* It was assumed that the mill will operate at 30% of its full capacity in the first year, 70% in the second year and 90% starting from the third year.

price of No.3 grade red oak logs was assumed to be \$110 per MBF (International 1/4-inch Scaling). This is based on current prices paid by Southern Virginia sawmills. The costs of glue (PVA) was estimated to be \$10.00 per MBF panel. This price was provided by Quick (1990) of James Taylor Manufacturing Company.

The labor cost (Table 4.3) includes both wages and fringe benefits. The average hourly wage rate was assumed to be \$7.50 per hour and fringe benefits were assumed to be 30 percent of wage cost. Workers will be paid 260 days a year. The lists of workers (not including administrative, maintenance and selling personnels) of the six designs are listed in Appendices 4.1 through 4.6.

The utility costs (Table 4.3) were estimated based on the total power of all machines and conveyors included in the manufacturing facility, except for the energy consumed by predrier and kiln driers which was included in the drying costs. The drying costs (Table 4.3) include only the cost of energy and the cost of stacking and sticking material. Other drying-related costs such as labor, equipment, and insurance costs on drying were included in the overall labor cost, equipment depreciation and insurance cost of the whole mill.

The administrative cost (Table 4.3) was assumed to be a fixed amount of \$150,000 per year. It will cover the salary and fringe benefits for one plant manager, one floor supervisor, one secretary and one receptionist, and the costs of phone bill and office supplies.

The annual selling expense (Table 4.3) was assumed to be 7.5 percent of sales of dimension parts plus cants (if there are any). The annual maintenance cost of equipment (including kiln driers) was assumed to be 10 percent of equipment expenditures, excepting installation costs.

**Table 4.3 Estimated annual operating costs**

| Design alternative | Item                       | Year 1      | Year 2      | Year 3 - 10 |
|--------------------|----------------------------|-------------|-------------|-------------|
| Modified Design 1  | Direct labor               | \$381,300   | \$762,600   | \$953,200   |
|                    | Raw material               | \$176,700   | \$412,300   | \$530,100   |
|                    | Utility <sup>1</sup>       | \$36,500    | \$85,300    | \$109,600   |
|                    | Drying costs <sup>2</sup>  | \$70,700    | \$165,000   | \$212,100   |
|                    | Selling costs <sup>3</sup> | \$177,400   | \$310,500   | \$399,200   |
|                    | Maintenance <sup>4</sup>   | \$119,800   | \$239,500   | \$239,500   |
|                    | Administration             | \$150,000   | \$150,000   | \$150,000   |
|                    | Insurance <sup>5</sup>     | \$61,600    | \$61,600    | \$61,600    |
| <b>Total:</b>      |                            | \$1,174,000 | \$2,186,800 | \$2,655,300 |
| Design 2           | Direct labor               | \$397,500   | \$795,000   | \$993,700   |
|                    | Raw material               | \$176,700   | \$412,300   | \$530,100   |
|                    | Utility <sup>1</sup>       | \$36,900    | \$86,100    | \$110,700   |
|                    | Drying costs <sup>2</sup>  | \$70,400    | \$164,400   | \$211,300   |
|                    | Selling costs <sup>3</sup> | \$176,600   | \$309,100   | \$397,400   |
|                    | Maintenance <sup>4</sup>   | \$104,300   | \$208,700   | \$208,700   |
|                    | Administration             | \$150,000   | \$150,000   | \$150,000   |
|                    | Insurance <sup>5</sup>     | \$58,800    | \$58,800    | \$58,800    |
| <b>Total:</b>      |                            | \$1,171,200 | \$2,184,400 | \$2,660,700 |
| Design 3           | Direct labor               | \$405,600   | \$811,200   | \$1,014,000 |
|                    | Raw material               | \$176,700   | \$412,300   | \$530,100   |
|                    | Utility <sup>1</sup>       | \$35,700    | \$83,300    | \$107,100   |
|                    | Drying costs <sup>2</sup>  | \$69,700    | \$162,500   | \$209,000   |
|                    | Selling costs <sup>3</sup> | \$147,600   | \$258,300   | \$332,100   |
|                    | Maintenance <sup>4</sup>   | \$101,200   | \$202,400   | \$202,400   |
|                    | Administration             | \$150,000   |             |             |
|                    | Insurance <sup>5</sup>     | \$58,500    | \$58,500    | \$58,500    |
| <b>Total:</b>      |                            | \$1,145,000 | \$2,138,500 | \$2,603,200 |
| Modified Design 4  | Direct labor               | \$356,900   | \$713,800   | \$892,300   |
|                    | Raw material               | \$160,700   | \$374,900   | \$482,000   |
|                    | Utility <sup>1</sup>       | \$40,600    | \$94,600    | \$121,700   |
|                    | Drying costs <sup>2</sup>  | \$53,100    | \$123,800   | \$159,200   |
|                    | Selling costs <sup>3</sup> | \$141,100   | \$247,000   | \$317,500   |
|                    | Maintenance <sup>4</sup>   | \$122,000   | \$244,000   | \$244,000   |
|                    | Administration             | \$150,000   | \$150,000   | \$150,000   |
|                    | Insurance <sup>5</sup>     | \$59,500    | \$59,500    | \$59,500    |
| <b>Total:</b>      |                            | \$1,083,900 | \$2,007,600 | \$2,426,200 |

**Table 4.3 Estimated annual operating costs (continued)**

| Design alternative | Item                       | Year 1      | Year 2      | Year 3 - 10 |
|--------------------|----------------------------|-------------|-------------|-------------|
| Modified Design 5  | Direct labor               | \$356,900   | \$713,800   | \$892,300   |
|                    | Raw material               | \$160,700   | \$374,900   | \$482,000   |
|                    | Utility <sup>1</sup>       | \$40,600    | \$94,600    | \$121,700   |
|                    | Drying costs <sup>2</sup>  | \$53,100    | \$123,800   | \$159,200   |
|                    | Selling costs <sup>3</sup> | \$141,100   | \$247,000   | \$317,500   |
|                    | Maintenance <sup>4</sup>   | \$106,500   | \$213,000   | \$213,000   |
|                    | Administration             | \$150,000   | \$150,000   | \$150,000   |
|                    | Insurance <sup>5</sup>     | \$56,000    | \$56,000    | \$56,000    |
|                    | <b>Total:</b>              | \$1,064,900 | \$1,973,100 | \$2,391,700 |
| Design 6           | Direct labor               | \$421,800   | \$843,700   | \$1,054,600 |
|                    | Raw material               | \$184,200   | \$429,900   | \$552,700   |
|                    | Utility <sup>1</sup>       | \$39,700    | \$92,600    | \$119,100   |
|                    | Drying costs <sup>2</sup>  | \$62,900    | \$146,700   | \$188,600   |
|                    | Selling costs <sup>3</sup> | \$151,400   | \$264,900   | \$340,600   |
|                    | Maintenance <sup>4</sup>   | \$106,500   | \$212,900   | \$212,900   |
|                    | Administration             | \$150,000   | \$150,000   | \$150,000   |
|                    | Insurance <sup>5</sup>     | \$60,000    | \$60,000    | \$60,000    |
|                    | <b>Total:</b>              | \$1,176,500 | \$2,200,700 | \$2,678,500 |

- 1 -The utility cost listed does not include the energy consumed by the drying operation.
- 2 -The drying cost includes only the cost of energy and stacking material. Other drying-related costs are included in the costs of other items for the whole mill such as labor, maintenance, insurance costs etc.
- 3 -Selling expense was assumed to be 7.5% of dimension parts and cants sales.
- 4 -Maintenance cost was assumed to be 10% of equipment expenditures (including kiln driers), excepting installation costs.
- 5 -This cost includes property tax and two small state taxes.

The insurance costs listed in Table 4.3 include general liability insurance and property insurance. These costs were obtained from two insurance companies who specialize in providing insurance for the lumber manufacturing industry. The annual cost of the general liability insurance was assumed to be 2.4 percent of the total wage of direct labor. The annual cost of the property insurance was assumed to be 0.6 percent of the total property value. An annual property tax rate of \$0.38 per \$100 of property value was used in calculating property tax. There are two minor state taxes in Virginia, inventory tax and forest products tax. The rate for inventory tax is \$0.30 per \$100 value of inventory and the rate of forest products tax is \$0.075 per MBF log processed. These two minor state taxes are relatively small and have little contribution to the total production costs of the direct processing system.

#### **4.2.4 Depreciation**

Depreciation of equipment and building is not cash flow but affects cash flow. This is because the depreciation of equipment and building is tax deductible and the depreciation schedules will affect the amount of income tax a company needs to pay. After the enactment of the Tax Reform Act of 1986, the Modified Accelerated Cost Recovery System (MACRS) which is mandatory for most tangible depreciable assets became the principle means for computing depreciation (DeGarmo et al. 1989). Under MACRS, no salvage value is allowed in the depreciation schedule, and the useful life estimate is not directly used in calculating depreciation. MACRS allows business to recover the cost basis of property over a recovery period that is called the class life. The class life is the life that would apply for depreciation purposes and is different from the useful life of an asset. The class life of various assets is determined by the



Internal Revenue Service (IRS). The cost basis of assets in 3, 5, 7, 10 year properties classes is recovered at a rate based on the 200% declining balance method, and the cost basis of assets in classes of more than 20 years are recovered based on the Straight Line method. According to the IRS, the class life of equipment used in the wood products manufacturing industry is 7 years (USDT-IRR 1991). The depreciation schedules for the equipment to be used in the proposed direct processing dimension mill were developed using the 200% declining balance method as provided for in Internal Revenue Service publication 534 (USDT-IRS 1991). For the building, the class life given by IRS is 31.5 years. The depreciation schedules for the building were developed using the Straight Line method as provided for in IRS publication 534 (USDT-IRS 1991). For the purpose of depreciation, kiln driers were treated as equipment instead of buildings.

#### **4.2.5 Estimation of After-tax cash Flow**

The before-tax cash flow for a given year is equal to the total revenue minus operating costs for that year. The taxable income is equal to the before-tax cash flow minus depreciation on building and equipment. Based on the income tax rate of 1992, the federal income tax rate is 34% and State income tax rate is 6%. Therefore, the effective income tax rate is:

$$34\% + 6\% - 34\% * 6\% = 38\%$$

The income tax rate of 38% was used in calculating income tax for each year. After-tax cash flow is equal to before-tax cash flow minus income tax.

#### 4.2.6 Calculation of NPV and IRR

The NPV and IRR were calculated as described by Weston and Copeland (1986) as:

$$NPV = \sum_{t=1}^{10} \frac{CF_t}{(1+r)^t} - I_0$$

Where,  $I_0$  = initial capital investment, which includes the costs of building, equipment, land and working capital.

$CF_t$  = after-tax cash flow in year t.

t = periods in years.

r = discount rate or minimum attractive return rate (assumed to be 12%).

IRR was calculated from the equation:

$$\sum_{t=1}^{10} \frac{CF_t}{(1+IRR)^t} - I_0 = 0$$

#### 4.2.7 Estimation of profitability

Return on sales (ROS) was used as the measure of profitability in this study. ROS was obtained by dividing net profit after taxes by annual net sales. ROS reveals the profits earned per dollar of sales and therefore measures the efficiency of the operation of a firm. This ratio is an indicator of the firm's ability to withstand adverse conditions, such as falling prices, rising costs and declining sales.

Net profit after taxes for a particular year was obtained by subtracting the depreciation of equipment and buildings and interest for initial capital expenditures

from after-tax earnings. The depreciation used in calculating ROS is different from that used in calculating NPV and IRR. Here, the depreciation is actually the cost of equipment and buildings, and the depreciation schedules specified by Internal Revenue Service were not used. Straight Line method was used for both equipment and buildings, and the economic life for equipment and buildings was assumed to be 10 and 15 years, respectively. A uniform annual depreciation charge was obtained by simply dividing the economic life into the initial cost.

The average ROS value from the third to the tenth year of the proposed direct processing mill was calculated and compared with the ROS value of the hardwood dimension industry and sawmills reported annually by Dun and Bradstreet. The upper quartile value of ROS data presented in Dun and Bradstreet's reports over the last five years (from 1987 to 1991) was averaged and used in comparing with the ROS value of the proposed direct processing system.

#### **4.2.8 Sensitivity Analysis**

In individual circumstances, the assumptions used in previous analysis may not reflect the real-life situation. For instance, prices for dimension parts and raw material may change over times. Part valuation may have some effects on the revenue which will affect NPV, IRR and ROS. Labor and insurance costs vary between different locations. Selling expense and maintenance costs may also vary among individual mills. If some used equipment are used, the require initial capital investment can be lower than that estimated in this study. If the costs for equipment and construction increase, the required initial capital investment will increase. The estimated dimension yield may be different from that can be obtained in real operations. Most importantly, the drying

and remanufacturing loss is uncertain. Therefore, a sensitivity analysis of NPV and ROS to changes in several parameters was carried out. These parameters include the dimension part price, log price, labor cost, overhead cost, initial capital investment, weighting factor for part lengths, green cutting yield, and drying and remanufacturing loss. The sensitivity analysis was conducted only for the design with the best NPV and ROS under the initial assumptions. In carrying out the sensitivity analysis on one variable, all assumptions for other variables remained unchanged.

## 5.

## RESULTS AND DISCUSSION

### 5.1 Economic Feasibility of The Direct Processing System

NPV and IRR were calculated based on after-tax cash flows to measure the economic feasibility of the direct processing system. Six design alternatives were evaluated. It was assumed that the economic life of the proposed direct processing mill was ten years. The NPV and IRR were calculated based on the after-tax cash flows over the ten year period. In calculating NPV, the annual discount rate of cash flow was assumed to be 12 percent. As shown in Table 4.4, the NPVs for all the six design alternatives of the direct processing system are positive. Positive NPVs indicate that these six design alternatives are all economically acceptable. From the investor's standpoint, the IRR is the highest rate of interest that can be paid without losing money if all funds required to finance the project are borrowed. The decision rule based on IRR would be to accept projects with an IRR greater than the minimum attractive rate of return that was used to discount the cash flows. It can be seen in Table 4.4 that the IRR suggests the same conclusions as NPV. The IRRs of the six design alternatives are all greater than the minimum attractive rate of return of 12 percent which was used to discount the after-tax cash flows. Therefore, they are all economically acceptable.

With the highest NPV of \$4,193,700 and the highest IRR of 29.6 percent (see Table 4.4), Design 2 which applies live-sawing followed by gang-rip first cutting and uses manual chop saws is clearly the most economically attractive of all the six design alternatives evaluated. Modified design 1 can have the same yield and dollar value recovery as design 2, but requires more initial capital investment due the high costs of the automatic chop saws. Therefore, design 2 is economically more attractive than

**Table 4.4 Summary of the financial analysis results for the six designs under initial assumptions**

| Design alternatives | NPV         | IRR    | ROS    |
|---------------------|-------------|--------|--------|
| Modified Design 1   | \$4,017,000 | 27.93% | 17.46% |
| Design 2            | \$4,192,000 | 29.60% | 18.32% |
| Design 3            | \$1,801,000 | 20.43% | 10.86% |
| Modified Design 4   | \$1,434,000 | 18.35% | 9.54%  |
| Modified Design 5   | \$1,838,000 | 20.59% | 11.30% |
| Design 6            | \$1,817,000 | 20.31% | 10.65% |

NPV -Net Present Value  
 IRR - Internal Rate of Return  
 ROS - Return on Sales

modified design 1. Although the same conclusions were reached by both NPV and IRR in this study, NPV criterion is more accurate than IRR in comparing mutually exclusive alternatives and selecting the optimal one, because NPV is always consistent with shareholder wealth maximization (Weston & Copeland, 1986).

An inherent drawback in the comparison of the different designs alternatives of the direct processing system is the that the cutting yield resulting from the automatic chop saws (in modified designs 1 and 4) was assumed to be equal to the cutting yield resulting from manual chop saws (design 2 and modified design 5). Automatic chop saws may result in higher cutting yield than manual chop saws in real operations. It was found that if the use of automatic chop saws in modified design 1 can improve cutting yield (green yield) by 1 percent, modified design 1 and design 2 will have equal NPV. And if the yield improvement can reach 2.4 percent, modified design 1 and design 2 will have the equal IRR.

## **5.2 Profitability of The Direct Processing System**

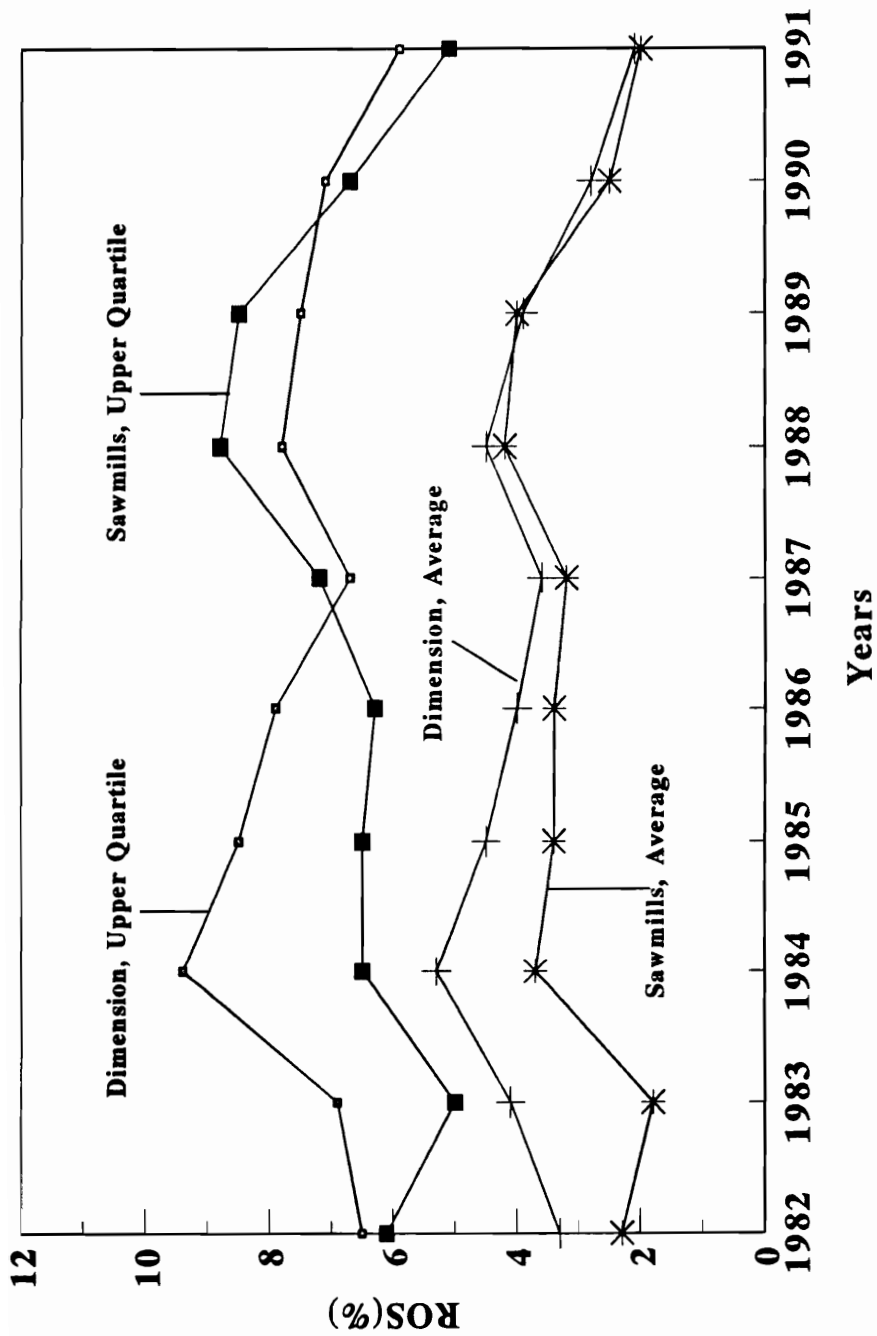
Return on Sales (ROS) was used as the measure of profitability of the designed direct processing system. ROS is an indicator of a firm's ability to withstand adverse conditions such as falling prices, rising costs, and declining sales. The average ROS value from the third to the tenth operation year was calculated for the six design alternatives of the direct processing system. This average value was compared with the average upper quartile value of the ROS from Dun and Bradstreet's reports for the hardwood dimension and flooring industry in the last five years (from 1987 to 1991). The average upper quartile value of the ROS from Dun and Bradstreet's reports in the last five years is 7.0. The ROSs of all the six design alternatives are greater than 7.0

(see Table 4.4). The ROSs of the six design alternatives of the direct processing system range from 9.54% (modified design 4) to 18.32% (design 2). Among the six design alternatives, design 2 has the best ROS. In fact, the ROSs of all the six design alternatives exceed the upper quartile ROS values of any individual year for the hardwood dimension and flooring industry, and for sawmills in the last decade (from 1982 to 1991). As shown in Figure 4.7, in the last decade, the reported upper quartile ROS values varied from 5.9% to 9.4% for the hardwood dimension and flooring industry, and from 5.0% to 8.8% for sawmills.

### **5.3 Sensitivity Analysis**

In certain circumstances, the assumptions used in the previous analysis may not be true. Some variables, such as dimension part price and log price, may change over time. And other variables such as labor costs, selling expenses, and administration costs can vary greatly among individual mills. The required capital investment can change if some used equipment are used or the costs for equipment and construction rise. In this study, the weighting factor used for determining cutting priorities and part valuation for different part lengths was 1.3. The changes in weighting factor may have some effects on the results of the economic performance of the direct processing system. To examine the possible effects of these variables on the economic performance of the direct processing system, the sensitivities of NPV and ROS to changes in dimension part prices, log prices, labor costs, overhead costs, initial capital investment, and weighting factor for part lengths were analyzed for the "best" design alternative, design 2. In carrying out the sensitivity analysis on one variable, all assumptions for other variables remain unchanged.





**Figure 4.7 Reported ROS for the hardwood dimension and flooring industry, and for sawmill in the last decade**

(Source: Dun and Bradstreet)

Additionally, the cutting yield (green yield) obtained by using the computer program CORY can be different from that obtained in a mill. In the initial analysis, a 5% yield was deducted from the cutting yield obtained from CORY to take into account the difference between the actual yield and the yield obtained from CORY.

The uncertainties surrounding the in dimension part drying and remanufacturing is another factor that needs to be considered in evaluating the economic performance of the direct processing system. Since very little work has been done in drying red oak dimension parts, the percentage of dimension parts that will be lost during post-drying remanufacturing is unknown. In the initial analysis, it was assumed that 15 percent of dimension parts will be lost during post-drying remanufacturing. This assumption has not been tested. It is necessary to find out whether the direct processing system would still be economically acceptable if this assumption did not hold.

