A Documentation and Analysis of the Physical, Operating, and Business Environments for Small-Tree Handling and Harvesting Systems

by

Matthew L. Corwin

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APPROVED:

William B. Stuart, Chairman

Thomas J. Nichols

Robert M. Shaffer

Thomas A. Walbridge, Jr.

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(ABSTRACT)

Study objectives were 1) to identify successful mechanized thinning and prelogging systems currently operating in the South, 2) to document system characteristics contributing to their success, and 3) to determine which factors affect levels of residual stand damage from thinning operations. The first objective was accomplished by a South-wide industry survey. The latter two objectives were realized through in-depth field studies of selected systems.

The survey indicated three system types used on small-tree operations. Feller-buncher/grapple skidder/hydraulic loader systems comprised the majority of operations described. No predictable relationships between system type and tree size were apparent, so examples of the most common type were chosen for detailed study.

Three thinning and three prelogging systems were selected, covering a range of ownership patterns and physiographic regions. Information was obtained pertaining to each system's application; crew organization and background; equipment spread and descriptions; performance; and special considerations provided by landowners or timber buyers. Residual stand damage cruises were conducted at each thinning operation's job site.

Case-by-case analyses and comparisons between systems based on economic and productivity criteria resulted in a number of recommendations. These suggestions represented system characteristics seen as keys to the success of the operations studied. The recommendations focused on desirable contractor and crew characteristics, equipment selection decisions, job layout, minimization of residual stand damage, and methods of landowner/timber buyer support for small-tree operations.

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Introduction

In the past, the most prevalent system used in thinning and prelogging[1] pine stands in the southeastern United States consisted of chainsaw felling and the use of manual loading or a Big Stick loader to place the wood onto a bobtail truck which drove practically stump-to-stump. This type of operation, while requiring low capital investments, also resulted in relatively low production rates. Although bobtail truck systems are sensitive to weather and terrain, they were economical when good labor was available at low wage rates.

In the last two decades, there has been a considerable increase in the demand for timber from the southern United States. During the 1960's the South entered into the plywood manufacturing industry. Technological advances such as the Chip-N-Saw also made possible the processing of smaller trees into lumber. The increased demand, coupled with the awareness of an impending loss of woods labor, caused a rush towards increasing the amount of mechanization used in logging the South's timberlands (Heist, 1980; Walbridge and Farrar, 1982). Mechanical harvesting equipment ultimately replaced the bobtail truck as the dominant smallwood system in the South, with the exception of a few areas of the Deep South. Mechanization has brought on a steady increase in job productivity for logging (Shartle, 1977).

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[1] Prelogging refers to the removal of smaller trees or undesirable species prior to final harvest.

Today, the system most commonly used for thinning and prelogging in the South is a combination of rubber-tired feller-bunchers and articulated grapple skidders, together with hydraulic loaders or, less frequently, chippers. Major questions remain: 1) which combination of equipment is most applicable? and, 2) what operating procedures can be used to most efficiently harvest the small-diameter trees associated with thinning and prelogging operations while holding residual site and stand damage to an acceptable level?

The objective of this research was threefold: 1) identification of successful small-tree harvesting systems, 2) determination of the importance and influence of such factors as equipment spread, site conditions, management strategy, and crew background on the economic survival of the southern logger when harvesting small trees and, 3) investigation of the incidence of and factors related to residual stand damage from thinning operations.

Literature Review

The handling and harvesting of small trees is a matter of concern among timberland managers and owners. The benefits derived from thinning or prelogging operations must be weighed against the cash outlays that bring them about. Recent shifts within the forest products market, however, have made small-tree operations more economically feasible. For instance, a potentially large outlet for the material removed in thinning or prelogging has been opened by the possibility of wood use for energy (Reisinger, 1983). Also, the gap between pulpwood and sawtimber stumpage prices sometimes widens, causing relative increases in the value of crop trees left following small-tree harvests. From 1974 to 1979, southern pine sawtimber prices increased by 21.4 percent while pulpwood prices rose only 8.3 percent (Clephane, 1980). This trend has reversed recently, however. Between 1980 and 1985, the southeastern average price for random length southern yellow pine sawlogs actually declined 3.8 percent, while the average pulpwood price increased 20.4 percent (Timber Mart-South, 1980 and 1985).

The challenge of dealing with small trees has become significant because the South supplies about two-thirds of the nation's pulpwood, one-half of the softwood plywood, one-third of the softwood lumber, and one-half of the hardwood lumber (Phillips, 1982). It has been projected that the South will have to supply an even larger portion of the demand for solid wood and fiber products that will increase more than twofold by 2030 (Hair, 1980; Heist, 1980; Phillips, 1982). Although Reisinger (1983) noted that many economists are predicting more moderate demand increases, Bailey and Pienaar (1983) believed that without thinning, the high quality sawlogs and veneer logs necessary to satisfy this predicted increase in demand may rarely be produced without lengthening the average rotation length. Reisinger (1983), however, found that when pulpwood prices were projected to increase at a real rate somewhat greater than the rate for sawlogs, a program of thinning, in economic terms, could seldom be advised over a final harvest at rotation age.

There may be reasons in addition to long-term economic returns to engage in small-tree operations. Tax benefits, material flow to the mill, and end product objectives can all play a role in the decision whether or not to conduct smallwood operations. Ultimately, the decision rests on direct or indirect economic considerations. Unless the operations can be undertaken in an economically acceptable fashion, they likely will be foregone (Reisinger, 1983).

The Small Tree Resource

Commercially Available Timber

The South contains a great abundance of small trees. In the 12 southern states from Virginia to Texas there are approximately 188.4 million acres of commercial forestland. Nearly 65 percent of this acreage is classified as poletimber stands (5 to 11 inches diameter at breast height or DBH) or smaller. Seventy two percent of the softwood trees and 86 percent of the hardwoods are less than 5 inches DBH. Fifty four percent of the South's commercial softwood volume and 62 percent of the hardwood volume is in trees less than 11 inches DBH; 14 and 34 percent of the softwood and hardwood volumes, respectively, are in trees under five inches DBH (Phillips, 1982).

The age class composition of the South's industrial forests exhibits a trend towards large increases in pine volumes. If current short rotation lengths remain the norm, a large portion of the inventory increase will consist of small trees (Phillips and Sheffield, 1984). Reisinger (1983) noted that during the 1980's, about 800,000 acres per year will become of proper age for first thinning treatments (15 to 19 years old). He estimated that by the 1990's, the area of timber reaching this age class will triple.

The supply of southern softwood timber comes from both natural and planted stands, but the relative amounts from each stand type is changing. In 1974, natural stands provided over 500 percent more volume than plantations. By 1980, natural-grown timber harvested was 50 percent more prevalent than planted timber, but plantations supplied 200 percent more volume from thinnings than natural stands. Assuming that operations can be conducted economically, plantations are projected to furnish over 80 percent of the southern softwood harvest and 700 percent more thinning volume than natural stands by the turn of the century (Shartle, 1977; Stuart et al., 1981).

The Impact of Small Trees

Tree size has a profound effect on the productivity and costs of harvesting operations. It has been found that a linear relationship exists between harvesting costs and the number of trees per unit of volume. Hypes (1979) noted that, since trees per cord deals with tree volumes, it is more significantly correlated with harvest costs than other measures.

The increased cost situation occurs because volume is a function of the square of DBH. Thus, the cost of an operation escalates quickly as tree diameter decreases or the number of trees per cord increases (Conway, 1977; Davidson, 1982; Horsfield, 1982). For example, a five-inch DBH tree contains only about half the volume of a tree seven inches DBH. Therefore, the costs of a cord of wood produced from a five-inch average DBH stand are approximately double the costs in a seven-inch DBH stand, all other factors held constant (Conway, 1977; Davidson, 1982). Hypes (1979) found that harvesting cost per cord nearly tripled as average stand DBH dropped from 8.9 inches to 5.6 inches.

Individual machines in a system are affected by changes in average stand diameter. Feller-bunchers without the benefit of an accumulating head have been found to produce about 1.5 cords per worked hour in four-inch diameter timber. Working with eight-inch trees, production jumped to approximately 12 cords per worked hour, or an eightfold increase (Walbridge and Stuart, 1980). Through a simulation study, Hypes (1979) inferred that the productivity of a cable skidder or a grapple skidder with gate delimbing would almost triple as average tree size in a stand increased from 5.6 inches (32.1 trees per cord) to 8.9 inches (8.8 trees per cord). This rise in productivity is inversely proportional to the roughly threefold decrease in number of trees per cord.

The smallwood impacts on individual machines are greatly compounded for some systems. In fact, the variable very often found to have the greatest influence on harvesting operation profitability is tree size (Walbridge, 1960; Winer, 1965; Conway, 1977; Spahr, 1983). Tufts (1976) examined the effects of ground conditions, brush conditions, cut per acre, slope, tract size, and tree size on logging costs for eight different system types. He concluded that tree size is the most significant factor affecting smallwood harvesting operations. Figure 1 shows estimated costs per cord for five different system types across a range of tree sizes. The figure supports the findings of several researchers that the degree of mechanization is positively correlated with sensitivity to changes in tree size (Tufts, 1976; Stuart, 1982).