Since cutting yield and drying and remanufacturing loss can vary substantially, sensitivity analysis was performed to determine how differences in green cutting yield and drying and remanufacturing loss affects the economical performance of the direct processing system.

### **5.3.1 Dimension Part Price**

The sensitivities of NPV and ROS to changes in dimension part price reflects the capability of a company using the proposed direct processing system to withstand against falling dimension part prices or to offer competitive prices. As shown in Figure 4.8, an increase in the price of dimension parts (based on 33" long, Clear-two-face, 4/4 red oak parts) will increase NPV, IRR and ROS, and vice versa. For example, if the price of dimension parts drops from \$2,000/MBF to \$1,500/MBF, the NPV will

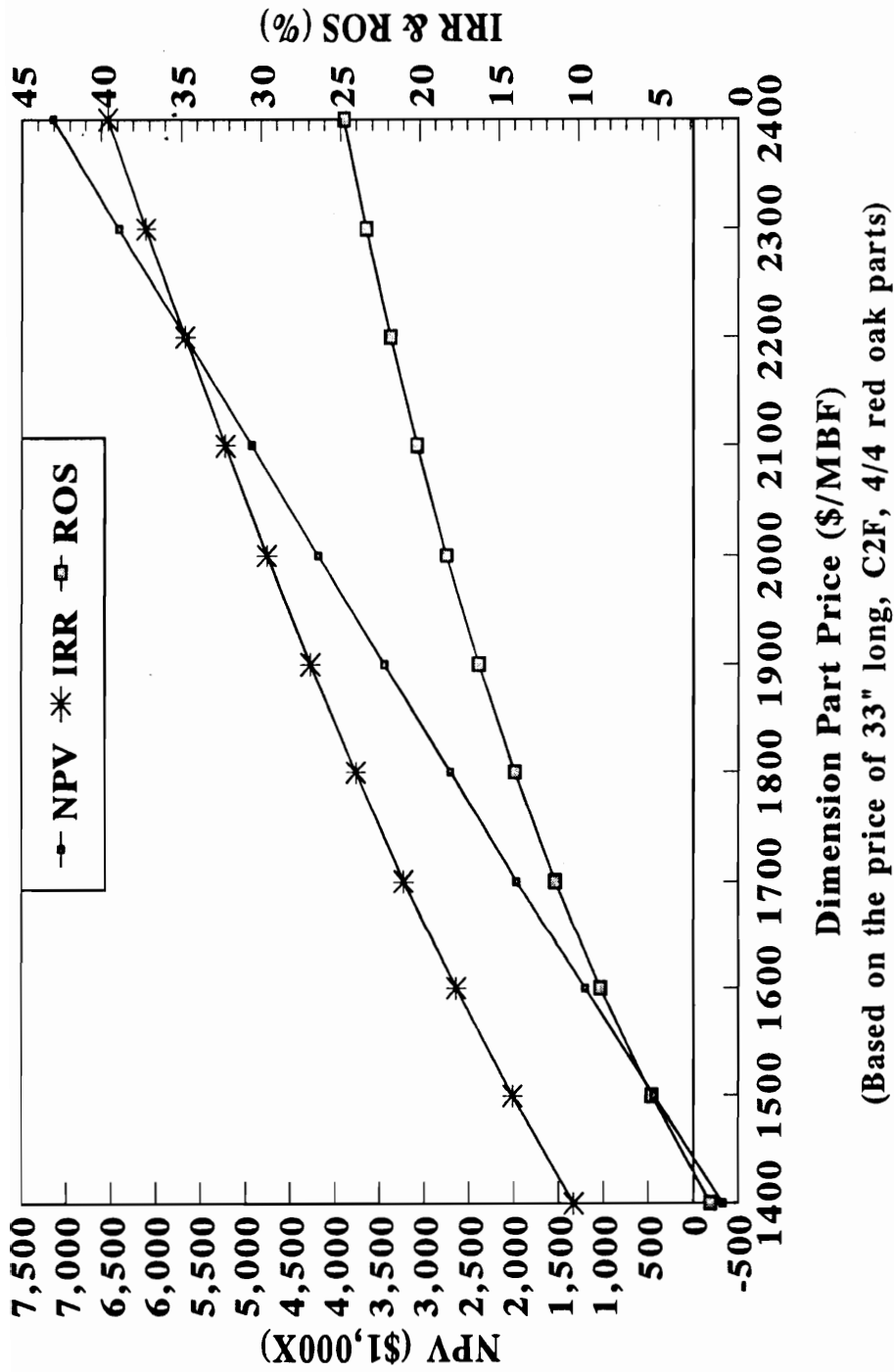


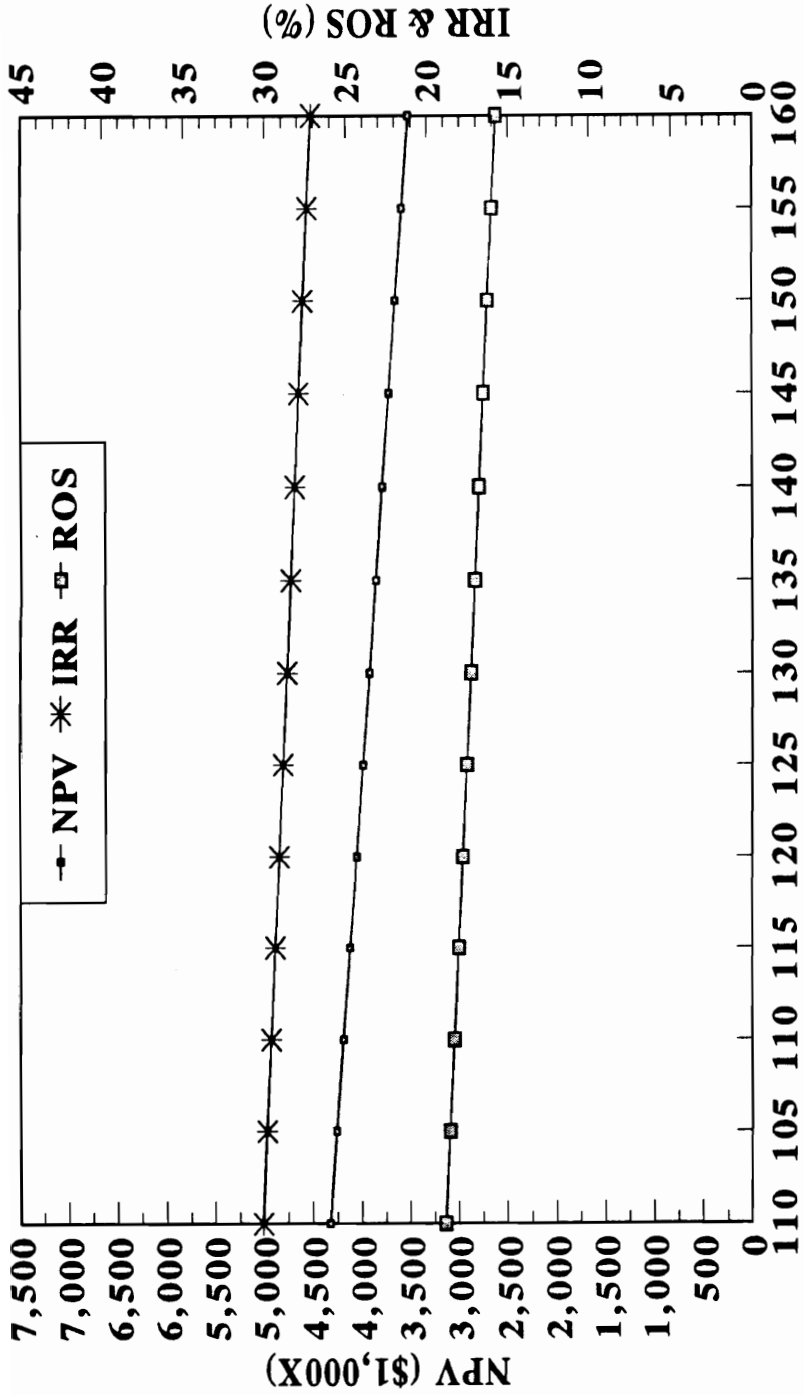
Figure 4.8 Sensitivity of NPV, IRR and ROS to the changes in dimension part price

decrease from \$4,193,700 to \$438,200. The change in NPV resulted from a \$100/MBF change in the dimension part price is about \$751,100. In other words, a one percent decrease in dimension part price will cause a \$150,000 (or 3.58 percent) decrease in NPV. Therefore, it was concluded that NPV is highly sensitive to the changes in dimension part price.

If the dimension part price (for 33" long, C2F 4/4 red oak parts) falls from \$2,000/MBF to \$1,500/MBF, the ROS will drop from 18.32 percent to 5.42 percent. On average, a \$100/MBF decrease in the dimension part price will reduce ROS by 2.6 percent, or a one percent change in the dimension part price will result in 0.516 percent change in ROS. To keep the ROS above 7 percent, which is the average upper quartile ROS obtained from Dun and Bradstreet's reports for the last five years, the dimension part price must be higher than \$1,548/MBF. If the dimension part price drops from \$2,000/MBF to \$1,500/MBF, the ROS will decrease from 18.32 percent to 5.42 percent.

### **5.3.2 Log Price**

Rising log prices can detract from the economical performance of the direct processing system. Figure 4.9 shows the sensitivities of NPV, IRR and ROS to changes in log price (No.3 red oak logs). An increase in log price will lower the NPV. If the log price is increased from \$110/MBF to \$160/MBF, the NPV will decrease by \$666,800. A one percent increase in log price will result in a \$14,700 (or 0.35 percent) decrease in the NPV. If the log price keep rising, at \$419/MBF the NPV will become zero. The effect of changes in log price on NPV is much less substantial than the effect of the change in the price of dimension parts.



Log Price (\$/MBF)  
 (Based on the price of No.3 Grade red oak logs)

Figure 4.9 Sensitivity of NPV, IRR and ROS to the changes in log price

As shown in Figure 4.9, the decrease in ROS caused by a \$10/MBF increase in log price is 0.52 percent, or a one percent increase in log price causes only a 0.057 percent decrease in ROS. If the log price continuously rises, at \$331/MBF the ROS will become 7% which is equal to the upper quartile ROS of the conventional processing systems. The effect of rising log price on the profitability of the direct processing system is relatively small because the cost of logs is only a small part of the total operating costs. The cost of logs makes up about 18 percent of the total operating costs. The raw material cost of a conventional processing system can be much higher than 18 percent of total operating costs.

### **5.3.3 Labor Costs**

Labor costs can vary greatly in different regions. The \$7.50 per hour wage rate used in the initial analysis is the average wage rate in the manufacturing sector in Wise County. If the proposed direct processing mill is to be located in other regions, the wage rate will be different from this \$7.50 per hour. The effects of the labor costs on the NPV, IRR and ROS can be seen in Figure 4.10. An increase in labor costs will decrease the NPV, IRR and ROS. For example, if the wage rate is increased from \$7.50 per hour to \$10.00 per hour, the NPV will be decreased from \$4,193,700 to \$3,176,100. A one percent increase in wage rate will result in a \$30,500 (or 0.73 percent) decrease in the NPV. If the wage rate increases from \$7.50 per hour to \$10.00 per hour, the ROS will decrease from 18.32 percent to 14.47 percent. Hence, a one percent increase in wage rate will result in a 0.116 percent decrease in ROS.

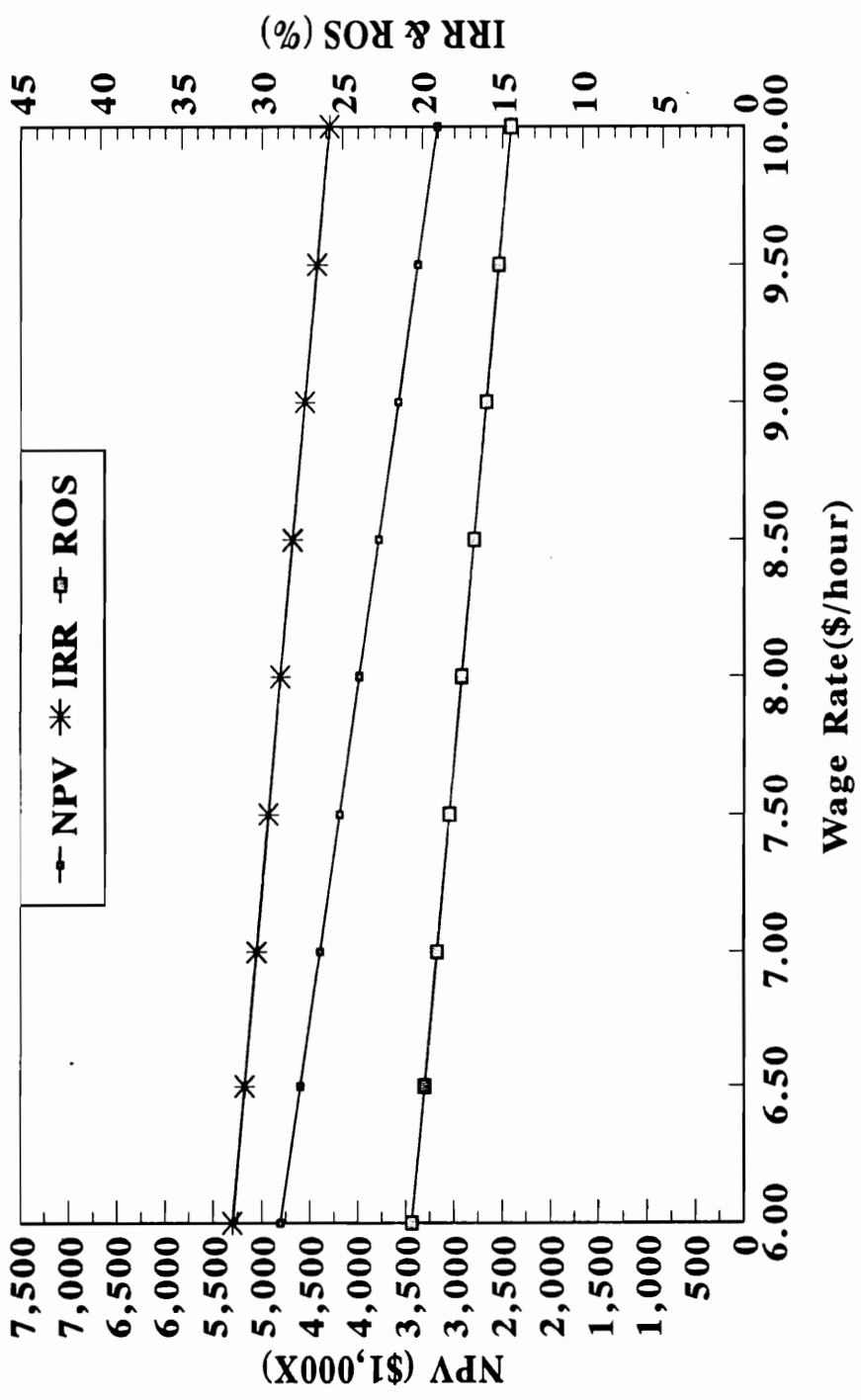


Figure 4.10 Sensitivity of NPV, IRR, and ROS to the changes in labor costs

#### **5.3.4 Overhead Costs**

The overhead cost was defined as the total of administration costs, selling expenses, maintenance costs, utility costs, insurance costs and small taxes. In this analysis, overhead cost was expressed as a percentage of the total direct labor and material costs. Under the initial assumptions, the overhead cost was 60.8 percent of the total direct labor and material costs. Figure 4.11 shows the changes in NPV, IRR and ROS as the ratio of overhead costs to total direct labor and material costs changes from 40 percent to 80 percent. If the overhead cost is increased from 60% to 80% of the total direct labor and material costs, or the overhead costs change from \$914,200 to \$1,219,000, the NPV will drop from \$4,230,300 to \$3,253,800. A one percent increase in the overhead cost will reduce the NPV by \$29,300 (or 0.69 percent).

As shown in Figure 4.11, when the overhead costs change from 60% to 80% of the total direct labor and material costs, or from \$914,200 to \$1,219,000, the ROS is changed from 18.45 percent to 14.91 percent. In terms of percent change over initial overhead cost, a one percent increase in overhead cost will cause a 0.106 percent decrease in ROS.

#### **5.3.5 Initial Capital Investment**

The required initial capital investment can change if the costs for equipment and buildings change. Figure 4.12 shows the effects of the changes in initial capital investment on NPV, IRR and ROS. If the initial capital investment increase by 30% from 4.37 to 5.68 million dollars, the NPV and ROS will decrease from 4.2 to 2.9 million dollars and from 18.3% to 10.8%, respectively. If the initial investment



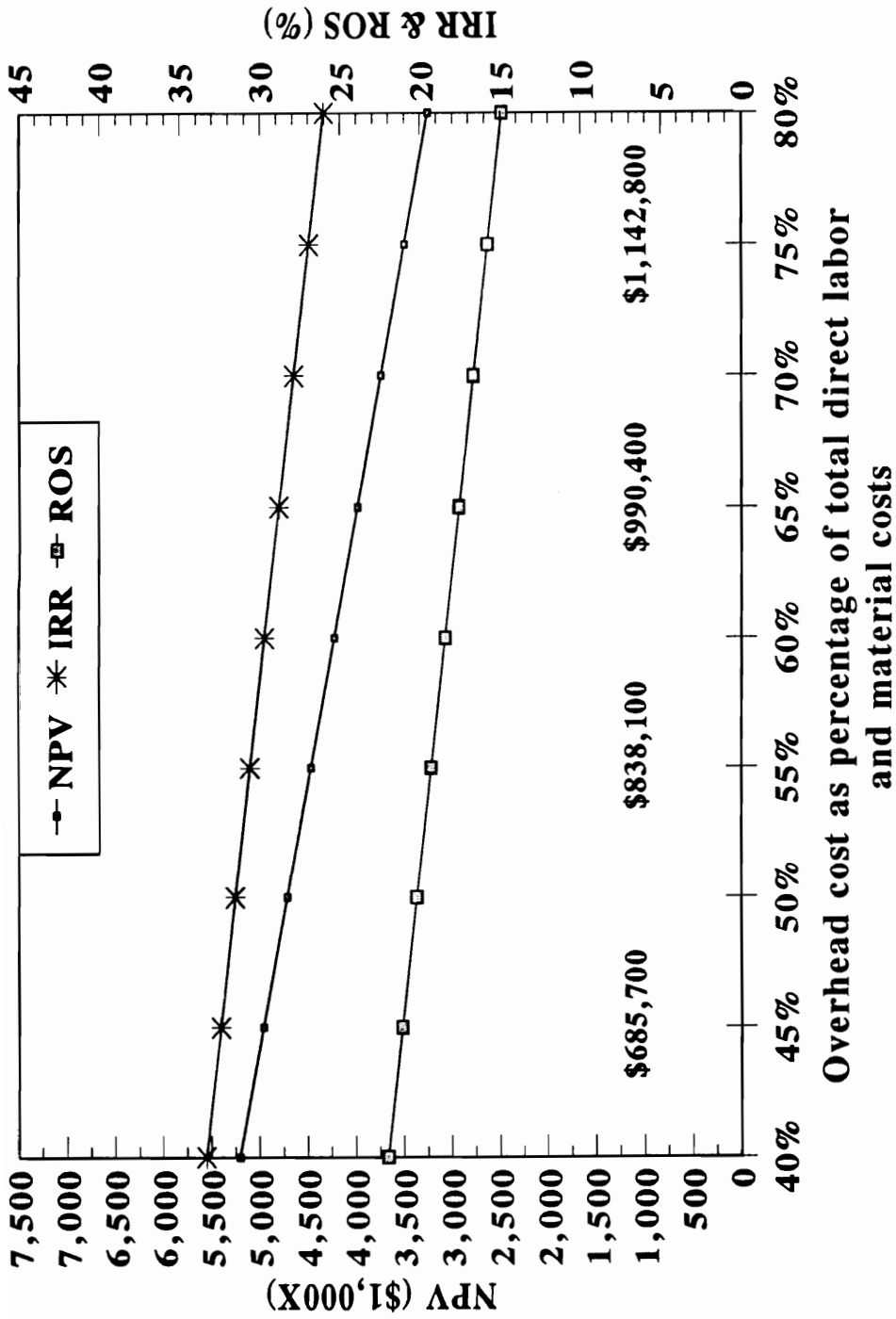


Figure 4.11 Sensitivity of NPV, IRR, and ROS to changes in overhead costs

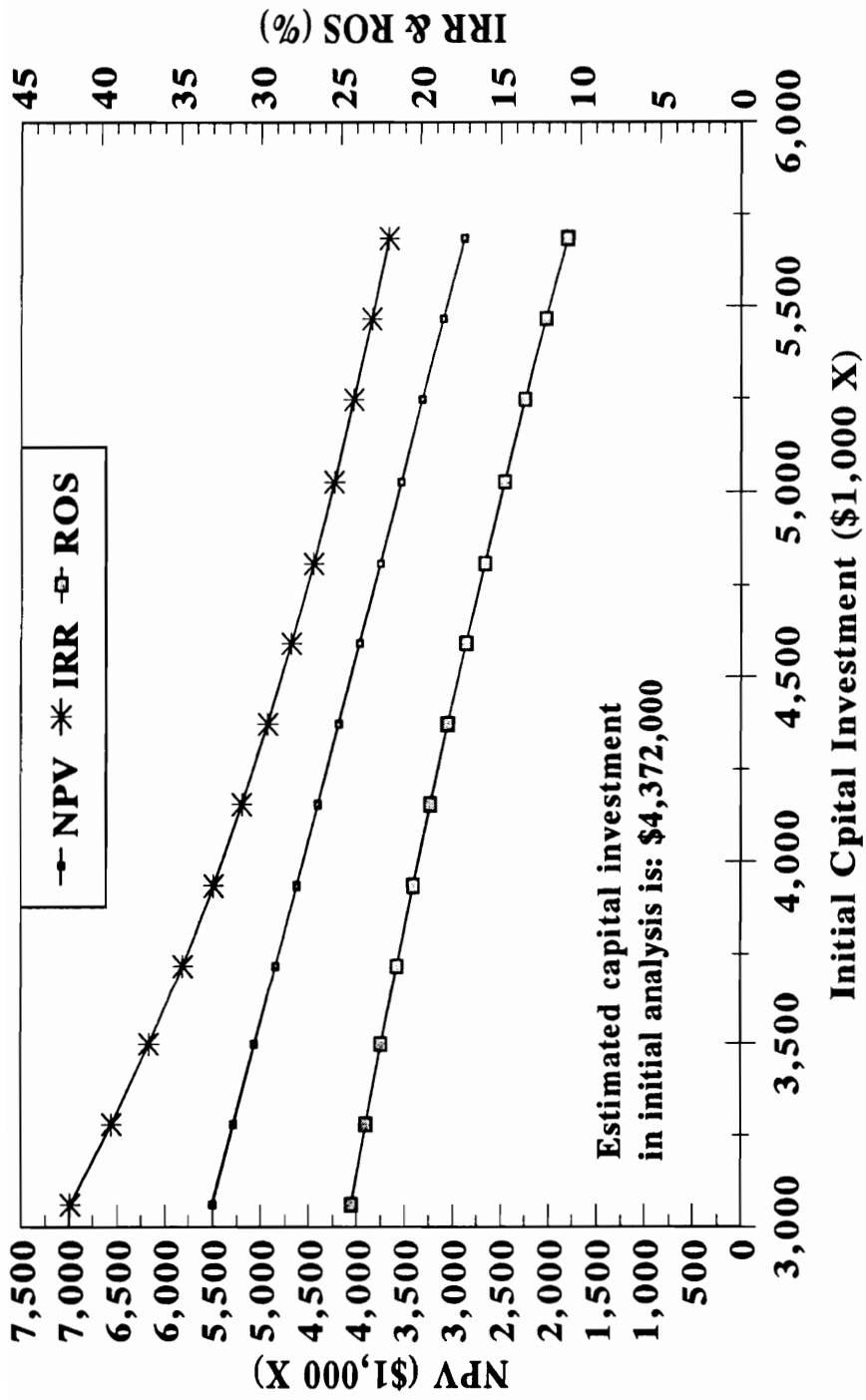


Figure 4.12 Sensitivity of NPV, IRR , and ROS to changes in capital investment

decrease by 30% from 4.37 to 3.06 million dollars, the NPV and ROS will increase from 4.2 to 5.5 million dollars and from 18.3% to 24.3%, respectively. On average, one percent change in the initial capital investment will cause \$43,700 (or 1.04 percent) change in NPV and 0.225 percent change in ROS.