In the past, when manual shortwood systems were the convention in the South, the effect of small trees was not as pronounced. Although felling, limbing, topping, and piling times per unit of volume increase with decreasing tree size, manual loading is better adapted to smaller piece size. Thus, higher loading rates partially offset the lower production of the other elements in manual small-tree harvesting operations (Stuart, 1982).

A factor that currently acts to limit the negative impacts of small trees is stand density. A greater number of trees per acre usually exists in young stands when compared to larger diameter stands. The higher density can reduce the amount of time taken to move between trees to be cut (Stuart, 1982), although more care must be taken to avoid damaging the residual stand when that is a concern.

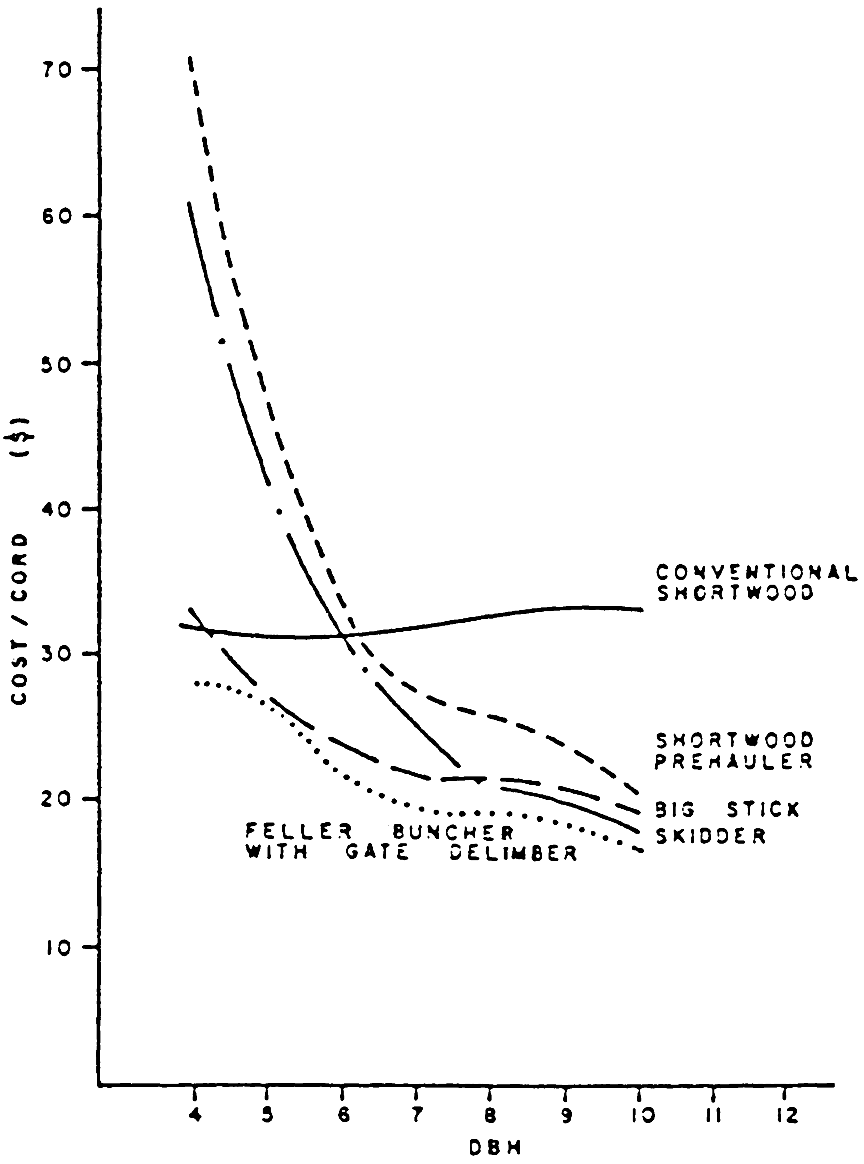

Figure 1. Estimated Total System Cost Per Cord: From Stuart (1982)

Products from Small Trees

Traditionally, thinned or prelogged material left the woods as shortwood. Shortwood's share of the pulpwood-sized timber cut is expected to drop to 25 percent or less by the turn of the century, but significant predicted increases in the quantities of whole tree chips and tree length material produced should compensate for this drop (Stuart et al., 1981).