### **5.3.6 Weighting Factor for Part Lengths**

Early in this study (Section 2 and Section 4), an exponential weighting factor of 1.3 for part lengths was used in two places: (1) for determining cutting priorities in CORY, and (2) for determining the relative values of different part lengths. In the former case, the weighting factor affects part length distributions. The larger the weighting factor, the more longer cuttings are obtained. In the latter case, the larger weighting factor gives higher values to longer cuttings, and weighting factor of 1.0 gives equal value to different part lengths. In both cases, the weighting factor will have effects on the estimated NPV, and ROS. To explore the effects of the weighting factor on the estimation of the economical performance of the direct processing system, a weighting factor of 1.1 for cutting priority and 1.0 and 1.1 for part valuation were tried. The NPV, IRR and ROS for mill design 2 under different weighting factors are given in Table 4.5. The larger weighting factor for part valuation resulted in higher NPV, IRR and ROS. The larger weighting factor for cutting priority resulted in higher NPV, IRR and ROS, except when all part lengths have equal value. It can be concluded that the weighting factor has significant effects on the estimation of the economic performance of the direct processing system. However, even when a weighting factor of 1.3 is used for cutting priority and 1.0 for part valuation, with NPV

**Table 4.5 NPV, IRR and ROS for Design 2 under different weighting factors for part lengths**

| WF for Part Valuation | Economical Index | WF for Cutting Priorities |             |
|-----------------------|------------------|---------------------------|-------------|
|                       |                  | 1.1                       | 1.3         |
| 1.0                   | NPV              | \$2,502,000               | \$2,482,000 |
|                       | IRR              | 23.2%                     | 23.1%       |
|                       | ROS              | 13.2%                     | 13.1%       |
| 1.1                   | NPV              | \$2,786,000               | \$2,991,000 |
|                       | IRR              | 24.3%                     | 25.1%       |
|                       | ROS              | 14.1%                     | 14.8%       |
| 1.3                   | NPV              | \$3,505,000               | \$4,194,000 |
|                       | IRR              | 27.1%                     | 29.6%       |
|                       | ROS              | 16.4%                     | 18.3%       |

WF - Weighting Factor  
 NPV - Net Present Value  
 IRR - Internal Rate of Return  
 ROS - Return on Sales

of 2.48 million dollars and ROS of 13.1%, the direct processing system is still economically attractive.

### **5.3.7 Cutting Yield, Drying and Remanufacturing Loss**

Table 4.6 shows changes in NPV as green cutting yield and drying and remanufacturing loss change. NPV decreases dramatically as green cutting yield decreases. For example, if the drying and remanufacturing loss is 15 percent, when the green cutting yield drops from 68.4 percent to 60 percent, the NPV will decrease from \$4,193,700 to \$2,454,400. In other words, a one percent decrease in green cutting yield will result in a \$207,000 (or 4.94 percent) decrease in NPV. As the drying and remanufacturing loss increases, NPV will decrease dramatically. If the green cutting yield is 68.4 percent and the drying and remanufacturing loss is increased from 15 percent to 25 percent, the NPV will drop from \$4,193,700 to \$2,452,300. A one percent increase in drying and remanufacturing loss will cause a \$174,000 (or 4.15 percent) decrease in NPV.

Table 4.7 shows the sensitivity of ROS to the changes in green cutting yield and drying and remanufacturing loss. ROS decreases as green cutting yield decreases and drying and remanufacturing loss increases. For example, if the drying and remanufacturing loss is kept at 15 percent and green cutting yield is decreased from 68.4 percent to 60 percent, the ROS will decrease from 18.32 percent to 13.24 percent, which is to say a one percent decrease in green cutting yield results in a 0.605 percent decrease in ROS. If the green cutting yield is kept at 68.4 percent and the drying and remanufacturing loss increases from 15 percent to 25 percent, the ROS will be

**Table 4.6 Sensitivity of NPV(in \$1000) to changes in green cutting yield and drying and remanufacturing loss**

| Cutting Yield(%) | Drying and Remanufacturing Loss (%) |        |        |        |         |         |         |
|------------------|-------------------------------------|--------|--------|--------|---------|---------|---------|
|                  | 10%                                 | 15%    | 20%    | 25%    | 30%     | 35%     | 40%     |
| 50%              | 984.6                               | 325.0  | -334.6 | -994.3 | -1687.8 | -2397.1 | -3129.7 |
| 52.5%            | 1554.0                              | 861.4  | 168.8  | -523.8 | -1217.3 | -1962.1 | -2706.9 |
| 55%              | 2119.3                              | 1397.9 | 672.3  | -53.3  | -778.9  | -1527.1 | -2307.3 |
| 57.5%            | 2668.8                              | 1934.4 | 1175.8 | 417.2  | -341.4  | -1100.0 | -1907.8 |
| 60%              | 3218.2                              | 2454.5 | 1679.2 | 887.7  | 96.1    | -695.5  | -1508.3 |
| 62.5%            | 3767.7                              | 2972.1 | 2176.6 | 1358.2 | 533.6   | -290.9  | -1115.5 |
| 65%              | 4317.1                              | 3489.7 | 2662.3 | 1828.7 | 971.1   | 113.6   | -743.9  |
| 67.5%            | 4866.5                              | 4007.3 | 3148.1 | 2288.9 | 1408.6  | 518.1   | -372.4  |
| 68.4%            | 5064.3                              | 4193.7 | 3323.0 | 2452.4 | 1566.2  | 663.8   | -238.6  |
| 70%              | 5416.0                              | 4524.9 | 3633.9 | 2742.9 | 1846.2  | 922.7   | -0.8    |
| 73.4%            | 6163.2                              | 5228.9 | 4294.6 | 3360.3 | 2426.0  | 1472.8  | 504.5   |

NPV - Net Present Value(\$)

**Table 4.7 Sensitivity of ROS(%) to changes in green cutting yield and drying and remanufacturing loss**

|                | Drying and Remanufacturing Loss (%) |       |       |       |       |        |        |
|----------------|-------------------------------------|-------|-------|-------|-------|--------|--------|
| Green Yield(%) | 10%                                 | 15%   | 20%   | 25%   | 30%   | 35%    | 40%    |
| 50%            | 7.87                                | 4.99  | 1.75  | -1.92 | -6.11 | -10.93 | -16.70 |
| 52.5%          | 10.10                               | 7.34  | 4.24  | 0.74  | -3.26 | -7.87  | -13.24 |
| 55%            | 12.12                               | 9.48  | 6.52  | 3.16  | -0.67 | -5.08  | -10.23 |
| 57.5%          | 13.97                               | 11.44 | 8.60  | 5.38  | 1.70  | -2.54  | -7.47  |
| 60%            | 15.67                               | 13.24 | 10.50 | 7.41  | 3.87  | -0.20  | -4.94  |
| 62.5%          | 17.23                               | 14.89 | 12.26 | 9.28  | 5.87  | 1.95   | -2.62  |
| 65%            | 18.68                               | 16.42 | 13.88 | 11.00 | 7.72  | 3.94   | -0.47  |
| 67.5%          | 20.01                               | 17.83 | 15.38 | 12.60 | 9.43  | 5.78   | 1.53   |
| 68.4%          | 20.47                               | 18.32 | 15.89 | 13.15 | 10.02 | 6.41   | 2.21   |
| 70%            | 21.26                               | 19.15 | 16.78 | 14.09 | 11.03 | 7.49   | 3.38   |
| 73.4%          | 21.26                               | 19.15 | 16.78 | 14.09 | 22.88 | 7.49   | 3.38   |

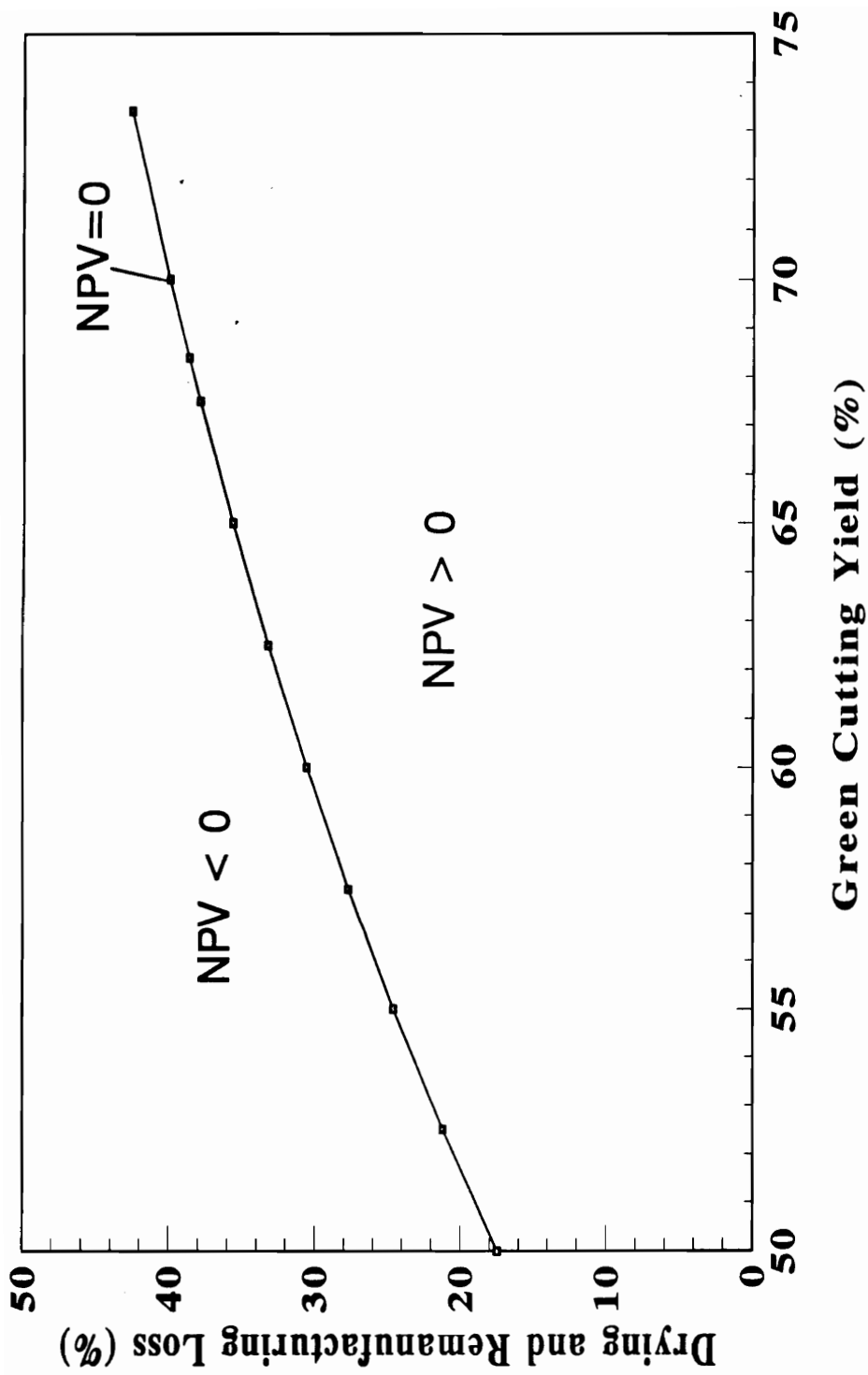
ROS - Return on Sales(%)

decreased from 18.32 percent to 13.15 percent, or a 1 percent increase in drying and remanufacturing loss results in a 0.517 percent decrease in ROS.

Obviously, NPV and ROS are highly sensitive to the changes in green cutting yield and drying and remanufacturing loss. Cutting yield and drying and remanufacturing loss can have the greatest impact on the economic performance of the direct processing system. For the direct processing system to be economically feasible and more profitable than most of the current hardwood dimension mills, green cutting yield and drying and remanufacturing loss must be maintained at certain levels. Figure 4.13 shows the breakeven drying and remanufacturing loss under a given green cutting yield. This breakeven drying and remanufacturing loss is defined as the drying and remanufacturing loss that makes the NPV equal to zero, or the maximum drying and remanufacturing loss that can be accepted if the direct processing system is to be economically acceptable. The area below the breakeven curve (see Figure 4.13) is the economically acceptable area and the area above the breakeven curve is economically unacceptable.

The breakeven prices for the dimension parts (based on 33" long, Clear-two-face 4/4 red oak parts) under varied green cutting yield and drying and remanufacturing loss are presented in Table 4.8. The breakeven price is defined as the price that will make the NPV equal to zero. In order for the direct processing system to be economically attractive, the dimension parts must be sold at a price that is higher than the breakeven price. For example, if the green cutting yield is 65 percent and the drying and remanufacturing loss is 30 percent, then the dimension parts must be sold at a price more than \$1,838/MBF in order to make the direct processing system economically attractive.





**Figure 4.13 Breakeven drying and remanufacturing loss under given cutting yield**

**Table 4.8 Dimension part breakeven price(\$/MBF) Vs. green cutting yield and drying and remanufacturing loss**

| Cutting Yield(%) | Drying and Remanufacturing Loss (%) |      |      |      |      |      |      |
|------------------|-------------------------------------|------|------|------|------|------|------|
|                  | 10%                                 | 15%  | 20%  | 25%  | 30%  | 35%  | 40%  |
| 50%              | 1834                                | 1942 | 2063 | 2201 | 2358 | 2540 | 2751 |
| 52.5%            | 1751                                | 1854 | 1970 | 2101 | 2251 | 2424 | 2626 |
| 55%              | 1675                                | 1773 | 1884 | 2010 | 2153 | 2319 | 2512 |
| 57.5%            | 1606                                | 1700 | 1806 | 1927 | 2064 | 2223 | 2408 |
| 60%              | 1542                                | 1633 | 1735 | 1850 | 1983 | 2135 | 2313 |
| 62.5%            | 1484                                | 1571 | 1669 | 1780 | 1908 | 2054 | 2226 |
| 65%              | 1430                                | 1514 | 1609 | 1716 | 1838 | 1980 | 2145 |
| 67.5%            | 1380                                | 1461 | 1552 | 1656 | 1774 | 1910 | 2070 |
| 68.4%            | 1363                                | 1443 | 1533 | 1635 | 1752 | 1887 | 2044 |
| 70%              | 1333                                | 1412 | 1500 | 1600 | 1714 | 1846 | 2000 |
| 73.4%            | 1275                                | 1350 | 1435 | 1531 | 1640 | 1766 | 1913 |

Figure 4.14 shows the green cutting yield and drying and remanufacturing loss that will make the ROS equal to 7 percent which is the upper quartile ROS of the conventional processing systems. For example, if the green cutting yield is 55 percent, the drying and remanufacturing loss must be controlled below 19.2 percent to keep the ROS of the system above 7 percent. If the drying and remanufacturing loss is 30 percent, the green cutting yield must be higher than 64 percent to keep the ROS above 7 percent.

### **5.3.8 Summary of Sensitivity Analysis**

Table 4.9 lists the changes in NPV and ROS caused by one percent change in selected variables on average. It can be seen from Table 4.9 that dimension part price, cutting yield, and drying and remanufacturing loss are the three most significant factors affecting NPV and ROS of the direct processing system. Change in log price has the least effect on NPV and ROS. It also can be concluded that NPV and ROS are less sensitive to changes in labor and overhead costs than to changes in dimension part price, cutting yield and drying and remanufacturing loss, but more sensitive than change in log price.

Although NPV and ROS are highly sensitive to changes in dimension part prices, cutting yield and drying and remanufacturing loss, they may not be equally important for the manager of a direct processing mill. Dimension part prices are determined by market, while cutting yield and drying and remanufacturing loss can be controlled and improved by the effort from within a mill. The manager of a direct processing mill should put a considerable effort into improving cutting yield and controlling drying and remanufacturing loss.

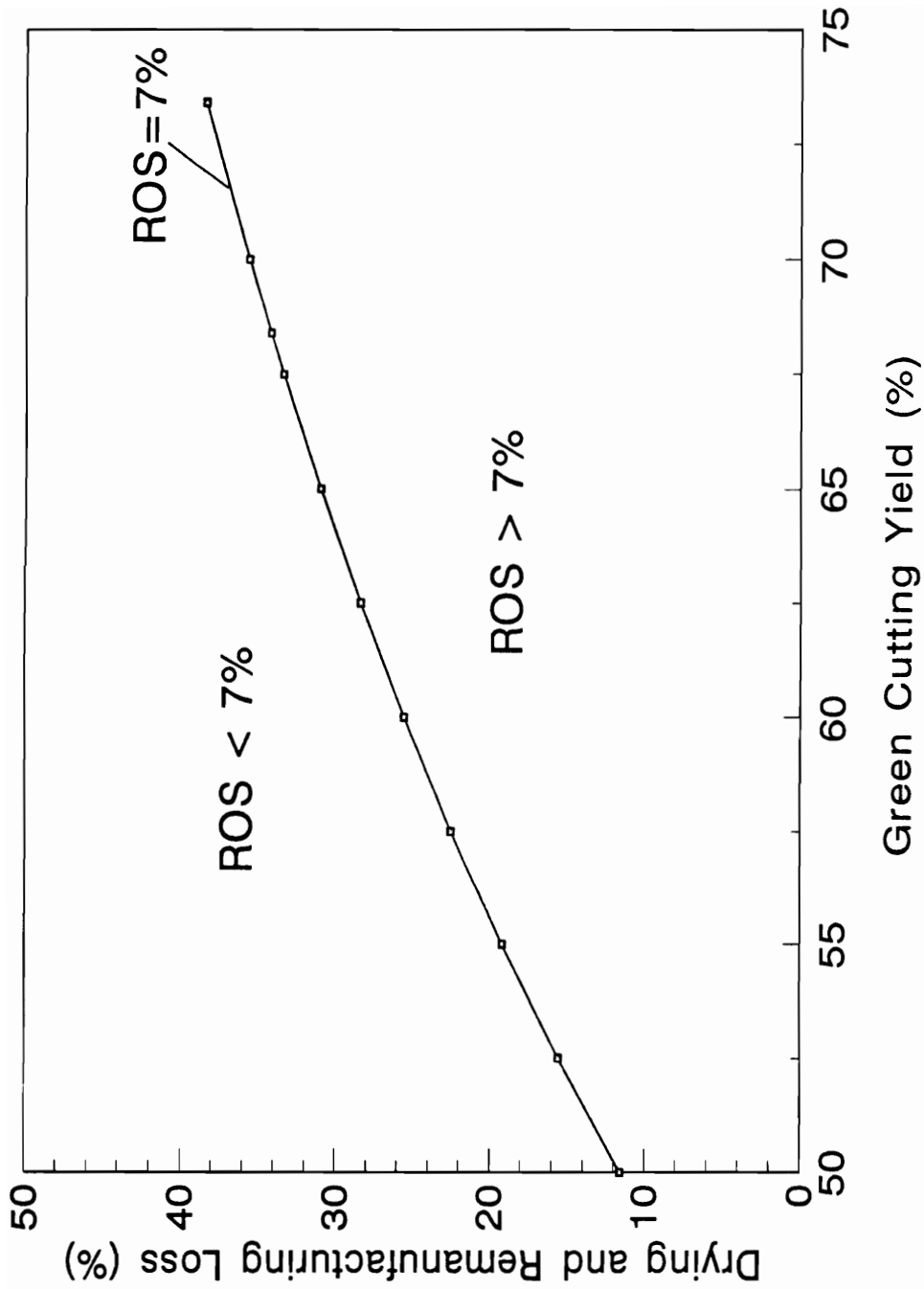


Figure 4.14 Green yield and drying and remanufacturing loss that make ROS=7%

**Table 4.9 Summary of sensitivity analysis**

(Changes in NPV and ROS resulting from one percent change in selected variables)

| Selected Variables              | Change in NPV      | Change in ROS |
|---------------------------------|--------------------|---------------|
| Dimension part price            | \$150,000 (+3.58%) | 0.516         |
| Log price                       | \$14,700 (-0.35%)  | 0.057         |
| Labor costs                     | \$30,500 (-0.73%)  | 0.116         |
| Overhead costs                  | \$29,300 (-0.69%)  | 0.106         |
| Capital investment              | \$43,700 (-1.04%)  | 0.225         |
| Cutting yield                   | \$207,000 (+4.94%) | 0.605         |
| Drying and remanufacturing loss | \$174,000 (4.15%)  | 0.517         |

NPV - Net Present Value  
ROS - Return on Sales

Because of its uncertainty, drying and remanufacturing loss can become a very critical factor to the success of the direct processing system. Future research in determining the drying and remanufacturing loss of hardwood dimension parts or the percentage loss of dimension parts during post-drying remanufacturing will be necessary. If research shows that drying of dimension parts becomes a constraint to the success of the direct processing system, there is an alternative processing system that can be considered. This alternative processing system still processes hardwood logs directly into dimension parts. It follows the procedures of sawing logs into flitches, drying flitches and cutting flitches into dimension parts. This alternative processing system can avoid drying dimension parts and can eliminate the remanufacturing step. However, the drying costs of this alternative processing system will be much higher because: (1) a higher volume of material will need to be dried, and (2) flitches with defects may have a higher level of drying degradation. The advantages and disadvantages of these two systems need to be further evaluated. The comparison of these two processing system will be a very interesting topic for future research.

There are many other factors that can have an effect on the economical performance of the direct processing system. These factors include species, production level, cutting sizes, cutting quality, types of machines (such as types of headrig and chop saw). However, looking at many of these factors is beyond the scope of this research. this dissertation has developed an important methodology that can be applied to look at all these factors in detail .

## 6.

## SUMMARY

The results of the NPV/IRR analysis showed that the direct processing system for converting No.3 grade red oak logs directly into rough dimension parts are economically feasible. Under the initial assumptions of this study, the after-tax NPVs of all six direct processing system designs evaluated are positive, with a range from \$1,434,200 to \$4,193,700. The IRRs of these six designs are all greater than the minimum attractive rate of return of 12 percent, with a range from 18.35 to 29.6 percent.

With the highest NPV of \$4,193,700 and the highest IRR of 29.6 percent, the design that uses Live-sawing and Rip-first with manual chop saws was found to be the most economically attractive design among the six design alternatives evaluated. From the investor's standpoint, 29.6 percent of IRR is a very attractive investment return rate.

When compared with the profitability of hardwood dimension and flooring industry obtained from Dun and Bradstreet's reports, it was found that the direct processing system for converting No.3 red oak logs into dimension parts is more profitable than the conventional processing system. Under the initial assumptions of this study, the Return on Sales of the six designs of the direct processing system evaluated are in the range from 9.54 to 18.32 percent. This compares with an average upper quartile ROS value over the last five years for the hardwood dimension and flooring industry only 7 percent. Among the six design alternatives, the design that uses Live-sawing followed by Gang-rip-first with manual chop saws has the highest ROS of 18.32 percent.

The sensitivity of NPV and ROS to the changes in dimension part price, log price, labor cost, overhead cost, initial capital requirement, weighting factor for part lengths, green cutting yield, drying and remanufacturing loss was analyzed. Of these variables, dimension part price, green cutting yield, and drying and remanufacturing loss appear to be the most important factors that affect the economic feasibility and profitability of the direct processing system.

Since the dimension part price used in the initial analysis was less than the going market price for the dimension parts, the estimates of NPV and IRR as well as ROS can be considered conservative. When used in financial analysis, the green cutting yield obtained from the computer program CORY was reduced by 5 percent, hence the difference between the computer simulated cutting yield and actual cutting yield has been considered. The greatest uncertainty will be the drying and remanufacturing loss. To keep the direct processing system economically attractive and more profitable than conventional processing system, the drying and remanufacturing loss of dimension parts must be controlled at a certain level. Future research in determining the drying and remanufacturing loss of dimension parts will be necessary.

Although NPV and ROS are highly sensitive to changes in dimension part price, cutting yield and drying and remanufacturing loss, they are not equally important to the manager of a direct processing mill. This is because that the selling prices of dimension parts are determined by market force, while cutting yield and drying and remanufacturing loss can be controlled and improved by the effort from within a mill. The manager of a direct processing mill should put a considerable effort into improving cutting yield and reducing drying and remanufacturing loss.



Araman, P. A. 1987. Standard sizes for rough dimension exports to Japanese and European fine hardwood users. A report for the scientific and technical exchange program with Japan. USDA Forest Service, Northeastern Forest Experimental Station, Princeton, WV.

Araman, P. A., and B. G. Hansen. 1983. Conventional processing of standard-size edge-glued blanks for furniture and cabinet parts: a feasibility study. USDA Forest Service, Northeastern Experiment Station, Research Paper NE-524, Princeton, WV, 11 pp.

DeGarmo, E. P., W. G. Sullivan, and J. A. Bontadelli. 1989. Engineering Economy. Eighth Edition. Macmillan Publishing Company, New York, 765 pp.

Dun and Bradstreet. Yearly. Industry Norms and Key Business Ratios. Dun and Bradstreet Credit Services, New York. (Yearly published statistic report).

Huber, H. A., S. Ruddell, K. Mukherjee, and C. McMillin. 1989. Economics of cutting hardwood dimension parts with an automated system. Forest Products Journal 39(5):46-50.

Lawser, S.V. 1991. Value added opportunities for primary processors. Proceedings of the Nineteenth Annual Hardwood Symposium. Hardwood Council, Starkville, Mississippi, March 10-12, 1991.

Quick, L.S.. 1990. Edge Gluing With Room Temperature and Thermal Setting Glues. James L. Taylor manufacturing Company, Poughkeepsie, NY. 12 pp.

Reynolds, H. W., C.J. Gatchell, P.A. Araman, and B.G. Hansen. 1983. System 6 used to make kitchen cabinet C2F blanks from small-diameter, low-grade red oak. USDA Forest Service, Northeastern Experimental Station, Research Paper NE-525, Princeton, WV, 11pp.

Reynolds, H. W. and B.G. Hansen. 1986. Making black cherry blanks from System 6. USDA Forest Service, Northeastern Experimental Station, Research Paper NE-574, Princeton, WV, 10 pp.

Southern Lumberman. 1992. Another trend. Southern Lumberman, August 1992.

Stewart, H. A. H. N. Rosen, H. A. Huber, and A. A. Rasher. 1982. 4/4 hardwood dimension from short bolts: economic and processing comparison of conventional and innovative production. Forest Products Journal 32(11/12):71-76.

U.S. Department of Treasury - Internal Revenue Service (USDT-IRS). 1991. Depreciation. Internal Revenue Service Publication 534.

Weston, J. F. and T. E. Copeland . 1986. Managerial Finance. 5th Edition. The Dryden Press, Chicago, New York, 1035 pp.

## **DISSERTATION SUMMARY**

The primary objective of this dissertation was to assess the economic feasibility and profitability of the direct processing system for converting No.3 grade red oak logs into rough dimension parts. This dissertation is presented in four sections. The first section describes the background and the scope of the problem studied. The second section provides the results of a yield study from No.3 grade red oak logs into rough dimension parts. The third section studies the system designs of the direct processing system for converting No.3 grade red oak logs into rough dimension parts. The fourth section presents the results of the economic analysis of the direct processing system for converting No.3 grade red oak logs into rough dimension parts.

### **Background and scope of the study**

Facing strong world competition, the U.S. hardwood dimension industry not only needs to keep in tune with ever-changing markets, but also needs to look for new processing technologies which can improve production efficiency and reduce production costs. Producing dimension parts directly from logs is a possible alternative that has potential in improving production efficiency and reducing production costs. However, the economic performance of this processing system is unknown. Hardwood dimension manufacturers and sawmillers need to find out whether this processing system is economically sound before they will accept it.

### **Cutting yield and dollar value recovery from No.3 grade red oak logs**

In the second section of this dissertation, the cutting yields of green parts and cutting details were obtained by actually sawing logs into flitches and "cutting" flitches into parts using a lumber cut-up computer program (CORY). This section is very important to the subsequent two sections, because the estimated cutting details will form the critical input

distributions needed in the third section and the estimated cutting yields will be needed in the fourth section.

Two sawing patterns (live-sawing and five-part-sawing) and two cutting sequences (rip-first and crosscut-first) were tested for their effects of sawing pattern and cutting sequence on dimension yields, cutting lengths, and dollar value recovery. If the same cutting length priority was used, live-sawing resulted in significantly higher dimension yield than five-part-sawing. Rip-first and crosscut-first had no significant difference in dimension yields, however, rip-first produced more longer cuttings than crosscut-first. If followed by crosscut-first, five-part-sawing produced more longer cuttings than live-sawing; however, if followed by rip-first, the effects of sawing pattern on cutting length depended on the cutting bill used.

Under the assumption that longer parts had more value, live-sawing resulted more dollar value recovery than five-part-sawing if followed by rip-first. However, if followed by crosscut-first, the difference in the dollar value recovery between the two sawing patterns was not significant for the two cutting bills containing no parts longer than 45 inches. The influence of cutting sequence on the dollar value recovery depended on the previous log sawing pattern and the cutting bill. Rip-first produced significantly higher dollar value recovery than crosscut-first under live-sawing, except for the cutting bill containing only short cuttings. Under five-part-sawing, rip-first produced higher dollar value recovery than crosscut-first if the cutting bill contained cuttings longer than 45 inches. These results suggested that in terms of dollar value recovery, the choice of cutting sequence is more important under live-sawing than under five-part-sawing and is more important for cutting longer parts than for cutting short parts. It can be concluded from the results of this study that the combination of live-sawing and rip-first has the highest dimension yield and dollar value recovery if the cutting bill contains some longer cuttings and longer cutting have higher value.

A strong negative linear relationship was detected between the cutting yield and the average cutting length within each combination of the sawing patterns and cutting sequences. This relationship can be used to roughly predict the changes in dimension yield when cutting bill is changed.

### **System simulation of direct processing mills**

In the third section of this dissertation, various mill designs of the direct processing system were developed for carrying out the various sawing patterns and cutting sequences. System simulation models of these designs were developed using SIMAN IV and used to predict the dynamic performances and production rates of the designed mills. Animation models were also built using CINEMA for each mill design in conjunction with simulation model development to assist simulation model development, model verification and validation. This system simulation approach is unique and provides a methodology to look at the "whole system".

Based on simulation results, bottlenecks in the initial designs were identified and production lines were balanced. Bottlenecks occur in different locations in those designs for carrying out live-sawing and those designs for carrying out five-part-sawing. Three of the six initial designs were modified for balancing production capacity. The production rate and labor productivity of these modified designs were much higher than their initial designs.

Based on simulation results of the six final models, the direct processing system with one headrig saw can process 17.8 to 20.5 MBF No.3 grade red oak logs and turn out 11 to 14.3 MBF, clear-two-face, 4/4 rough green dimension parts of random width per shift. The production rate varies among the different mill designs. Production rates in both daily log volume processed and daily volume of green part output are significantly different between those designs for using live-sawing and those for using five-part-sawing. For the designs using

the same sawing pattern, the productivity in terms of green parts output per worker per day is slightly higher for rip-first designs than for crosscut-first designs.

### **Economical evaluation of the direct processing system**

In the fourth section of this dissertation, a financial analysis using discounted cash flow methods was conducted over a ten year planning horizon to determine the economic feasibility and profitability of the direct processing system for converting No.3 red oak logs into rough dimension parts. The results of the NPV/IRR analysis showed that the direct processing system for converting No.3 grade red oak logs into rough dimension parts are economically feasible. Under the initial assumptions of this study, the after-tax NPVs of all the six designs of the direct processing system evaluated are positive, with a range from \$1,434,200 to \$4,193,700. The IRRs of all of these six designs are greater than the minimum attractive rate of return of 12 percent, with a range from 18.35 to 29.6 percent.

With the highest NPV of \$4,193,700 and the highest IRR of 29.6 percent, the design that uses live-sawing and rip-first with manual chop saws was found to be the most economically attractive design among the six design alternatives evaluated. From the investor's standpoint, 29.6 percent of IRR is a very attractive investment return rate.

When compared with profitability for hardwood dimension and flooring industry, and for sawmills reported by Dun and Bradstreet, it was found that the direct processing system for converting No.3 red oak logs into rough dimension parts is more profitable than the conventional processing system of hardwood dimension and sawmills. The design which uses live-sawing followed by rip-first with manual chop saws has the highest ROS of 18.32 percent.

The sensitivities of NPV and ROS to the changes in dimension part price, log price, labor costs, overhead costs, initial capital investment, weighting factor for part lengths, green cutting yield, drying and remanufacturing loss were analyzed. Among these variables tested,

dimension part price, green cutting yield and drying and remanufacturing loss were found to be the most important factors that affect the economic feasibility and profitability of the direct processing system.

Although NPV and ROS are highly sensitive to changes in dimension part price, cutting yield and drying and remanufacturing loss, they are not equally important to the manager of a direct processing mill. This is because that the selling prices of dimension parts are determined by market force, while cutting yield and drying and remanufacturing loss can be controlled and improved by the efforts from within a mill. The manager of a direct processing mill should put considerable efforts into improving cutting yield and reducing drying and remanufacturing loss. To keep the direct processing system economically attractive and more profitable than conventional processing systems, it is critical that the drying and remanufacturing loss must be controlled at a certain level. Future research in determining the drying and remanufacturing loss of rough dimension parts will be necessary.

## APPENDIX

### Appendix 1.

### Computer Program Code for Mill Design 2

#### A. Model Frame

```
;*****
;****
;*****          MODEL: "Design2.mod"          *****
;****
;*****
;* This model simulates the direct processing system which carries *
;* out Live-sawing and Gang-rip-first operations. In this design, *
;* six manual chop saws are used in the the operations following the *
;* gang-rip-saw.
;*****
;
;
BEGIN, YES, Mill Design 2;
;
;
REFILL    CREATE,      1;
          STATION,    Log_Yard;                The station of log yard
          ASSIGN:
          M = 1;                                Assign station attribute
          QUEUE,      Log_wardQ;              Log wait in log yard
          SCAN:      (NEC(logdeck1)+         !Refill logs if less than
                    NEA(logdeck1) <=5;      5 logs on the log deck 1
;
          ASSIGN:    Symbol=1;
          QUEUE,      Log_LoadQ;              Wait for log loader
          REQUEST,    1:                       !Request a log loader
                    Log_Loader,200;
GEN1      ASSIGN:
          LoadTime=
          WEIB(17.15,1.55)+3;                 !Generate the time for
                                           !Loading a load of logs
                                           onto log loader
;
          BRANCH,    1:
                    IF,LoadTime <=50,ACCEPT1:
                    ELSE,GEN1;                Truncate generated data
;
ACCEPT1   DELAY:
          LoadTime;                             !Delay for loading logs
          TRANSPORT:
          Log_Loader,Logdeck1_In,175;         !Transport logs to
                                           logdeck 1
;
```

```

;      Station 2 - the entrance of logdeck 1
;
;      STATION,   Logdeck1_In;
;
;      ASSIGN:    M=2;
;      ASSIGN:    Symbol=4;
;      ASSIGN:    N_Logs=DP(1);           !Assign the number of
;      ASSIGN:    X(7)=0;                 Set the counter of logs
;                                         from one log load to 0
;
;      GEN2      ASSIGN:    UNLOADT=WEIB(14,1.4)+3;   Time for unloading a
;                                         load of logs
;
;      BRANCH,   1:
;              IF,UNLOADT <=50,ACCEPT2:   !Truncate generated data
;              ELSE,GEN2;
ACCEPT2  DUPLICATE:   !Split log load into
;              N_Logs-1;                   individual logs
;      ASSIGN:    Length=96;               !Assign log length
;      ASSIGN:    SD=TRIA(9,13,16,1);       Assign log diameter
;      ASSIGN:    Taper=UNIFORM(0,1.5);     Assign taper of a log
;      ASSIGN:    BD=SD+Taper;              Bottom Diameter
;      ASSIGN:    Cells=ANINT(BD);          Space required for a
;                                         log on logdecks
;
;      QUEUE,    Logdeck1Q;                Waiting for unloading
;                                         logs onto logdeck1
;
;      ACCESS:    Logdeck1,Cells+2:         !Get space on logdeck 1
;              MARK(TimeIn);
;      DELAY:     UnloadT/N_Logs;           !Delay for unloading a
;                                         log onto logdeck 1
;      ASSIGN:    Symbol=2;
;      ASSIGN:    X(7)=X(7)+1;              Counter logs from one
;                                         log load
;
;      BRANCH,   1:
;              IF,X(7)< N_Logs,UNLOAD:     !Unload a log on logdeck1
;              IF,X(7)==N_Logs,FREE_Load;
;
;      FREE_Load  ASSIGN:    X(7)=0;         Reset X(7) to 0
;      FREE:      Log_Loader;               Free log loader
;      BRANCH,   2:
;              ALWAYS,UNLOAD:              !Unload the final log of
;              ALWAYS,REFILL;              the log load and refill
;
;      UNLOAD    CONVEY:    Logdeck1,Deck1_End;   Transfer log to debarker
;
;      STATION,   Deck1_End;                The station of debarker
;      ASSIGN:    M = 3;

```



```

        QUEUE,      DebarkQ;
        SCAN:       Debark==0;
        QUEUE,      DBKQ;
        SEIZE:      DBK_Op:
                    DBK;
                    Wait for debarking
                    !Seize the debarker
                    and debarker operator
        ASSIGN:     Debark=1;
        EXIT:       Logdeck1;
                    Get off logdeck 1

GEN3  ASSIGN:
        LoadDBK=WEIB(1.35,1.8)+1;
        !Generate the time for
        loading and positioning
        a log onto debarker
;
        BRANCH,    1:
                    IF,LoadDBK <=4.5,GEN4:
                    ELSE,GEN3;
                    !Truncate generated data
;
GEN4  ASSIGN:     DBKTime=
                    WEIB(12.4,1.72,2)+6;
                    Generate debarking time
BRANCH,    1:
                    IF,DBKTime <=45,ACCEPT4:
                    ELSE,GEN4;
                    !Data truncation
; ACCEPT4  BRANCH,    2:
                    ALWAYS,DEBARK:
                    ALWAYS,ANIMA1;
;
DEBARK  ROUTE:
        LoadDBK,Debarking;
        !Delay for loading and
        positioning a log onto
        debarker
;
;
        STATION,   Debarking;
        ASSIGN:    M=4;
        QUEUE,     DebarkerQ;
        SEIZE:     Debarker;
        DELAY:     DBKTime;
                    !Delay for debarking
                    a log
        ASSIGN:    Symbol=3;
        RELEASE:   DBK:
                    DBK_Op;
                    !Release debarker
                    operator
;
        QUEUE,     ChainSpaceQ;
        SEIZE:     ChainSpace,Length+12;
        Wait for space on
        logchain to logdeck 2
;
        RELEASE:   Debarker;
        ASSIGN:    Debark=0;
                    !Debarker stops working
                    NEXT(GEN5);
ANIMA1  ASSIGN:   Symbol=4;
        STATION,   DBKHEAD1;
        ASSIGN:    M=45;
        QUEUE,     DBKheadQ;
        REQUEST,   1:
                    DBKHEAD,100/LoadDBK;
                    Following 13 lines are
                    used only for animation
                    purpose

```

```

TRANSPORT:
    DBKHEAD, DBKHEAD2, 100/
    DBKTime;
;
STATION,    DBKHEAD2;
ASSIGN:     M=46;
FREE:       DBKHEAD:
            DISPOSE;
;
GEN5        ASSIGN:
            UnloadDBK=                               !Time for unloading a
            WEIB(2.1, 2.3)+1.5;                       log from debarker
BRANCH,     1:
            IF, UnloadDBK <=6.5, ACCEPT5:
            ELSE, GEN5;                               Data truncation
;
ACCEPT5     ROUTE:
            UnloadDBK, Logchain_In;                   !Transfer a log onto
                                                    logchain
;
STATION,    Logchain_In;                               Station of logchain
                                                    entrance
;
ASSIGN:     M=5;
QUEUE,     LogChainQ;
;
ACCESS:     LogChain, Length+12;                       !Get space on logchain
CONVEY:     LogChain, LogChain_End;                   !Convey to logdeck2
;
STATION,    Logchain_End;                               Station of the end of
ASSIGN:     M=6;                                       logchain
;
QUEUE,     Scan_Deck2Q;
SCAN:      (CLA(Logdeck2)+
            LEC(logdeck2)) <180;                   !Check space availability
                                                    on logdeck 2
;
EXIT:       Logchain;                                   Exit logchain
ROUTE:     TRIA(1, 2.5, 4), Logdeck2_In;
;
STATION,    Logdeck2_In;                               Station of logdeck 2
ASSIGN:     M=7;                                       entrance
RELEASE:    ChainSpace, length+12;
QUEUE,     Logdeck2Q;
ACCESS:     Logdeck2, Cells;                           Get space on logdeck 2
CONVEY:     Logdeck2, Log_Loading;
;
STATION,    Log_Loading;                               Station of the end of
ASSIGN:     M=8;                                       logdeck 2
QUEUE,     Scan1Q;
SCAN:      (LEC(To_Edger)+CLA(
            To_Edger)) <=110;                   !Check space on the
                                                    cpnveyor to edger

```

```

;
    QUEUE,      CarriageQ;           Waiting for carriage
    REQUEST,    1:
    Carriage, 110;                   Request a carriage
    QUEUE,      CarriQ;
    SEIZE,      2: Carri;
    EXIT:       Logdeck2;           Exit logdeck 2
;
    BRANCH,     1:  IF, SD<10.2, MCUT1:  !Calculating the number
                    IF, SD<11.6 .AND.  !of sawing lines for a
                    SD>=10.2, MCUT2:    !given log
                    IF, SD<13 .AND.
                    SD>=11.6, MCUT3:
                    IF, SD<14.4 .AND.
                    SD>=13, MCUT4:
                    IF, SD<15.8 .AND.
                    SD>=14.4, MCUT5:
                    IF, SD>=15.8, MCUT6;
;
MCUT1  ASSIGN:   Mcuts=7:           !Assign the number of
                    NEXT(GEN6);      sawing lines for a
MCUT2  ASSIGN:   Mcuts=8:           !given log
                    NEXT(GEN6);
MCUT3  ASSIGN:   Mcuts=9:
                    NEXT(GEN6);
MCUT4  ASSIGN:   Mcuts=10:
                    NEXT(GEN6);
MCUT5  ASSIGN:   Mcuts=11:
                    NEXT(GEN6);
MCUT6  ASSIGN:   Mcuts=12;
;
GEN6   ASSIGN:
                    LPT=Lognormal(3.5,1.83,3) !Generate the time for
                    +1.5;                !loading and positioning
                    BRANCH,             a log onto the carriage
                    1:
                    IF,LPT <=10,ACCEPT6: !Data truncation
                    ELSE,GEN6;
ACCEPT6 DELAY:   0.3*LPT,1;          Delay for loading a log
;
    DELAY:
                    0.7*LPT,2;          !Delay for positioning
                    ASSIGN:             a log onto the carriage
                    Cuts=0;            !Set the number of cuts
                    ASSIGN:           completed to 0
                    ConA(1)=0;
    QUEUE,      HeadrigQ;
    SEIZE,      2: Headrig;           !Headrig saw is ready
    TRANSPORT:  Carriage,Car_Back,80; Moving to headrig saw
;
    STATION,    Car_Back;
    ASSIGN:     M=9;                 Station where the carr-
                                        iage stops in backward

```

```

;
    BRANCH, 1: IF,SD<=12.AND. Cuts==3,
              TURNING:
              IF,SD>12.AND. Cuts==4,
              TURNING:
              ELSE, SAWING;
;
TURNING ASSIGN:
              ConA(1)=0;
              !Turning the log 180
              degree
;
GEN7 ASSIGN:
              Turn_Time=
              WEIB(1.78,1.36,4)+1.4;
              Time of log turning
    BRANCH, 1:
              IF,Turn_Time <=8,ACCEPT7:
              ELSE,GEN7;
ACCEPT7 DELAY:
              Turn_Time,3;
              !Delay for log turning
SAWING TRANSPORT:
              Carriage,Headrig_In, 80;
              !Continue sawing log
;
    STATION, Headrig_In;
    ASSIGN: M=10;
              Station where the log
              start engaging in the
              the headrig saw
;
    RELEASE: Headrig:
              Carri;
;
    QUEUE, Head_InQ;
    SCAN: NQ(Off_HeadrigQ)<=0;
;
    QUEUE, Head_SawQ;
    SEIZE, 1: Headrig:
              Carri:
              Headrig Saw;
              Headrig saw is ready
;
    TRANSPORT:
              Carriage,Headrig_Out,50;
;
    STATION, Headrig_Out;
              Station where the carriage
              stops for dropping the
              sawn flitches
;
    ASSIGN:
              M=11;
    RELEASE:
              Headrig saw;
              !Release the headrig saw
    ASSIGN:
              Cuts=Cuts+1;
              !update the number of
              cuts completed
    ASSIGN:
              ConA(1)=ConA(1)+1;
    BRANCH, 2:
              ALWAYS,FLITCH,NO:
              ALWAYS,CARRIAGE;
              Part of log remaining on

```

```

;
CARRIAGE BRANCH, 1: the carriage
IF, Mcuts-cuts >= 0.5, REPEAT: !Repeat sawing
IF, Mcuts-cuts < 0.5,
FREEcarriage; Go to load another log
;
REPEAT TRANSPORT: Carriage, Car_Back, 110; Carriage back for
another sawing pass
;
FREEcarriage DELAY: !Delay for removing the
final flitch
2;
RELEASE: Headrig;
FREE: !Free carriage and
Carriage; release the final flitch
BRANCH, 2:
ALWAYS, FLITCH, NO:
ALWAYS, LOG_TALLY;
;
;
LOG_TALLY DELAY: 2.8; Tally the logs processed
RELEASE: Carri;
ASSIGN: CubicV=(1/12**3)*(3.14/16)*
Length*((BD+SD)**2);
ASSIGN: Scaled=ANINT(SD);
ASSIGN: ScaleBF=TF(LogBF, Scaled);
WRITE, LogFile:
SD, BD, CubicV, ScaleBF;
ASSIGN: Total_CubicV=Total_CubicV
+CubicV;
TALLY: Log Cubic Footage,
Total_CubicV;
ASSIGN: Total_ScaleBF=Total_ScaleBF
+ScaleBF;
TALLY: Log Board Footage,
Total_ScaleBF;
COUNT: Total Num of Logs;
ASSIGN: Logs=Logs+1;
DISPOSE;
;
FLITCH BRANCH, 1:
IF, ConA(1).EQ. 1, !Slabs go to chip
SLAB;
ELSE, Dimension; The other flitches go
to dimension
;
SLAB ASSIGN: Symbol=6;
ROUTE: 10, Chipper;
;
STATION, Chipper; Chipper Station
ASSIGN:
M=12:
DISPOSE;

```

```

;
DIMENSION ASSIGN: Symbol=5;
ASSIGN: DFC=1.4*ABS(Mcuts-2*ConA(1)
          +1)-0.28;
ASSIGN: Width=SQRT(SD*SD-DFC*DFC);
ASSIGN: Cells=ANINT(BD-SD+Width); Assign space required on
; conveyors for a flitch
QUEUE, Off_HeadrigQ;
ACCESS: Off_Headrig,Length+6; !Get space on the
conveyor off-headrig
CONVEY: Off_Headrig,Roller_End;
;
STATION, Roller_End; Station of the end of
ASSIGN: M=13; the off-headrig conv.
QUEUE, To_EdgerQ; Wait for to be transferd
; to edger
ACCESS:
To_Edger,Cells;
EXIT: Off_Headrig;
CONVEY: To_Edger,Edger_In; !Convey to edging saw
;
STATION, Edger_In; Station of edging saw
ASSIGN:
M=14;
QUEUE, Scan2Q;
SCAN: (LEC(To_Planer)+ !Check space on the
CLA(To_Planer))<=110; conveyor to planer
QUEUE, EdgerQ;
ACCESS: Edger_Inf, length;
QUEUE, E_OperatorQ; Wait for edging
SEIZE: E_OperatorQ; !Get edging operator
Edger Operator;
EXIT: To_Edger;
DELAY: To_Edger; !Delay for picking up
and positioning a flitch
QUEUE, Edging_SawQ;
SEIZE: Edging_Saw; Engaged in edging saw
RELEASE: Edger Operator; Release edging operator
CONVEY: Edger_Inf,Edger_Out; Moving through edging
; saw
;
STATION, Edger_Out; Station of edging saw
ASSIGN: M=15; exit
RELEASE: Edging_Saw;
BRANCH, 2:
ALWAYS,MIDDLE: !Edged flitch
ALWAYS,SIDES; Edging waste
SIDES ASSIGN: Symbol=10;
QUEUE, Pick_WasteQ;
SEIZE, 1: Planer Operator;

```

```

MIDDLE      DELAY:      TRIA(2,3,4);
            RELEASE:   Planer Operator;
            ROUTE:     10,CHIPPER;
            ASSIGN:    Symbol=7;
            CONVEY:    Edger_Inf,Edger_End;
;
;
;
            STATION,   Edger_End;
            ASSIGN:    M=16;
            QUEUE,     To_PlanerQ;
            ACCESS:    To_Planer,Cells;
;
            EXIT:      Edger_Inf;
            CONVEY:    To_Planer, Planer_In;
;
;
            STATION,   Planer_In;
            ASSIGN:    M=17;
            QUEUE,     Scan3Q;
            SCAN:      (LEC(To_Laser)+
                       CLA(To_Laser))<=140;
;
            QUEUE,     PlanerQ;
            ACCESS:    Planer_Belt, length;
            QUEUE,     P_OperatorQ;
            SEIZE, 2:   Planer Operator;
            EXIT:      To_Planer;
            DELAY:     TRIA(1.5,2,2.5);
;
            QUEUE,     PlanQ;
            SEIZE:     Planer;
            RELEASE:   Planer Operator;
            CONVEY:    Planer_Belt, Plan_Exit;
;
            STATION,   Plan_Exit;
            ASSIGN:    M=18;
            RELEASE:   Planer;
            CONVEY:    Planer_Belt, Plan_End;
;
            STATION,   Plan_End;
            ASSIGN:    M=19;
            QUEUE,     To_LaserQ;
            ACCESS:    To_Laser,Cells;
            EXIT:      Planer_Belt;
            CONVEY:    To_Laser,Laser;
;
            STATION,   Laser;
            ASSIGN:

```

Waste go to chipper  
Edged flitch continues moving to the end of the edging saw conveyor

Station of the end of the edging saw conveyor

Get on the conveyor to planer

Conveying on the conv. to planer

Station of the planer entrance

!Check space on the conveyor to laser scan

Wait for planer operator

Delay for picking up a flitch

In planing

Station of planer exit

Station of the end of the planer conveyor

!Get space on the conv. to laser scan station

!Convey to laser scan station

Station of laser scanning

```

M=20;
QUEUE, LaserQ; Wait for laser scanning
SEIZE: Scanning Operator: !Get laser scan operator
Scanner; and occupy scanner
EXIT: To_Laser;
ASSIGN: Symbol=8;
GEN8 ASSIGN: !generate scanning time
Scan_Time=
WEIB(1.95,3.4,5)+3.5;
;
;
BRANCH, 1:
IF,Scan_Time <=10, ACCEPT8:
ELSE,GEN8; Data truncation
ACCEPT8 DELAY: Scan_Time; !Delay for scanning
RELEASE: Scanning Operator;
ASSIGN: Symbol=7;
QUEUE, Scan4Q;
SCAN:
NERIP==0; Hold flitch if there is
; no space on the rip saw
; infeed conveyor
RELEASE:
Scanner; Release scanner
ROUTE: !Released flitch goes to
1,RipInfeed; rip infeed conveyor
;
STATION, RipInfeed; Starting point of rip
; infeed conveyor
ASSIGN:
M=21;
QUEUE, Rip_InQ;
ACCESS: Rip_Inf,length+12; !Get onto rip infeed
conveyor
ASSIGN: NERIP=NERIP+1;
QUEUE, RipQ;
SEIZE: Rip;
BRANCH, 2:
ALWAYS, Ripping:
ALWAYS, Watch_Rip;
;
WATCH_Rip DELAY: 4.8; For animation
ASSIGN: NERIP=NERIP-1;
DISPOSE;
;
RIPPING CONVEY: !Convey to gang rip saw
Rip_Inf,Gang_Rip;
STATION, Gang_Rip; Station of gang rip
ASSIGN:
M=22;

```



```

        QUEUE,      Rip_SawQ;
        SEIZE:      Rip Saw;                Start ripping
        CONVEY:     !Pass through gang rip saw
                    Rip_Inf,Rip_Exit;
;
        STATION,    Rip_Exit;                Station of the gang rip
        ASSIGN:     !exit
                    M=23;
        RELEASE:    Rip:
                    Rip Saw;
        ASSIGN:     Symbol=9;
        CONVEY:     Rip_Inf,Rip_End;
;
;
        STATION,    Rip_End;                Station of the end of rip
        ASSIGN:     !conveyor
                    M=24;
        ASSIGN:     Pieces=DP(2);           The number of strips
;                                               ripped from one flitch
        PICKQ,      CYC:
                    Chop_Line1:
                    Chop_Line2;
;
;*****
;*****                Chop Line 1                *****
;*****
;
Chop_Line1 QUEUE,    ChopLine1Q;
        SEIZE:      ChopLine1;
        DELAY:      TRIA(0.3,0.5,0.6);
        EXIT:       Rip_Inf;
        RELEASE:    ChopLine1;
        DUPLICATE:  Pieces-1;
        ASSIGN:     Width=(Width/Pieces)-0.19;
        ASSIGN:     Cells=ANINT(Width);
        ASSIGN:     Symbol=11;
;
        QUEUE,      Chain1Q;                Wait for space on chain1
;
        ACCESS:     !Get space on Chain1
                    Chain1,Cells;
        DELAY:      0.3;
        ASSIGN:     NES1=NES1+1;           NES1 is the number of
;                                               strips on the segment of
;                                               conveyor Chain1 before
;                                               station chop1
;
        CONVEY:     !Ripped pieces go to
                    Chain1,Chop1_In;      chop saws
;
        STATION,    Chop1_In;                Station of chop saw 1

```

```

        ASSIGN:      M=25;
        ASSIGN:      NES1=NES1-1;
        BRANCH,     1:
                    IF,NQ(Chop1Q)==0 .AND.NR(
                        Chop1)==0, ADD_Chop1:      !Go to chop saw 1
                    IF,Buffer1< 3 .AND. Buffer1
                        > 0, ADD_Chop1:           !Go to chop saw 1
                    ELSE,To_Chop2;                go to chop saw 2
;
ADD_Chop1  QUEUE,   C1_PickQ;
           SEIZE,   2: Chop1;                    Get chop saw1 operator
           EXIT:   Chain1,Cells;
           ASSIGN: Buffer1=Buffer1+1;
           DELAY:  TRIA(0.5,1.0,1.5);           Delay for picking up
           RELEASE: Chop1;
           ASSIGN: Symbol=15;
           BRANCH, 1:
                    IF,Buffer1==3 .OR.NES1<=1,
                        RESETC1:
                    ELSE,PICK_MORE1;
;
RESETC1   ASSIGN:   Buffer1=0;
;
PICK_MORE1  QUEUE, Buffer1Q;
           SCAN:    Buffer1==0;
;
           QUEUE,   Chop1Q;
           SEIZE, 1: Chop1:
                    Chop saw1;

           ASSIGN:
                    Chops_Need=DP(3);           The number o chops needed
           ASSIGN:   X(1)=Chops_Need;           Store the number of chops
                                                needed for a strip
;
;
Chop_More1  ASSIGN: Symbol=15+X(1)-Chops_Need;
;
GEN9       ASSIGN:  ChopTime=
                    LOGNORMAL(1.88,0.15,7);    Time for one chop
           BRANCH, 1:
                    IF,ChopTime > 3.4 .OR.
                    ChopTime < 1.2,GEN9:
                    ELSE,ACCEPT9;
ACCEPT9    DELAY:   ChopTime,4;                !Delay for one chop
           ASSIGN:  Chops_Need=Chops_Need-1;   Count the number of
                                                chops finished
;
           BRANCH, 2:
                    ALWAYS,PART1,NO:          !Get one chopping piece
                    IF,Chops_Need >0,
                    Chop_More1:
                    IF,Chops_Need==0,

```

```

;
RELC1    RELEASE:    Chop1:
                                Chop Saw1:
                                NEXT(Defect1);
                                Get the final chopping
                                piece

;
PART1    ASSIGN:     Symbol=4;
          ASSIGN:     ConA(1)=1;
          BRANCH,     1,2:
                                WITH,0.3,Defect1:
                                WITH,0.7,Good_Piece1;
                                !Defective pieces
                                Good pieces

Defect1  ASSIGN:     Symbol=12;
          ASSIGN:     Def_Length=TR(4);
          ASSIGN:     Length=ANINT(Def_Length):
                                NEXT(OUTBELT1);
                                Assign the length to
                                the defective piece

;
;
Good_Piece1  ASSIGN:
                                Part_Length=DP(5);
                                Length=Part_Length;
                                !Assign cutting length
                                to the good pieces
          ASSIGN:     BRANCH, 1:
                                IF, Length>40, SYMB1:
                                ELSE, SYMB2;

SYMB1    ASSIGN:     Symbol=14;
                                NEXT(OUTBELT1);

SYMB2    ASSIGN:     Symbol=13;

;
OUTBELT1  STATION,   Chop1_Out;
          ASSIGN:     M=26;
          QUEUE,     Chop1_OutQ;
          ACCESS:    Out_Belt1,Cells;
          CONVEY:    Out_Belt1, Belt1_End;
                                Station of Chop1 out

;
;*****
;*****
To_Chop2  ASSIGN:     NES2=NES2+1;
          CONVEY:     Chain1,Chop2_In;

;
          STATION,   Chop2_In;
          ASSIGN:     M=27;
          ASSIGN:     NES2=NES2-1;
          BRANCH, 1:
                                IF,NQ(Chop2Q)==0 .AND. NR(
                                    Chop2)==0, Add_Chop2:
                                IF,Buffer2< 3 .AND.Buffer2 >
                                    0,ADD_Chop2:
                                ELSE,To_Chop3;

;
ADD_Chop2  QUEUE,     C2_PickQ;
          SEIZE, 2:   Chop2;
          EXIT:       Chain1,Cells;

```

```

ASSIGN:    Buffer2=Buffer2+1;
DELAY:    TRIA(0.5,1.0,1.5);
RELEASE:   Chop2;
ASSIGN:    Symbol=15;
BRANCH, 1:
            IF,Buffer2==3 .OR.NES2<=1,
              RESETC2:
            ELSE,PICK_MORE2;

;
RESETC2  ASSIGN:    Buffer2=0;
;
PICK_MORE2  QUEUE,  Buffer2Q;
            SCAN:   Buffer2==0;
;
            QUEUE,   Chop2Q;
            SEIZE, 1: Chop2:
              Chop Saw2;
            ASSIGN:  Chops_Need=DP(3);
            ASSIGN:  X(2)=Chops_Need;
;
CHOP_MORE2  ASSIGN:
            Symbol=15+X(2)-Chops_Need;
GEN10      ASSIGN:  ChopTime=LOGNORMAL(1.88,0.15,7);
            BRANCH, 1:
              IF,ChopTime >3.4 .OR.
                ChopTime <1.2,GEN10:
              ELSE,ACCEPT10;
;
ACCEPT10  DELAY:    ChopTime,5;
            ASSIGN:  Chops_Need=Chops_Need-1;
            BRANCH, 2:
              ALWAYS, PART2, NO:
              IF, Chops_Need >0,
                Chop_More2:
              IF, Chops_Need==0,
                RELC2;
;
RELC2     RELEASE:  Chop2:
            Chop Saw2:
            NEXT(Defect2);
;
PART2     ASSIGN:   Symbol=4;
;
            ASSIGN:  ConA(1)=2;
            BRANCH, 1, 2:
              WITH,0.3,Defect2:
              WITH,0.7,Good_Piece2;
Defect2   ASSIGN:   Symbol=12;
            ASSIGN:  Def_Length=TR(4);
            ASSIGN:  Length=ANINT(Def_Length):
            NEXT(OUTBELT2);

```

```

Good_Piece2 ASSIGN: Part_Length=DP(5);
              ASSIGN: Length=Part_Length;
              BRANCH, 1:
                    IF, Length>40, SYMB3:
                    ELSE, SYMB4;
SYMB3 ASSIGN: Symbol=14;
              NEXT(OUTBELT2);
SYMB4 ASSIGN: Symbol=13;
;
OUTBELT2 STATION, Chop2_Out;
          ASSIGN: M=28;
          QUEUE, Chop2_OutQ;
          ACCESS: Out_Belt1,Cells;
          CONVEY: Out_Belt1, Belt1_End;
;
;*****
;*****
;
To_Chop3 ASSIGN: NES3=NES3+1;
          CONVEY: Chain1,Chop3_In;
;
          STATION, Chop3_In;
          ASSIGN: M=29;
          ASSIGN: NES3=NES3-1;
;
          QUEUE, C3_PickQ;
          SEIZE, 2: Chop3;
          EXIT: Chain1,Cells;
          ASSIGN: Buffer3=Buffer3+1;
          DELAY: TRIA(0.5,1.0,1.5);
          RELEASE: Chop3;
          ASSIGN: Symbol=15;
          BRANCH, 1:
                    IF, Buffer3==5 .OR.
                    NES3==0, RESETC3:
                    ELSE, PICK_MORE3;
;
RESETC3 ASSIGN: Buffer3=0;
;
PICK_MORE3 QUEUE, Buffer3Q;
           SCAN: Buffer3==0;
;
           QUEUE, Chop3Q;
           SEIZE, 1: Chop3:
                   Chop Saw3;
           ASSIGN: Chops_Need=DP(3);
           ASSIGN: X(3)=Chops_Need;
;
Chop_More3 ASSIGN: Symbol=15+X(3)-Chops_Need;
GEN11 ASSIGN: ChopTime=LOGNORMAL(1.88,0.15,7);
        BRANCH, 1:

```

```

IF, ChopTime > 3.4 .OR.
    ChopTime <1.2, GEN11:
ELSE, ACCEPT11;
ACCEPT11  DELAY:    ChopTime,6;
          ASSIGN:   Chops_Need=Chops_Need-1;
          BRANCH, 2:
                ALWAYS, PART3, NO:
                IF, Chops_Need >0,
                    Chop_More3:
                IF, Chops_Need==0,
                    RELC3;
RELC3    RELEASE:  Chop3:
                Chop Saw3:
                NEXT(Defect3);
PART3    ASSIGN:   Symbol=4;
          ASSIGN:   ConA(1)=3;
          BRANCH, 1, 2:
                WITH, 0.3, Defect3:
                WITH, 0.7, Good_Piece3;
Defect3  ASSIGN:   Symbol=12;
          ASSIGN:   Def_Length=TR(4);
          ASSIGN:   Length=ANINT(Def_Length):
                NEXT(OUTBELT3);
;
Good_Piece3  ASSIGN:  Part_Length=DP(5);
              ASSIGN:  Length=Part_Length;
              BRANCH, 1:
                    IF, Length>40, SYMB5:
                    ELSE, SYMB6;
SYMB5    ASSIGN:   Symbol=14:
                NEXT(OUTBELT3);
SYMB6    ASSIGN:   Symbol=13;
;
OUTBELT3  STATION, Chop3_Out;
          ASSIGN:   M=30;
          QUEUE,    Chop3_OutQ;
          ACCESS:   Out_Belt1,Cells;
          CONVEY:   Out_Belt1,Belt1_End;           Go to sorting table
;
          STATION,  Belt1_End;                     Station of the end of
          ASSIGN:   M=31;                           belt conveyor 1
          EXIT:     Out_Belt1,Cells;
          ASSIGN:   ConA(2)=0;
          ROUTE:    0.3,Tab1_Ent;                   Go to sorting table 1
;
          STATION,  Tab1_Ent;                       Station of sorting
          ASSIGN:   M=32;                           table 1
          BRANCH,  1:
                IF, ConA(2)==1, GOTAB1:
                IF, ConA(2)==0, GOSQ1;
GOSQ1    QUEUE,    Sort1Q;

```

```

ACCESS:      Sort_Table1,Cells;           Get on sorting table 1
GOTAB1 CONVEY: Sort_Table1,Off_Point1;
;
      STATION, Off_Point1;               Position of sorter 1
      ASSIGN:  M=33;
      BRANCH,  1,1:
              IF,NR(Sorter1)==0 .AND.
                Length >=25,Get_Off1:
              ELSE,TO_Sorter2;
To_Sorter2 CONVEY: Sort_Table1,Off_Point2;   Position of sorter 2
      STATION, Off_Point2;
      ASSIGN:  M=34;
      BRANCH,  1:
              IF,NR(Sorter2)==0 .AND.
                Length < 25,Get_Off2:
              ELSE,Stay1;
;
Stay1  ASSIGN:  ConA(2)=1;               Parts that staying on
      CONVEY:   !the sorting table 1
              Sort_Table1,Tab1_Ent;
;
Get_Off1 EXIT:      Sort_Table1,Cells;
      QUEUE,      Sorter1Q;           Wait for sorter 1
      SEIZE:      !Get sorter 1
              Sorter1;
      DELAY:      !Delay for grasping and
              TRIA(0.5,1.5,2.5);      moving one part
      RELEASE:    !Release sorter 1
              Sorter1;
      BRANCH,    1:
              IF,Symbol==12,CHIP2:
              IF,Symbol>=13,PARTS;
;
Get_Off2 EXIT:      Sort_Table1,Cells;
      QUEUE,      Sorter2Q;           Wait for sorter 2
      SEIZE:      !Get sorter 2
              Sorter2;
      DELAY:      !Delay for grasping and
              TRIA(0.5,1.5,2.5);      moving one part
      RELEASE:    !Release sorter 2
              Sorter2;
      BRANCH,    1:
              IF,Symbol==12,CHIP2:
              IF,Symbol>=13,PARTS;
;
;*****
;*****          Chop Line 2          *****
;*****
;
Chop_Line2 QUEUE,  ChopLine2Q;
      SEIZE:      ChopLine2;

```

```

DELAY:      TRIA(0.3,0.5,0.6);
EXIT:       Rip_Inf;
RELEASE:    ChopLine2;
DUPLICATE:  Pieces-1;
ASSIGN:     Width=(Width/Pieces)-0.19;
ASSIGN:     Cells=ANINT(Width);
ASSIGN:     Symbol=11;
QUEUE,     Chain2Q;
;
ACCESS:
Chain2,Cells;
DELAY:     0.3;
ASSIGN:    NES4=NES4+1;
;
;
CONVEY:
Chain2,Chop4_In;
;
STATION,   Chop4_In;
ASSIGN:
M=35;
ASSIGN:    NES4=NES4-1;
BRANCH, 1:
IF, NQ(Chop4Q)==0 .AND.
NR(Chop4)==0,
ADD_Chop4:
IF, Buffer4< 3 .AND. Buffer4>0,
ADD_Chop4:
ELSE, TO_CHOP5;
;
ADD_Chop4  QUEUE,   C4_PickQ;
SEIZE, 2:  Chop4;
EXIT:     Chain2, Cells;
ASSIGN:    Buffer4=Buffer4+1;
DELAY:    TRIA(0.5,1.0,1.5);
RELEASE:   Chop4;
ASSIGN:    Symbol=15;
BRANCH, 1:
IF, Buffer4==3 .OR.
NES4<=1, RESETC4:
ELSE, PICK_MORE4;
RESETC4   ASSIGN:   Buffer4=0;
;
PICK_MORE4 QUEUE,   Buffer4Q;
SCAN:     Buffer4==0;
;
QUEUE,    Chop4Q;
SEIZE, 1: Chop4:
Chop Saw4;
ASSIGN:
Chops_Need=DP(3);

```



```

        ASSIGN:      X(4)=Chops_Need;
;
Chop_More4  ASSIGN:  Symbol=15+X(4)-Chops_Need;
;
GEN12      ASSIGN:  ChopTime=LOGNORMAL(1.88,0.15,7);
            BRANCH, 1:
                IF,ChopTime > 3.4 .OR.
                    ChopTime < 1.2,GEN12:
                ELSE,ACCEPT12;
;
ACCEPT12 DELAY:
            ChopTime,7;
            ASSIGN:  Chops_Need=Chops_Need-1;
;
            BRANCH, 2:
                ALWAYS,PART4,NO:
                IF,Chops_Need >0,
                    Chop_More4:
                IF,Chops_Need==0,
                    RELC4;
RELC4      RELEASE:  Chop4:
                Chop Saw4:
                NEXT(Defect4);
;
PART4      ASSIGN:  Symbol=4;
            ASSIGN:  ConA(1)=4;
            BRANCH, 1, 2:
                WITH,0.3,Defect4:
                WITH,0.7,Good_Piece4;
Defect4    ASSIGN:  Symbol=12;
            ASSIGN:  Def_Length=TR(4);
            ASSIGN:  Length=ANINT(Def_Length):
                NEXT(OUTBELT4);
Good_Piece4 ASSIGN:
            Part_Length=DP(5);
            ASSIGN:  Length=Part_Length;
            BRANCH, 1:
                IF, length>40, SYMB7:
                ELSE, SYMB8;
SYMB7      ASSIGN:  Symbol=14:
                NEXT(OUTBELT4);
SYMB8      ASSIGN:  Symbol=13;
;
OUTBELT4   STATION, Chop4_Out;
            ASSIGN:  M=36;
            QUEUE,   Chop4_OutQ;
            ACCESS:  Out_Belt2,Cells;
            CONVEY:  Out_Belt2,Belt2_End;
;
;*****
;*****

```

```

;
To_Chop5  ASSIGN:  NES5=NES5+1;
          CONVEY:  Chain2, Chop5_In;
;
          STATION,  Chop5_In;
          ASSIGN:  M=37;
          ASSIGN:  NES5=NES5-1;
          BRANCH,  1:
                    IF, NQ(Chop5Q)==0 .AND.
                      NR(Chop5)==0,
                      ADD_Chop5:
                    IF, Buffer5 < 3 .AND.
                      Buffer5 >0, ADD_Chop5:
                    ELSE, To_CHOP6;
ADD_Chop5  QUEUE,  C5_PickQ;
          SEIZE,  2:  Chop5;
          EXIT:   Chain2, Cells;
          ASSIGN: Buffer5=Buffer5+1;
          DELAY:  TRIA(0.5,1.0,1.5);
          RELEASE: Chop5;
          ASSIGN: Symbol=15;
          BRANCH, 1:
                    IF, Buffer5==3 .OR. NES5
                      <=1, RESETC5:
                    ELSE, PICK_MORE5;
RESETC5    ASSIGN:  Buffer5=0;
;
PICK_MORE5  QUEUE,  Buffer5Q;
          SCAN:
                    Buffer5==0;
;
          QUEUE,  Chop5Q;
          SEIZE,  1:  Chop5:
                    Chop Saw5;
          ASSIGN:  Chops_Need=DP(3);
          ASSIGN:  X(5)=Chops_Need;
;
Chop_More5  ASSIGN:
                    Symbol=15+X(5)-Chops_Need;
GEN13      ASSIGN:  ChopTime=NORMAL(1.88,0.15,7);
          BRANCH,  1:
                    IF, ChopTime >3.4 .OR.
                      ChopTime <1.2, GEN13:
                    ELSE, ACCEPT13;
ACCEPT13   DELAY:  ChopTime,8;
          ASSIGN:  Chops_Need=Chops_Need-1;
          BRANCH,  2:
                    ALWAYS, PART5, NO:
                    IF, Chops_Need >0,
                      Chop_More5:
                    IF, Chops_Need==0,

```

```

                                RELC5;
RELC5    RELEASE:
                                Chop5:
                                Chop Saw5:
                                NEXT(Defect5);
PART5    ASSIGN:    Symbol=4;
                                ASSIGN:    ConA(1)=5;
                                BRANCH, 1, 2:
                                                With, 0.3, Defect5:
                                                With, 0.7, Good_Piece5;
Defect5  ASSIGN:    Symbol=12;
                                ASSIGN:    Def_Length=TR(4);
                                ASSIGN:    Length=ANINT(Def_Length):
                                NEXT(OUTBELT5);
;
Good_Piece5  ASSIGN:    Part_Length=DP(5);
                                ASSIGN:    Length=Part_Length;
                                BRANCH, 1:  IF, length>40, SYMB9:
                                                ELSE, SYMB10;
SYMB9      ASSIGN:    Symbol=14:
                                NEXT(OUTBELT5);
SYMB10     ASSIGN:    Symbol=13;
;
OUTBELT5   STATION,    Chop5_Out;
                                ASSIGN:    M=38;
                                QUEUE,     Chop5_OutQ;
                                ACCESS:    Out_Belt2, Cells;
                                CONVEY:    Out_Belt2, Belt2_End;
;
;*****
;*****
;
To_Chop6   ASSIGN:    NES6=NES6+1;
                                CONVEY:    Chain2, Chop6_In;
;
                                STATION,    Chop6_In;
                                ASSIGN:    M=39;
                                ASSIGN:    NES6=NES6-1;
                                QUEUE,     C6_PickQ;
                                SEIZE,     2: Chop6;
                                EXIT:      Chain2, Cells;
                                ASSIGN:    Buffer6=Buffer6+1;
                                DELAY:     TRIA(0.5,1.0,1.5);
                                RELEASE:    Chop6;
                                ASSIGN:    Symbol=15;
                                BRANCH,     1:
                                                IF, Buffer6==5 .OR. NES6
                                                    ==0, RESETC6:
                                                ELSE, PICK_More6;
RESETC6    ASSIGN:    Buffer6=0;
;

```

```

PICK_MORE6  QUEUE,   Buffer6Q;
            SCAN:   Buffer6==0;
;
            QUEUE,   Chop6Q;
            SEIZE,  1: Chop6:
            Chop Saw6;
            ASSIGN:  Chops_Need=DP(3);
            ASSIGN:  X(6)=Chops_Need;
;
Chop_More6  ASSIGN:  Symbol=15+X(6)-Chops_Need;
GEN14      ASSIGN:  ChopTime=LOGNORMAL(1.88,0.15,7);
            BRANCH, 1:
                    IF, ChopTime >3.4 .OR.
                        ChopTime <1.2, GEN14:
                    ELSE, ACCEPT14;
ACCEPT14    DELAY:   ChopTime,9;
            ASSIGN:  Chops_Need=Chops_Need-1;
            BRANCH, 2:
                    ALWAYS, PART6, NO:
                    IF, Chops_Need > 0,
                        Chop_More6:
                    IF, Chops_Need==0,
                        RELC6;
RELC6      RELEASE:  Chop6:
            Chop Saw6:
            NEXT(Defect6);
;
PART6      ASSIGN:  Symbol=4;
            ASSIGN:  ConA(1)=6;
            BRANCH, 1, 2:
                    With, 0.3, Defect6:
                    With, 0.7, Good_Piece6;
Defect6    ASSIGN:  Symbol=12;
            ASSIGN:  Def_Length=TR(4);
            ASSIGN:  Length=ANINT(Def_Length):
            NEXT(OUTBELT6);
;
Good_Piece6 ASSIGN:  Part_Length=DP(5);
            ASSIGN:  Length=Part_Length;
            BRANCH, 1:
                    IF, length>40, SYMB11:
                    ELSE, SYMB12;
SYMB11    ASSIGN:  Symbol=14:
            NEXT(OUTBELT6);
SYMB12    ASSIGN:  Symbol=13;
;
OUTBELT6   STATION,  Chop6_Out;
            ASSIGN:  M=40;
            QUEUE,   Chop6_OutQ;
            ACCESS:  Out_Belt2,Cells;
            CONVEY:  Out_Belt2,Belt2_End;

```

```

;
    STATION,    Belt2_End;
    ASSIGN:    M=41;
    EXIT:      Out_Belt2,Cells;
    ASSIGN:    ConA(2)=0;
    ROUTE:    0.3,Tab2_Ent;
;
    STATION,    Tab2_Ent;
    ASSIGN:    M=42;
    BRANCH, 1:
        IF,ConA(2)==1,GOTAB2:
        IF,ConA(2)==0,GOSQ2;
GOSQ2    QUEUE,    Sort2Q;
        ACCESS:    Sort_Table2,Cells;
GOTAB2    CONVEY:    Sort_Table2,Off_Point3;
;
    STATION,    Off_Point3;
    ASSIGN:    M=43;
    BRANCH,
        1,1:
        IF,NR(Sorter3)==0 .AND.
            Length >=25,Get_Off3:
        ELSE,TO_Sorter4;
TO_Sorter4 CONVEY: Sort_Table2,Off_Point4;
        STATION,    Off_Point4;
        ASSIGN:    M=44;
        BRANCH,
            1:
            IF, NR(Sorter4)==0 .AND.
                Length < 25,Get_Off4:
            ELSE,Stay2;
;
Stay2    ASSIGN:    ConA(2)=1;
        CONVEY:
            Sort_Table2,Tab2_Ent;
;
Get_Off3 EXIT:      Sort_Table2,Cells;
        QUEUE,      Sorter3Q;
        SEIZE:
            Sorter3;
        DELAY:
            TRIA(0.5,1.5,2.5);
        RELEASE:
            Sorter3;
        BRANCH,
            1:
            IF, Symbol==12,CHIP2:
            IF, Symbol>=13,PARTS;
;
Get_Off4 EXIT:      Sort_Table2,Cells;
        QUEUE,      Sorter4Q;
        SEIZE:
            Sorter4;
        DELAY:

```

```

                TRIA(0.5,1.5,2.5);
RELEASE:
                Sorter4;
BRANCH,      1:
                IF,Symbol==12,CHIP2:
                IF,Symbol>=13,PARTS;
;
PARTS        TALLY:      FlowTime,INT(TimeIn);
              COUNT:      Total Num of Parts;
              ASSIGN:      Total_Parts=Total_Parts+1:
                          Part_BF=Part_BF+length*width/144:
                          DISPOSE;
;
CHIP2        ROUTE:      15, CHIPPER;
END;         END;

```

## B. Experimental Frame

```

BEGIN, YES, YES;
PROJECT, Dimension_Mill_Design2, Wenjie Lin, 12/10/1991;
REPLICATE,20,0,27000;
SEEDS:
    1, 432131:
    2, 555117:
    3, 899913:
    4, 600333:
    5, 2474521:
    6, 6123453:
    7, 7894321:
    8, 6543201:
    9, 3537429:
   10, 1040123;
;
VARIABLES:
    1, N_Logs,0:           !Number of log per load
    2, LoadTime,0:        !Time of loading a load of logs
    3, UnloadT,0:         !Time for Unloading a log onto logdeck1
    4, LoadDBK,0:         !Time for lloading a log onto debarker
    5, DBKTime,0:         !Time for debarking a log
    6, UnloadDBK,0:       !Time for unloading a log from debarker
    7, LPT,0:             !Time for loading & positioning a log
                          onto carriage
;
    8, Turn_Time,0:       !Time for making one log turn
    9, DFC,0:
   10, Scan_Time,0:       !Time for scanning a flitch
   11, PlanerL,48:       !The length of the planer
   12, ChopTime,0:       !Time for making one chop by chop saw
   13, Scaled,0:         !Scaling diameter (inches) of a log

```

```

14, Taper,0:                !Log taper
15, MCuts,0:               !Maximum cuts needed for a log
16, CubicV,0:              !Cubic footage of a log
17, ScaleBF,0:             !Scaling board footage of a log
18, Total_CubicV,0:
19, Total_ScaleBF,0:
20, NES1,0:
21, NES2,0:
22, NES3,0:
23, NES4,0:
24, NES5,0:
25, NES6,0:
26, Buffer1,0:              !Number of strips on chop 1 table
27, Buffer2,0:              !Number of strips on chop 2 table
28, Buffer3,0:              !Number of strips on chop 3 table
29, Buffer4,0:              !Number of strips on chop 4 table
30, Buffer5,0:              !Number of strips on chop 5 table
31, Buffer6,0:              !Number of strips on chop 6 table
32, Def_Length,0:          !length of chop waste
33, Part_Length,0:         !Part length
34, DT,0:
35, Total_Parts,0:         !Number of total parts produced
36, Logs,0:                !Number of total logs processed
37, NERIP,0:               !Number of flitch on rip infeed Conv.
38, Debark,0:
39, Part_BF,0;             Board footages of parts produced
;
;
ATTRIBUTES:
    1, Length,0:           !Length of logs, flitches, or parts
    2, Cuts,0:              !The number of cuts finished
    3, SD,0:                !Scaling diameter of a log
    4, Width,0:             !Width of flitches or parts
    5-6, ConA(2),0:         !Status control attributes
    7, Symbol,0:           !Animation symbol
    8, TimeIn,0:
    9, Cells,0:             !The space needs on conveyors
    10, BD,0:               !Bottom diameter of a log
    11, Chops_Need,0:       !Number of chops needed for a strip
    12, Pieces, 0;         Number of strips ripped from a flitch
;
;
RESOURCES:
    1, Headrig Saw,1:
    2, Debarker,1:
    3, Planer,1:
    4, Planer Operator,1:
    5, Edging saw,1:
    6, Edger Operator,1:
    7, Scanner,1:
    8, Scanning Operator,1:

```

```
9, ChopLine1,1:
10, ChopLine2,1:
11, Chop Saw1,1:
12, Chop Saw2,1:
13, Chop Saw3,1:
14, Chop Saw4,1:
15, Chop Saw5,1:
16, Chop Saw6,1:
17, Chop1,1:
18, Chop2,1:
19, Chop3,1:
20, Chop4,1:
21, Chop5,1:
22, Chop6,1:
23, Sorter1,1:
24, Sorter2,1:
25, Sorter3,1:
26, sorter4,1:
27, ChainSpace,340:
28, DBK,1:
29, Head,1:
30, Rip Saw,1:
31, DBK_Op, 1:
32, Carri, 1:
33, Headrig,1:
34, Rip,1;
```

```
;
```

```
;
```

```
STATIONS:
```

```
1, Log_Yard:
2, Logdeck1_In:
3, Deck1_End:
4, Debarking:
5, Logchain_In:
6, Logchain_End:
7, Logdeck2_In:
8, Log_Loading:
9, Car_Back:
10, Headrig_In:
11, Headrig_Out:
12, Chipper:
13, Roller_End:
14, Edger_In:
15, Edger_Out:
16, Edger_End:
17, Planer_In:
18, Plan_Exit:
19, Plan_End:
20, Laser:
21, RipInfeed:
22, Gang_Rip:
```



23, Rip\_Exit:  
24, Rip\_End:  
25, Chop1\_In:  
26, Chop1\_Out:  
27, Chop2\_In:  
28, Chop2\_Out:  
29, Chop3\_In:  
30, Chop3\_Out:  
31, Belt1\_End:  
32, Tab1\_Ent:  
33, Off\_Point1:  
34, Off\_Point2:  
35, Chop4\_In:  
36, Chop4\_Out:  
37, Chop5\_In:  
38, Chop5\_Out:  
39, Chop6\_In:  
40, Chop6\_Out:  
41, Belt2\_End:  
42, Tab2\_Ent:  
43, Off\_Point3:  
44, Off\_Point4:  
45, DBKhead1:  
46, DBKhead2;

;

;

QUEUES:

1, Log\_YardQ:  
2, Log\_LoadQ:  
3, Logdeck1Q:  
4, DebarkerQ:  
5, LogChainQ:  
6, Logdeck2Q:  
7, CarriageQ:  
8, HeadrigQ:  
9, Off\_HeadrigQ:  
10, To\_PlanerQ:  
11, P\_OperatorQ:  
12, PlanerQ:  
13, PlanQ:  
14, To\_EdgerQ:  
15, E\_OperatorQ:  
16, EdgerQ:  
17, Edging\_SawQ:  
18, To\_LaserQ:  
19, LaserQ:  
20, Rip\_InQ:  
21, Rip\_SawQ:  
22, Gang\_RipQ:  
23, Chain1Q:  
24, ChopLine1Q:

```

25, Chop1Q:
26, Chop1_OutQ:
27, Chop2Q:
28, Chop2_OutQ:
29, Chop3Q:
30, Chop3_OutQ:
31, Sort1Q:
32, Sorter1Q:
33, Sorter2Q:
34, Chain2Q:
35, ChopLine2Q:
36, Chop4Q:
37, Chop4_OutQ:
38, Chop5Q:
39, Chop5_OutQ:
40, Chop6Q:
41, Chop6_OutQ:
42, Sort2Q:
43, Sorter3Q:
44, Sorter4Q:
45, ChainSpaceQ:
46, Scan_Deck2Q:
47, DBKheadQ:
48, Scan1Q:
49, Scan2Q:
50, Scan3Q:
51, Scan4Q:
52, DBKQ:
53, C1_PickQ:
54, C2_PickQ:
55, C3_PickQ:
56, C4_PickQ:
57, C5_PickQ:
58, C6_PickQ:
59, Buffer1Q:
60, Buffer2Q:
61, Buffer3Q:
62, Buffer4Q:
63, Buffer5Q:
64, Buffer6Q:
65, Head_InQ:
66, DebarkQ:
67, CarriQ:
68, Head_SawQ:
69, Pick_WasteQ:
70, RipQ;

;
;
CONVEYORS:
; Number,Name,SegmentSet,Vel,CellSize,Status,MaxPerEnt,Type,EntSize
;

```

1, Logdeck1, 1, 10, 1, A, 18, A, Cells:  
 2, Logchain, 2, 20, 1, A, 100, N:  
 3, Logdeck2, 3, 10, 1, A, 18, A, Cells:  
 4, Off\_Headrig, 4, 40, 1, A, 100, N:  
 5, To\_Edger, 5, 12, 1, A, 18, A, Cells:  
 6, Edger\_Inf, 6, 25, 1, A, 100, A, length:  
 7, To\_Planer, 7, 12, 1, A, 18, A, Cells:  
 8, Planer\_Belt, 8, 30, 1, A, 100, A, length:  
 9, To\_Laser, 9, 12, 1, A, 18, A, Cells:  
 10, Rip\_Inf, 10, 30, 1, A, 100, A, length:  
 11, Chain1, 11, 10, 1, A, 10, A, Cells:  
 12, Chain2, 12, 10, 1, A, 10, A, Cells:  
 13, Out\_Belt1, 13, 30, 1, A, 10, A, Cells:  
 14, Out\_Belt2, 14, 30, 1, A, 10, A, Cells:  
 15, Sort\_Table1, 15, 30, 1, A, 10, A, Cells:  
 16, Sort\_Table2, 16, 30, 1, A, 10, A, Cells;

;

SEGMENTS:

1, Logdeck1\_In, Deck1\_End-180:  
 2, Logchain\_In, Logchain\_End-240:  
 3, Logdeck2\_In, Log>Loading-200:  
 4, Headrig\_Out, Roller\_End-160:  
 5, Roller\_End, Edger\_In-124:  
 6, Edger\_In, Edger\_Out-150, Edger\_End-130:  
 7, Edger\_End, Planer\_In-125:  
 8, Planer\_In, Plan\_Exit-150, Plan\_End-140:  
 9, Plan\_End, Laser-160:  
 10, RipInfeed, Gang\_Rip-40, Rip\_Exit-140, Rip\_End-120:  
 11, Rip\_End, Chop1\_In-100, Chop2\_In-72, Chop3\_In-72:  
 12, Rip\_End, Chop4\_In-100, Chop5\_In-72, Chop6\_In-72:  
 13, Chop1\_Out, Chop2\_Out-72, Chop3\_Out-72, Belt1\_End-84:  
 14, Chop4\_Out, Chop5\_Out-72, Chop6\_Out-72, Belt2\_End-84:  
 15, Tab1\_Ent, Off\_Point1-140, Off\_Point2-140,  
 Tab1\_Ent-130:  
 16, Tab2\_Ent, Off\_Point3-140, Off\_Point4-140,  
 Tab2\_Ent-130;

;

;

TRANSPORTERS:

1, Log Loader, 1, 1, 250, Log\_Yard-Active:  
 2, Carriage, 1, 2, 120, Log>Loading-Active:  
 3, DBKHEAD, 1, 3, 20, DBKhead1-Active;

;

DISTANCES:

1, Log\_Yard-Logdeck1\_In-3000:  
 2, Log>Loading-Car\_Back-70, Car\_Back-Headrig\_In-60,  
 Headrig\_In-Headrig\_Out-180, Headrig\_Out-Car\_Back-240,  
 Headrig\_Out-Log>Loading-310:  
 3, DBKhead1-DBKhead2-100;

;

STORAGES:

```

1, Loading:
2, On_Carriage:
3, Log_Turning:
4, Chop1_Time:
5, Chop2_Time:
6, Chop3_Time:
7, Chop4_Time:
8, Chop5_Time:
9, Chop6_Time;

;
TALLIES:
    Log Cubic Footage:
    Log Board Footage:
    Part_BF:
    FlowTime;

;
DSTATS:
    NT(Log Loader)*100, Util Log Loader:
    NT(Carriage)*100, Util Carriage:
    NR(Carri)*100, Util Carri:
    NR(Debarker)*100, Util Debarker:
    NR(DBK_Op)*100, Util DBK_Op:
    NR(DBK)*100, Util DBK:
    NR(Headrig)*100, Util Headrig:
    NR(Headrig Saw)*100, Util Headrig Saw:
    NR(Planer)*100, Util Planer:
    NR(Planer Operator)*100, Util Plan Operator:
    NR(Edging Saw)*100, Util Edging Saw:
    NR(Edger Operator)*100, Util Edger Operator:
    NR(Scanner)*100, Util Scanner:
    NR(Scanning operator)*100, Util Scanning Operator:
    NR(Rip Saw)*100, Util Rip Saw:
    NR(Rip)*100, Util Rip:
    NR(Chop1)*100, Util Chop1 Operator:
    NR(Chop2)*100, Util Chop2 Operator:
    NR(Chop3)*100, Util Chop3 Operator:
    NR(Chop4)*100, Util Chop4 Operator:
    NR(Chop5)*100, Util Chop5 Operator:
    NR(Chop6)*100, Util Chop6 Operator:
    NR(Chop Saw1)*100, Util Chop Saw1:
    NR(Chop Saw2)*100, Util Chop Saw2:
    NR(Chop Saw3)*100, Util Chop Saw3:
    NR(Chop Saw4)*100, Util Chop Saw4:
    NR(Chop Saw5)*100, Util Chop Saw5:
    NR(Chop Saw6)*100, util Chop Saw6:
    NR(Sorter1)*100, Util Sorter1:
    NR(sorter2)*100, Util Sorter2:
    NR(sorter3)*100, Util Sorter3:
    NR(sorter4)*100, Util Sorter4:
    NEC(Logdeck1)+NEA(Logdeck1), Logs on Logdeck1:
    NEC(Logdeck2)+NEA(Logdeck2), Logs on Logdeck2:

```

NEC(To\_Planer)+NEA(To\_Planer),Flitches on To\_Planer:  
 NEC(To\_Edger)+NEA(To\_Edger),Flitches on To\_Edger:  
 NEC(To\_Laser)+NEA(To\_Laser),Flitches on To\_Laser:  
 NEC(Rip\_Inf), Flitches on Rip\_Inf:  
 NEC(Chain1)+NEA(Chain1), pieces on Chain1:  
 NEC(Chain2)+NEA(Chain2), pieces on Chain2:  
 NEC(Out\_Belt1),Parts on Sort\_Belt1:  
 NEC(Out\_Belt2),Parts on Sort\_Belt2:  
 NEC(Sort\_Table1)+NEA(Sort\_table1),Parts on Sorting Tabeel:  
 NEC(Sort\_Table2)+NEA(Sort\_Table2),Parts on Sorting Table2:  
 NQ(LogDeck1Q), Queue logdeck1:  
 NQ(LogchainQ), Queue Logchain:  
 NQ(Scan\_Deck2Q), Queue Scan\_Deck2:  
 NQ(Logdeck2Q), Queue logdeck2:  
 NQ(CarriageQ), Queue Carriage:  
 NQ(HeadrigQ), Queue Headrig:  
 NQ(To\_PlanerQ),Queue To\_Planer:  
 NQ(P\_OperatorQ), Queue P\_Operator:  
 NQ(PlanerQ), Queue Planer:  
 NQ(To\_EdgerQ), Queue To\_Edger:  
 NQ(E\_OperatorQ), Queue Edger\_Operator:  
 NQ(EdgerQ),Queue Edger:  
 NQ(To\_LaserQ), Queue To\_Laser:  
 NQ(LaserQ), Queue Laser:  
 NQ(Scan1Q), Scan Conv To\_Edger:  
 NQ(Scan2Q), Scan Conv To\_Planer:  
 NQ(Scan3Q), Scan Conv To\_Laser:  
 NQ(Scan4Q), Scan Chain1 and Chain2:  
 NQ(Rip\_InQ), Queue Rip\_In:  
 NQ(RipQ), Queue Rip:  
 NQ(ChopLine1Q), Queue ChopLine1:  
 NQ(ChopLine2Q), Queue ChopLine2:  
 NQ(Chop1Q), Queue Chop1:  
 NQ(Chop2Q), Queue Chop2:  
 NQ(Chop3Q), Queue Chop3:  
 NQ(Chop4Q), Queue Chop4:  
 NQ(Chop5Q), Queue Chop5:  
 NQ(Chop6Q), Queue Chop6:  
 NQ(Chop1\_OutQ), Queue Chop1\_Out:  
 NQ(Chop2\_OutQ), Queue Chop2\_Out:  
 NQ(Chop3\_OutQ), Queue Chop3\_Out:  
 NQ(Chop4\_OutQ), Queue Chop4\_Out:  
 NQ(Chop5\_OutQ), Queue Chop5\_Out:  
 NQ(Chop6\_OutQ), Queue Chop6\_Out:  
 NQ(Sort1Q), Queue Sort1:  
 NQ(Sort2Q), Queue Sort2:  
 NQ(Sorter1Q), Queue Sorter1:  
 NQ(Sorter2Q), Queue Sorter2:  
 NQ(Sorter3Q), Queue Sorter3:  
 NQ(Sorter4Q), Queue Sorter4;

;

```

COUNTERS:
    1, Total Num of Logs:
    2, Total Num of Parts;
;
TABLES: LogBF, 9,1,20,30,35,45,55,65,75,85;
;
;TRACE,3000 ,22800,      ,NR(Chop1),NR(Chop2);
;
FILES: LogFile,"C:\siman\log.dat",SEQ, "(5x,4(F5.2,5x))";
;
PARAMETERS:
    1, Logs_Per_Load, 0.23,3, 0.52,4, 0.74,5, 0.87,6,
      0.94,7,0.98,8,1,9:
    2, R_Pieces, 0.18,2, 0.53, 3, 0.85,4, 1,5:
    3, Chops, 0.03,2,0.32,3,0.56,4,0.78,5,0.9,6,0.98,7,1,8:
    4, WasteLength, 4,8,20:
    5, PartLength, 0.066,15,0.138,18,0.233,21,0.303,25,
      0.398,29,0.464,33,0.543,38,0.673,45,
      0.801,50,0.877,60,1,75;
;
LAYOUTS: "Mill2.lay", Symbol;
END;

```

## Appendix 2.1 Building Costs of Design 1

|  |                    |
|--|--------------------|
| 1. Main building(16,000 sq.ft @ \$18/sq.ft, including 2400 sq.ft maintenance room)   | \$288,000          |
| 2. Boiler room building(2400 sq. @\$20.00/sq.ft)   | \$48,000           |
| 3. Predryer(@ \$1,000 per MBF capacity)<br>Required capacity: 360 MBF/5 weeks<br>Designed capacity: 450 MBF/5 weeks                      | \$450,000          |
| 4. Kiln driers(@ \$3,500 per MBF capacity)<br>Required capacity: 87 MBF/week<br>Designed capacity: 110 MBF/week<br>Two 55 MBF kln driers | \$385,000          |
| 5. Dry part storage area(5600 sq.ft @\$18/sq.ft)   | \$100,800          |
| 6. Resawing, gluing areas(5600 sq.ft @ \$18.00/sq.ft)  | \$100,800          |
| 7. Finished part and panel storage, and shipping area<br>(4000 sq.ft @ \$18.00/sq.ft)  | \$72,000           |
| 8. Rest area(1600 sq.ft @ \$18.00/sq.ft)   | \$28,800           |
| 9. Office(3200 sq.ft @ \$40/sq.ft)   | \$128,000          |
| 10. Electrical installation (complete)   | \$120,000          |
| 11. Plumbing installation (complete)   | \$50,000           |
| 12. Heating system with humidity control   | \$100,000          |
| 13. Fire protection system   | \$50,000           |
| <b>Total Building Costs:</b>   | <b>\$1,921,400</b> |

## Appendix 2.2 Building Costs of Design 2

|   |                    |
|---|--------------------|
| 1. Main building(15,000 sq.ft @ \$18/sq.ft, including<br>2400 sq.ft maintenance room)   | \$270,000          |
| 2. Boiler room building(2400 sq. @\$20.00/sq.ft)  | \$48,000           |
| 3. Predryer(@ \$1,000 per MBF capacity)<br>Required capacity: 360 MBF/5 weeks<br>Designed capacity: 450 MBF/5 weeks                       | \$450,000          |
| 4. Kiln driers(@ \$3,500 per MBF capacity)<br>Required capacity: 87 MBF/week<br>Designed capacity: 110 MBF/week<br>Two 55 MBF kiln driers | \$385,000          |
| 5. Dry part storage area(5600 sq.ft @\$18/sq.ft)  | \$100,800          |
| 6. Resawing, gluing areas(5600 sq.ft @ \$18.00/sq.ft)   | \$100,800          |
| 7. Finished part and panel storage, and shipping area<br>(4000 sq.ft @ \$18.00/sq.ft)   | \$72,000           |
| 8. Rest area(1600 sq.ft @ \$18.00/sq.,ft)   | \$28,800           |
| 9. Office(3200 sq.ft @ \$40/sq.ft)  | \$128,000          |
| 10. Electrical installation (complete)  | \$120,000          |
| 11. Plumbing installation (complete)  | \$50,000           |
| 12. Heating system with humidity control  | \$100,000          |
| 13. Fire protection system  | \$50,000           |
| <b>Total Building Costs:</b>  | <b>\$1,903,400</b> |



### Appendix 2.3 Building Costs of Design 3

|   |                    |
|---|--------------------|
| 1. Main building(15,000 sq.ft @ \$18/sq.ft, including 2400 sq.ft maintenance room)  | \$270,000          |
| 2. Boiler room building(2400 sq. @\$20.00/sq.ft)  | \$48,000           |
| 3. Predryer(@ \$1,000 per MBF capacity)<br>Required capacity: 360 MBF/5 weeks<br>Designed capacity: 450 MBF/5 weeks                       | \$450,000          |
| 4. Kiln driers(@ \$3,500 per MBF capacity)<br>Required capacity: 87 MBF/week<br>Designed capacity: 110 MBF/week<br>Two 55 MBF kiln driers | \$385,000          |
| 5. Dry part storage area(5600 sq.ft @\$18/sq.ft)  | \$100,800          |
| 6. Resawing, gluing areas(5600 sq.ft @ \$18.00/sq.ft)   | \$100,800          |
| 7. Finished part and panel storage, and shipping area<br>(4000 sq.ft @ \$18.00/sq.ft)   | \$72,000           |
| 8. Rest area(1600 sq.ft @ \$18.00/sq.ft)  | \$28,800           |
| 9. Office(3200 sq.ft @ \$40/sq.ft)  | \$128,000          |
| 10. Electrical installation (complete)  | \$120,000          |
| 11. Plumbing installation (complete)  | \$50,000           |
| 12. Heating system with humidity control  | \$100,000          |
| 13. Fire protection system  | \$50,000           |
| <b>Total Building Costs:</b>  | <b>\$1,903,400</b> |

## Appendix 2.4 Building Costs of Design 4

|  |                        |
|--|------------------------|
| 1. Main building(17,500 sq.ft @ \$18/sq.ft, including<br>2400 sq.ft maintenance room)  | \$315,000              |
| 2. Boiler room building(2400 sq. @\$20.00/sq.ft)   | \$48,000               |
| 3. Predryer(@ \$1,000 per MBF capacity)<br>Required capacity: 275 MBF/5 weeks<br>Designed capacity: 345 MBF/5 weeks                      | \$345,000              |
| 4. Kiln driers(@ \$3,500 per MBF capacity)<br>Required capacity: 66 MBF/week<br>Designed capacity: 90 MBF/week<br>Two 45 MBF kiln driers | \$315,000              |
| 5. Dry part storage area(5600 sq.ft @\$18/sq.ft)   | \$100,800              |
| 6. Resawing, gluing areas(5600 sq.ft @ \$18.00/sq.ft)  | \$100,800              |
| 7. Finished part and panel storage, and shipping area<br>(4000 sq.ft @ \$18.00/sq.ft)  | \$72,000               |
| 8. Rest area(1600 sq.ft @ \$18.00/sq.ft)   | \$28,800               |
| 9. Office(3200 sq.ft @ \$40/sq.ft)   | \$128,000              |
| 10. Electrical installation (complete)   | \$120,000              |
| 11. Plumbing installation (complete)   | \$50,000               |
| 12. Heating system with humidity control   | \$100,000              |
| 13. Fire protection system   | \$50,000               |
| <br><b>Total Building Costs:</b>   | <br><b>\$1,773,400</b> |

## Appendix 2.5 Building Costs of Design 5

|  |                    |
|--|--------------------|
| 1. Main building(16,500 sq.ft @ \$18/sq.ft, including<br>2400 sq.ft maintenance room)  | \$297,000          |
| 2. Boiler room building(2400 sq. @\$20.00/sq.ft)   | \$48,000           |
| 3. Predryer(@ \$1,000 per MBF capacity)<br>Required Capacity: 275 MBF/5 weeks<br>Designed Capacity: 345 MBF/5 weeks                      | \$345,000          |
| 4. Kiln driers(@ \$3,500 per MBF capacity)<br>Required capacity: 66 MBF/week<br>Designed capacity: 90 MBF/week<br>Two 45 MBF kiln driers | \$315,000          |
| 5. Dry part storage area(5600 sq.ft @\$18/sq.ft)   | \$100,800          |
| 6. Resawing, gluing areas(5600 sq.ft @ \$18.00/sq.ft)  | \$100,800          |
| 7. Finished part and panel storage, and shipping area<br>(4000 sq.ft @ \$18.00/sq.ft)  | \$72,000           |
| 8. Rest area(1600 sq.ft @ \$18.00/sq.ft)   | \$28,800           |
| 9. Office(3200 sq.ft @ \$40/sq.ft)   | \$128,000          |
| 10. Electrical installation (complete)   | \$120,000          |
| 11. Plumbing installation (complete)   | \$50,000           |
| 12. Heating system with humidity control   | \$100,000          |
| 13. Fire protection system   | \$50,000           |
| <b>Total Building Costs:</b>   | <b>\$1,755,400</b> |

## Appendix 2.6 Building Costs of Design 6

|   |                        |
|---|------------------------|
| 1. Main building(16,000 sq.ft @ \$18/sq.ft, including<br>2400 sq.ft maintenance room)   | \$288,000              |
| 2. Boiler room building(2400 sq. @\$20.00/sq.ft)  | \$48,000               |
| 3. Predryer(@ \$1,000 per MBF capacity)<br>Required capacity: 325 MBF/5 weeks<br>Designed capacity: 410 MBF/5 weeks                       | \$410,000              |
| 4. Kiln driers(@ \$3,500 per MBF capacity)<br>Required capacity: 78 MBF/week<br>Designed capacity: 100 MBF/week<br>Two 45 MBF kiln driers | \$350,000              |
| 5. Dry part storage area(5600 sq.ft @\$18/sq.ft)  | \$100,800              |
| 6. Resawing, gluing areas(5600 sq.ft @ \$18.00/sq.ft)   | \$100,800              |
| 7. Finished part and panel storage, and shipping area<br>(4000 sq.ft @ \$18.00/sq.ft)   | \$72,000               |
| 8. Rest area(1600 sq.ft @ \$18.00/sq.ft)  | \$28,800               |
| 9. Office(3200 sq.ft @ \$40/sq.ft)  | \$128,000              |
| 10. Electrical installation (complete)  | \$120,000              |
| 11. Plumbing installation (complete)  | \$50,000               |
| 12. Heating System with humidity control  | \$100,000              |
| 13. Fire Protection System  | \$50,000               |
| <br><b>Total Building Costs:</b>  | <br><b>\$1,846,400</b> |

### Appendix 3.1      List of Equipment Costs for Design 1

|  |           |
|--|-----------|
| 1. Two log loaders(@ \$10,000/each)  | \$20,000  |
| 2. Three fork lifts(one 20,000 lb fork lift @ \$62,000/each, and two 12,000 lb @ \$43,500/each)                        | \$149,000 |
| 3. Debarker(36" Rosser Head, including a 30' bark conveyor)  | \$44,600  |
| 4. Headrig saw(including carriage, log turner, belt offbearer and Comp-Set control system)                             | \$157,800 |
| 5. Edging saw  | \$12,000  |
| 6. Rough planer  | \$115,400 |
| 7. Gang-Rip saw(including Gang-Rip Optimizer)  | \$200,000 |
| 8. Four automatic chop saws(Oliver Model 3000, @ \$85,500/each) (including roller tables for defect marking)           | \$342,000 |
| 9. Four single arbor rip saws (@ \$19000/each)   | \$76,000  |
| 10. Three salvage chop saws(@ \$3,000/each)  | \$9,000   |
| 11. Two 40 section clamp carriers(James Taylor, @ \$40,000/each) (8 feet wide with six 6-inch-wide clamps per section) | \$80,000  |
| 12. Two glue applicators(@ \$45,000/each)  | \$90,000  |
| 13. One abrasive planner   | \$50,000  |
| 14. One double end trim saw  | \$28,000  |
| 15. Chipping system  | \$52,000  |
| 16. Circular saw sharpener for rip and chop saws   | \$11,000  |
| 17. Saw sharpener for headrig saw  | \$20,000  |
| 18. Knife grinder  | \$10,000  |
| 19. Forty factory trucks (@ \$350/each)  | \$14,000  |
| 20. Boiler and accessory(packaged, 500 hp, 150 psi, oil burning) (including aa 90-ton silo)                            | \$184,000 |
| 21. Compressed air system(Screw type 100 hp)   | \$40,000  |
| 22. Dust system (including bag house)  | \$80,000  |
| 23. Tools  | \$20,000  |
| 24. Office furnishings:  | \$25,000  |
| 25. Log deck before debarker   | \$17,000  |
| 26. Log conveyor(including kick-off unit)  | \$19,000  |
| 27. Log deck after debarker(including loading unit)  | \$26,700  |
| 28. Drop belt(including retracting pins)   | \$7,700   |

|   |          |
|---|----------|
| 29. Slab conveyor   | \$5,500  |
| 30. Jump skid transfer between headrig and rough planer<br>(including 4 chain, 14' long transfer chain, 20' long<br>roller conveyor, air powered lift and stop gate,<br>and electric foot switch) | \$12,000 |
| 31. Rough planer infeeding and outfeeding belt conveyor   | \$6,200  |
| 32. Edging saw infeeding and outfeeding roller conveyors  | \$5,600  |
| 33. Chain conveyor between rough planer and edging saw  | \$4,200  |
| 34. Chain conveyor between edging saw and scanning station  | \$4,700  |
| 35. Gang-Rip scanning station   | \$2,000  |
| 36. Gang-Rip infeeding and outfeeding conveyor  | \$9,600  |
| 37. Two chain conveyors to chop saws  | \$13,500 |
| 38. Two turntables (@ \$4000/each)  | \$8,000  |
| 39. Conveyor net for waste  | \$58,000 |
| 40. Elevated waste conveyor   | \$5,000  |
| 41. Roller tables(for resawing area)  | \$6,000  |

**Total Costs of Equipment Purchased:** \$2,040,500

**Installation Costs**(@ 10% of equipment expenditures)  
(except furniture, log loaders, fork lifts, and factory trucks) \$183,300

**Total Costs of Equipment Installed:** \$2,223,800

## Appendix 3.2

## List of Equipment Costs for Design 2

|  |           |
|--|-----------|
| 1. Two log loaders(@ \$10,000/each)  | \$20,000  |
| 2. Three fork lifts(one 20,000 lb fork lift @ \$62,000/each, and two 12,000 lb @ \$43,500/each)                        | \$149,000 |
| 3. Debarker(36" Rosser Head, including a 30' bark conveyer)  | \$44,600  |
| 4. Headrig saw(including carriage, log turner, belt offbearer and Comp-Set control system)                             | \$157,800 |
| 5. Edging saw  | \$12,000  |
| 6. Rough planer  | \$115,400 |
| 7. Gang-Rip saw(including Gang-Rip Optimizer)  | \$200,000 |
| 8. Six manual chop saws(@ \$4,250/each) (including roller tables and Compu-gauge)                                      | \$25,500  |
| 9. Four single arbor rip saws (@ \$19000/each)   | \$76,000  |
| 10. Three salvage chop saw(@ \$3,000/each)   | \$9,000   |
| 11. Two 40 section clamp carriers(James Taylor, @ \$40,000/each) (8 feet wide with six 6-inch-wide clamps per section) | \$80,000  |
| 12. Two glue applicators(@ \$45,000/each)  | \$90,000  |
| 13. One abrasive planner   | \$50,000  |
| 14. One double end trim saw  | \$28,000  |
| 15. Chipping system  | \$52,000  |
| 16. Circular saw sharpener for rip and chop saws   | \$11,000  |
| 17. Saw sharpener for headrig saw  | \$20,000  |
| 18. Knife grinder  | \$10,000  |
| 19. Forty factory trucks (@ \$350/each)  | \$14,000  |
| 20. Boiler and accessory(packaged, 500 hp, 150 psi, oil burning) (including aa 90-ton silo)                            | \$184,000 |
| 21. Compressed air system(Screw type 100 hp)   | \$40,000  |
| 22. Dust system (including bag house)  | \$80,000  |
| 23. Tools  | \$20,000  |
| 24. Office furnishings:  | \$25,000  |
| 25. Log deck before debarker   | \$17,000  |
| 26. Log conveyor(including kick-off unit)  | \$19,000  |
| 27. Log deck after debarker(including loading unit)  | \$26,700  |
| 28. Drop belt(including retracting pins)   | \$7,700   |

|   |                    |
|---|--------------------|
| 29. Slab conveyor   | \$5,500            |
| 30. Jump skid transfer between headrig and rough planer<br>(including 4 chain, 14' long transfer chain, 20' long<br>roller conveyor, air powered lift and stop gate,<br>and electric foot switch) | \$12,000           |
| 31. Rough planer infeeding and outfeeding belt conveyor   | \$6,200            |
| 32. Edging saw infeeding and outfeeding roller conveyors  | \$5,600            |
| 33. Chain conveyor between rough planer and edging saw  | \$4,200            |
| 34. Chain conveyor between edging saw and scanning station  | \$4,700            |
| 35. Gang-Rip scanning station   | \$2,000            |
| 36. Gang-Rip infeeding and outfeeding conveyor  | \$9,600            |
| 37. Two chain conveyors to chop saws  | \$13,500           |
| 38. Two belt conveyors off chop saws(@ 4,000 each)  | \$8,000            |
| 39. Two turntables (@ \$4000/each)  | \$8,000            |
| 40. Conveyor net for waste  | \$58,000           |
| 41. Elevated waste conveyor   | \$5,000            |
| 42. Roller tables(for resawing area)  | \$6,000            |
| <b>Total Costs of Equipment Purchased:</b>  | <b>\$1,732,000</b> |
| <b>Installation Costs(@ 10% of equipment expenditures)<br/>(except furniture, log loaders, fork lifts, and factory trucks)</b>  | <b>\$152,400</b>   |
| <b>Total Costs of Equipment Installed:</b>  | <b>\$1,884,400</b> |



**Appendix 3.3****List of Equipment Costs for Design 3**

|   |           |
|---|-----------|
| 1. Two log loaders(@ \$10,000/each)   | \$20,000  |
| 2. Three fork lifts(one 20,000 lb fork lift @ \$62,000/each, and two 12,000 lb @ \$43,500/each)                       | \$149,000 |
| 3. Debarker(36" Rosser Head, including a 30' bark conveyor)   | \$44,600  |
| 4. Headrig saw(including carriage, log turner, belt offbearer and Comp-Set control system)                            | \$157,800 |
| 5. Rough planer   | \$115,400 |
| 6. Three Crosscut saws(@ \$16,000/each)   | \$48,000  |
| 7. Nine single arbor rip saws (@ \$19000/each)  | \$171,000 |
| 8. Three salvage chop saws(@ \$3,000/each)  | \$9,000   |
| 9. Two 40 section clamp carriers(James Taylor, @ \$40,000/each) (8 feet wide with six 6-inch-wide clamps per section) | \$80,000  |
| 10. Two glue applicators(@ \$45,000/each)   | \$90,000  |
| 11. One abrasive planner  | \$50,000  |
| 12. One double end trim saw   | \$28,000  |
| 13. Chipping system   | \$52,000  |
| 14. Circular saw sharpener for rip and chop saws  | \$11,000  |
| 15. Saw sharpener for headrig saw   | \$20,000  |
| 16. Knife grinder   | \$10,000  |
| 17. Forty factory trucks (@ \$350/each)   | \$14,000  |
| 18. Boiler and accessory(packaged, 500 hp, 150 psi, oil burning) (including aa 90-ton silo)                           | \$184,000 |
| 19. Compressed air system(Screw type 100 hp)  | \$40,000  |
| 20. Dust system (including bag house)   | \$80,000  |
| 21. Tools   | \$20,000  |
| 22. Office furnishings:   | \$25,000  |
| 23. Log deck before debarker  | \$17,000  |
| 24. Log conveyor(including kick-off unit)   | \$19,000  |
| 25. Log deck after debarker(including loading unit)   | \$26,700  |
| 26. Drop belt(including retracting pins)  | \$7,700   |
| 27. Slab conveyor   | \$5,500   |

|   |          |
|---|----------|
| 28. Jump skid transfer between headrig and rough planer<br>(including 4 chain, 14' long transfer chain, 20' long roller conveyor, air powered lift and stop gate, and electric foot switch) | \$12,000 |
| 29. Rough planner infeeding and outfeeding belt conveyer  | \$6,200  |
| 30. Three section chain conveyer to three Crosscut saws   | \$11,800 |
| 31. Roller tables for three Crosscut saws   | \$9,000  |
| 32. Belt conveyer off Crosscut saws   | \$5,000  |
| 33. Belt conveyer to turntable  | \$12,000 |
| 34. One turntable   | \$4,000  |
| 35. Length sorting device(Automatic Lumber Handling Co.)  | \$35,000 |
| 36. Buffer tables before rip saws(five tables @ \$2,000/each)   | \$10,000 |
| 37. Conveyer net for waste  | \$58,000 |
| 38. Elevated waste conveyer   | \$5,000  |
| 39. Roller tables(for resawing area)  | \$6,000  |

**Total Costs of Equipment Purchased:** \$1,668,700

**Installation Costs(@ 10% of equipment expenditures)** \$146,100  
(except furniture, log loaders, fork lifts, and factory trucks)

**Total Costs of Equipment Installed:** \$1,814,800

## Appendix 3.4

## List of Equipment Costs for Design 4

|  |           |
|--|-----------|
| 1. Two log loaders(@ \$10,000/each)  | \$20,000  |
| 2. Three fork lifts(one 20,000 lb fork lift @ \$62,000/each, and two 12,000 lb @ \$43,500/each)                        | \$149,000 |
| 3. Debarker(36" Rosser Head, including a 30' bark conveyor)  | \$44,600  |
| 4. Headrig saw(including carriage, log turner, belt offbearer and Comp-Set control system)                             | \$157,800 |
| 5. Gang resaw(Ligna Machine)   | \$125,000 |
| 6. Edging saw  | \$12,000  |
| 7. Rough planer  | \$115,400 |
| 8. Gang-Rip saw(including Gang-Rip Optimizer)  | \$200,000 |
| 9. Four automatic chop saws(Oliver Model 3000, @ \$85,500/each) (including roller tables for defect marking)           | \$342,000 |
| 10. Three single arbor rip saws (@ \$19000/each)   | \$57,000  |
| 11. Two salvage chop saws(@ \$3,000/each)  | \$6,000   |
| 12. Two 40 section clamp carriers(James Taylor, @ \$40,000/each) (8 feet wide with six 6-inch-wide clamps per section) | \$80,000  |
| 13. Two glue applicators(@ \$45,000/each)  | \$90,000  |
| 14. One abrasive planner   | \$50,000  |
| 15. One double end trim saw  | \$28,000  |
| 16. Chipping system  | \$52,000  |
| 17. Circular saw sharpener for rip and chop saws   | \$11,000  |
| 18. Saw sharpener for headrig saw  | \$20,000  |
| 19. Knife grinder  | \$10,000  |
| 20. Forty factory trucks (@ \$350/each)  | \$14,000  |
| 21. Boiler and accessory(packaged, 500 hp, 150 psi, oil burning) (including aa 90-ton silo)                            | \$184,000 |
| 22. Compressed air system(Screw type 100 hp)   | \$40,000  |
| 23. Dust system (including bag house)  | \$80,000  |
| 24. Tools  | \$20,000  |
| 25. Office furnishings:  | \$25,000  |
| 26. Log deck before debarker   | \$17,000  |
| 27. Log conveyor(including kick-off unit)  | \$19,000  |
| 28. Log deck after debarker(including loading unit)  | \$26,700  |

|   |          |
|---|----------|
| 29. Drop belt(including retracting pins)  | \$7,700  |
| 30. Slab conveyor   | \$5,500  |
| 31. Jump skid transfer between headrig and gang resaw<br>(including 4 chain, 14' long transfer chain, 20' long<br>roller conveyor, air powered lift and stop gate,<br>and electric foot switch) | \$12,000 |
| 32. Gang resaw infeed and outfeed roller conveyors  | \$9,800  |
| 33. Roller conveyor directly linking headrig and edging saw   | \$4,500  |
| 34. Chain conveyor to edging saw  | \$4,000  |
| 35. Edging saw infeeding and outfeeding conveyors   | \$5,400  |
| 36. Rough planer outfeed conveyor   | \$3,000  |
| 37. Chain conveyor between planer and scanning station  | \$4,700  |
| 38. Gang-Rip scanning station   | \$2,000  |
| 39. Gang-Rip infeeding and outfeeding conveyor  | \$9,600  |
| 40. Two chain conveyors to chop saws  | \$13,500 |
| 41. Two turntables (@ \$4000/each)  | \$8,000  |
| 42. Conveyor net for waste  | \$58,000 |
| 43. Elevated waste conveyor   | \$5,000  |
| 44. Roller tables(for resawing area)  | \$6,000  |

**Total Costs of Equipment Purchased:** \$2,154,200

**Installation Costs(@ 10% of equipment expenditures)** \$194,600  
(except furniture, log loaders, fork lifts, and factory trucks)

**Total Costs of Equipment Installed:** \$2,348,800

**Appendix 3.5****List of Equipment Costs for Design 5**

|   |           |
|---|-----------|
| 1. Two log loaders(@ \$10,000/each)   | \$20,000  |
| 2. Three fork lifts(one 20,000 lb fork lift @ \$62,000/each, and two 12,000 lb @ \$43,500/each)   | \$149,000 |
| 3. Debarker(36" Rosser Head, including a 30' bark conveyor)   | \$44,600  |
| 4. Headrig saw(including carriage, log turner, belt offbearer and Comp-Set control system)  | \$157,800 |
| 5. Gang resaw(Ligna Machine)  | \$125,000 |
| 6. Edging saw   | \$12,000  |
| 7. Rough planer   | \$115,400 |
| 8. Gang-Rip saw(including Gang-Rip Optimizer)   | \$200,000 |
| 9. Six manual chop saws(@ \$4,250/each)<br>(including roller tables and Compu-gauge)  | \$25,500  |
| 10. Three single arbor rip saws (@ \$19000/each)  | \$57,000  |
| 11. Two salvage chop saws(@ \$3,000/each)   | \$6,000   |
| 12. Two 40 section clamp carriers(James Taylor, @ \$40,000/each)<br>(8 feet wide with six 6-inch-wide clamps per section)   | \$80,000  |
| 13. Two glue applicators(@ \$45,000/each)   | \$90,000  |
| 14. One abrasive planer   | \$50,000  |
| 15. One double end trim saw   | \$28,000  |
| 16. Chipping system   | \$52,000  |
| 17. Circular saw sharpener for rip and chop saws  | \$11,000  |
| 18. Saw sharpener for headrig saw   | \$20,000  |
| 19. Knife grinder   | \$10,000  |
| 20. Forty factory trucks (@ \$350/each)   | \$14,000  |
| 21. Boiler and accessory(packaged, 500 hp, 150 psi, oil burning)<br>(including aa 90-ton silo)  | \$184,000 |
| 22. Compressed air system(Screw type 100 hp)  | \$40,000  |
| 23. Dust system (including bag house)   | \$80,000  |
| 24. Tools   | \$20,000  |
| 25. Office furnishings:   | \$25,000  |
| 26. Log deck before debarker  | \$17,000  |
| 27. Log conveyor(including kick-off unit)   | \$19,000  |
| 28. Log deck after debarker(including loading unit)   | \$26,700  |
| 29. Drop belt(including retracting pins)  | \$7,700   |
| 30. Slab conveyor   | \$5,500   |
| 31. Jump skid transfer between headrig and gang resaw<br>(including 4 chain, 14' long transfer chain, 20' long roller conveyor, air powered lift and stop gate, and electric foot switch) | \$12,000  |
| 32. Gang resaw infeed and outfeed roller conveyors  | \$9,800   |
| 33. Roller conveyor directly linking headrig and edging saw   | \$4,500   |
| 34. Chain conveyor to edging saw  | \$4,000   |
| 35. Edging saw infeeding and outfeeding conveyors   | \$5,400   |
| 36. Rough planer outfeed conveyor   | \$3,000   |
| 37. Chain conveyor between planer and scanning station  | \$4,700   |
| 38. Gang-Rip scanning station   | \$2,000   |
| 39. Gang-Rip infeeding and outfeeding conveyor  | \$9,600   |

|  |          |
|--|----------|
| 40. Two chain conveyors to chop saws                 | \$13,500 |
| 41. Two belt conveyors off chop saws(@ \$4,000/each) | \$8,000  |
| 41. Two turntables (@ \$4000/each)                   | \$8,000  |
| 42. Conveyor net for waste                           | \$58,000 |
| 43. Elevated waste conveyor                          | \$5,000  |
| 44. Roller tables(for resawing area)                 | \$6,000  |

**Total Costs of Equipment Purchased:** \$1,846,000

**Installation Costs(@ 10% of equipment expenditures)** \$163,800  
(except furniture, log loaders, fork lifts, and factory trucks)

**Total Costs of Equipment Installed:** \$2,009,800

## Appendix 3.6      List of Equipment Costs for Design 6

|  |           |
|--|-----------|
| 1. Two log loaders(@ \$10,000/each)  | \$20,000  |
| 2. Three fork lifts(one 20,000 lb fork lift @ \$62,000/each, and two small one @ \$43,500/each)                        | \$149,000 |
| 3. Debarker(36" Rosser Head, including a 30' bark conveyor)  | \$44,600  |
| 4. Headrig saw(including carriage, log turner, belt offbearer and Comp-Set control system)                             | \$157,800 |
| 5. Gang resaw(Ligna Machine)   | \$125,000 |
| 6. Rough planer  | \$115,400 |
| 7. Three Crosscut saws(@ \$16,000/each)  | \$48,000  |
| 8. Nine single arbor rip saws (@ \$19000/each)   | \$171,000 |
| 9. Three salvage chop saws(@ \$3,000/each)   | \$9,000   |
| 10. Two 40 section clamp carriers(James Taylor, @ \$40,000/each) (8 feet wide with six 6-inch-wide clamps per section) | \$80,000  |
| 11. Two glue applicators(@ \$45,000/each)  | \$90,000  |
| 12. One abrasive planner   | \$50,000  |
| 13. One double end trim saw  | \$28,000  |
| 14. Chipping system  | \$52,000  |
| 15. Circular saw sharpener for rip and chop saws   | \$11,000  |
| 16. Saw sharpener for headrig saw  | \$20,000  |
| 17. Knife grinder  | \$10,000  |
| 18. Forty factory trucks (@ \$350/each)  | \$14,000  |
| 19. Boiler and accessory(packaged, 500 hp, 150 psi, oil burning) (including aa 90-ton silo)                            | \$184,000 |
| 20. Compressed air system(Screw type 100 hp)   | \$40,000  |
| 21. Dust system (including bag house)  | \$80,000  |
| 22. Tools  | \$20,000  |
| 23. Office furnishings:  | \$25,000  |
| 24. Log deck before debarker   | \$17,000  |
| 25. Log conveyor(including kick-off unit)  | \$19,000  |
| 26. Log deck after debarker(including loading unit)  | \$26,700  |
| 27. Drop belt(including retracting pins)   | \$7,700   |
| 28. Slab conveyor  | \$5,500   |

|   |                    |
|---|--------------------|
| 29. Jump skid transfer between headrig and gang resaw<br>(including 4 chain, 14' long transfer chain, 20' long<br>roller conveyor, air powered lift and stop gate,<br>and electric foot switch) | \$12,000           |
| 31. Roller conveyor directly linking headrig and rough planer   | \$4,500            |
| 32. Gang resaw infeed and outfeed roller conveyors  | \$9,800            |
| 33. Rough planner infeeding and outfeeding belt conveyor  | \$6,200            |
| 34. Three section chain conveyor to three Crosscut saws   | \$11,800           |
| 35. Roller tables for three Crosscut saws   | \$9,000            |
| 36. Belt conveyor off Crosscut saws   | \$5,000            |
| 37. Belt conveyor to turntable  | \$12,000           |
| 38. One turntable   | \$4,000            |
| 39. Length sorting device(Automatic Lumber Handling Co.)  | \$35,000           |
| 40. Buffer tables before rip saws(five tables @ \$2,000/each)   | \$10,000           |
| 41. Conveyor net for waste  | \$58,000           |
| 42. Elevated waste conveyor   | \$5,000            |
| 43. Roller tables(for resawing area)  | \$6,000            |
| <b>Total Costs of Equipment Purchased:</b>  | <b>\$1,808,000</b> |
| <b>Installation Costs(@ 10% of equipment expenditures)<br/>(except furniture, log loaders, fork lifts, and factory trucks)</b>  | <b>\$160,000</b>   |
| <b>Total Costs of Equipment Installed:</b>  | <b>\$1,968,000</b> |



## Appendix 4.1 List of Workers for Design 1\*

| Working Duty                               | Number of workers |
|--|-------------------|
| Log loader driver                          | 2                 |
| Log receiving & scaling                    | 1                 |
| Fork lift driver                           | 3                 |
| Deabark                                    | 1                 |
| Headrig saw                                | 1                 |
| Edging saw                                 | 1                 |
| Rough planner                              | 1                 |
| Gang-Rip scan                              | 1                 |
| Defect marking                             | 4                 |
| Sorting                                    | 4                 |
| Sacking & unstacking                       | 4                 |
| Kiln drying                                | 1                 |
| Single arbor rip saws(4 saws for resawing) | 8                 |
| Salvage chop saw(3 saws for resawing)      | 3                 |
| Panel gluing                               | 3                 |
| Abrasive planner                           | 2                 |
| Double end trim saw                        | 2                 |
| Packaging & shipping                       | 2                 |
| Saw sharpener                              | 1                 |
| Floaing worker                             | 1                 |
| Clean-up                                   | 1                 |
| <b>Total Workers:</b>                      | <b>47</b>         |

\* Administration, maintenance and sales personnels are not included in this list.

## Appendix 4.2 List of Workers for Design 2\*

| Working Duty                               | Number of Workers |
|--|-------------------|
| Log loader driver                          | 2                 |
| Log receiving & scaling                    | 1                 |
| Fork lift driver                           | 3                 |
| Deabark                                    | 1                 |
| Headrig saw                                | 1                 |
| Edging saw                                 | 1                 |
| Rough planner                              | 1                 |
| Gang-Rip scan                              | 1                 |
| Chop saws(6 saws for green cutting)        | 6                 |
| Sorting                                    | 4                 |
| Stacking & unstacking                      | 4                 |
| Kiln drying                                | 1                 |
| Single arbor rip saws(4 saws for resawing) | 8                 |
| Salvage chop saws(3 saws for resawing)     | 3                 |
| Panel gluing                               | 3                 |
| Abrasive planner                           | 2                 |
| Double end trim saw                        | 2                 |
| Packaging & shipping                       | 2                 |
| Saw sharpener                              | 1                 |
| Floating worker                            | 1                 |
| Clean-up                                   | 1                 |
| <b>Total Workers:</b>                      | <b>49</b>         |

\* Administration, maintenance and sales personnels are not included in this list.

### Appendix 4.3 List of Workers for Design 3\*

| Working Duty                                    | Number of Workers |
|---|-------------------|
| Log loader driver                               | 2                 |
| Log receiving & scaling                         | 1                 |
| Fork lift driver                                | 3                 |
| Deabark   | 1                 |
| Headrig saw                                     | 1                 |
| Rough planner                                   | 1                 |
| Crosscut saws(3 saws for green cutting)         | 3                 |
| Single arbor rip saws(5 saws for green cutting) | 10                |
| Stacking & unstacking                           | 4                 |
| Kiln drying                                     | 1                 |
| Single arbor rip saws(4 saws for resawing)      | 8                 |
| Salvage chop saws(3 saws for resawing)          | 3                 |
| Panel gluing                                    | 3                 |
| Abrasive planner                                | 2                 |
| Double end trim saw                             | 2                 |
| Packaging & shipping                            | 2                 |
| Saw sharpener                                   | 1                 |
| Floating worker                                 | 1                 |
| Clean-up  | 1                 |
| <b>Total Workers:</b>                           | <b>50</b>         |

\* Administration, maintenance and sales personnels are not included in this list.

## Appendix 4.4 List of Workers for Design 4\*

| Working Duty                               | Number of Workers |
|--|-------------------|
| Log loader driver                          | 2                 |
| Log receiving & scaling                    | 1                 |
| Fork lift driver                           | 3                 |
| Deabark                                    | 1                 |
| Headrig saw                                | 1                 |
| Gang resaw                                 | 1                 |
| Cant stacking                              | 1                 |
| Edging saw                                 | 1                 |
| Gang-Rip scan                              | 1                 |
| Defect marking                             | 4                 |
| Sorting                                    | 4                 |
| Stacking & unstacking                      | 3                 |
| Kiln drying                                | 1                 |
| Single arbor rip saws(3 saws for resawing) | 6                 |
| Salvage chop saw(2 saws for resawing)      | 2                 |
| Panel gluing                               | 3                 |
| Abrasive planner                           | 2                 |
| Double end trim saw                        | 2                 |
| Packaging & shipping                       | 2                 |
| Saw sharpener                              | 1                 |
| Floating worker                            | 1                 |
| Clean-up                                   | 1                 |
| <b>Total Workers:</b>                      | <b>41</b>         |

\* Administration, maintenance and sales personnels are not included in this list.

## Appendix 4.5 List of Workers for Design 5\*

| Working Duty                               | Number of Workers |
|--|-------------------|
| Log loader driver                          | 2                 |
| Log receiving & scaling                    | 1                 |
| Fork lift driver                           | 3                 |
| Deabark                                    | 1                 |
| Headrig saw                                | 1                 |
| Gang resaw                                 | 1                 |
| Cant stacking                              | 1                 |
| Edging saw                                 | 1                 |
| Gang-Rip scan                              | 1                 |
| Chop saws(2 saws for green cutting)        | 4                 |
| Sorting                                    | 4                 |
| Stacking & unstacking                      | 3                 |
| Kiln drying                                | 1                 |
| Single arbor rip saws(3 saws for resawing) | 6                 |
| Salvage chop saw(2 saws for resawing)      | 2                 |
| Panel gluing                               | 3                 |
| Abrasive planner                           | 2                 |
| Double end trim saw                        | 2                 |
| Packaging & shipping                       | 2                 |
| Saw sharpener                              | 1                 |
| Floating worker                            | 1                 |
| Clean-up                                   | 1                 |
| <b>Total Workers:</b>                      | <b>44</b>         |

\* Administration, maintenance and sales personnels are not included in this list.

## Appendix 4.6 List of Workers for Design 6\*

| Working Duty                                    | Number of Workers |
|---|-------------------|
| Log loader driver                               | 2                 |
| Log receiving & scaling                         | 1                 |
| Fork lift driver                                | 3                 |
| Deabark   | 1                 |
| Headrig saw                                     | 1                 |
| Gang resaw                                      | 1                 |
| Cant stacking                                   | 1                 |
| Rough planer                                    | 1                 |
| Crosscut saws(3 saws for green cutting)         | 3                 |
| Single arbor rip saws(5 saws for green cutting) | 10                |
| Stacking & unstacking                           | 4                 |
| Kiln drying                                     | 1                 |
| Single arbor rip saws(4 saws for resawing)      | 8                 |
| Salvage chop saws(3 saws for resawing)          | 3                 |
| Panel gluing                                    | 3                 |
| Abrasive planner                                | 2                 |
| Double end trim saw                             | 2                 |
| Packaging & shipping                            | 2                 |
| Saw sharpener                                   | 1                 |
| Floating worker                                 | 1                 |
| Clean-up  | 1                 |
| <b>Total Workers:</b>                           | <b>52</b>         |

\* Administration, maintenance and sales personnels are not included in this list.

## VITA

Wenjie Lin was born in Huang Yan County, Zheijian Province, China in 1961. He graduated from Nanjing Forestry University in 1982 with a Bachelor of Engineering degree in Forest Products. He was awarded a Master of Engineering degree in Wood Technology from the Chinese Academy of Forestry in 1985. After three years of employment as a research associate in the Chinese Academy of Forestry in Beijing, China, he entered Virginia Polytechnic Institute and State University in the Fall of 1988. He Graduated in April, 1993 from Virginia Tech with a Doctorate of Philosophy degree in Forest Products. He is a member of Forest Products Society and the Society for Computer Simulation.

A handwritten signature in black ink, appearing to read 'Wenjie Lin', is centered on the page. The signature is fluid and cursive, with the first name 'Wenjie' and the last name 'Lin' clearly distinguishable.