From analysis of a recent survey, Lanford (1985) concluded that 90 percent of the material thinned in the South is currently harvested as pulpwood. Chips comprise seven percent of the small-tree harvest and less than two percent is sawtimber (generally Chip-N-Saw logs) or other products, such as poles or fuelwood. In an earlier study, Dunwoody (1982) found that ninety percent of thinned loblolly pine was used for pulpwood, one to two percent for wood energy, and eight to nine percent for sawtimber.

Smallwood may present another problem once harvested. The value and utility of the timber can be greatly affected by high percentages of juvenile wood relative to material cut at final harvest, a common occurrence with smallwood (Pearson et al., 1980). Regardless of the relative benefits and weaknesses of smallwood, it is a resource that should be utilized in order to assist in meeting the constantly rising demand for southern forest products. To ensure that small-tree harvesting operations are economically feasible, the most acceptable harvesting procedures must be identified so that the necessary intermediate stand prescriptions can be performed.

Smallwood Operations

Small-tree operations may have both positive and negative effects on three segments of the forest industry: the stumpage producers (timberland owners), the wood producers (contractors and suppliers), and the final product producers (manufacturers). If the operations can be conducted at a profit, timberland owners can realize an earlier return on investment through small-tree harvests and can grow higher quality residual trees with their corresponding rise in value. Also, removal of a portion of a potentially stagnant stand can help maintain or improve the vigor of the remaining trees, which can be good protection against disease and insects. On the negative side, small-tree operations represent high administrative costs to the stumpage producer (Neal, 1985). Also, damage from the operations can reduce the value of the remaining crop trees.

The wood producers do not reap the same benefits from intermediate stand treatments that they do from a final cut. When thinning or prelogging, loggers are in the position of dealing with smaller and/or younger trees, which constitute considerably less weight per unit of volume than the material found in a final harvest cut (Neal, 1985). This leaves the small-tree operator in the situation of harvesting a lower value product while costs increase. Also, site damage from intermediate harvests can adversely affect future productivity and harvesting costs.

The final product producers, usually pulp and paper mills, can expect both beneficial and unfavorable influences, depending on the end product manufactured. Thinned material contains a higher percentage of juvenile wood and yields five to fifteen percent less fiber when compared to the same volume of mature timber (Zobel, 1976; Pearson et al., 1980). Reduced yields increase procurement costs, mill handling costs, and require extra pulping chemicals. The fiber produced from juvenile wood has a distinctly different nature, which may or may not be advantageous to the mill, depending on the desired properties of the final product (Pearson et al., 1980; Neal, 1985).

Operation Objectives

Wood-receiving facilities dictate the form of delivered material. The form accepted is one of the governing factors over the types and sizes of harvesting equipment required. Prior to making decisions concerning equipment needs, however, the involved parties must determine objectives for the operations. A partial list of common objectives would include:

In Thinning

- To maximize diameter growth of the remaining stand
- To obtain more rapid recovery of costs (Jackson and Schmitt, 1980)

- To harvest potential mortality
- To develop habitat for wildlife (Muckenfuss, 1985)

In Prelogging

- To utilize resources formerly considered non-commercial
- To reduce site preparation costs (Kellison, 1984)
- To increase logging efficiency by increasing size and level of uniformity of the residual stand (Owens, 1968)

In Both Thinning and Prelogging

- To reduce the cost of final harvest (Jackson and Schmitt, 1980)
- To procure additional raw materials for the mill (Muckenfuss, 1985)

Young and Bowling (1980) felt that their company could thin earlier in the rotation using mechanized systems which led to the possibility of shortening rotation length. Small-tree clearfelling may be conducted for the purpose of stand salvage, conversion, or sanitation.

Obviously, with such a diversity of potential objectives, management decisions will exert a great influence on system type and individual machinery required for thinning/prelogging jobs.

Production Factors

There are many other determinants of the level of productivity and costs of small-tree operations aside from tree size. Trucking distance is often cited as a force acting on production and cost. In fact, Lanford and Stokes (1985) stated that the two most influential factors regarding harvesting profitability are tree size and haul distance.

Skidding distance is also identified as an influence on production. The most important production factor can be skidding or forwarding distance when operating in small timber, according to Walbridge (1960). Spahr (1983), however, qualifies the impact of in-woods travel distance by noting that it is appreciable only when utilization of equipment capacity is low or travel time is a high percentage of the total. Pennanen and Farrar (1982) noted that small load capacity can cause dramatic responses to skidding distance, but with today's larger capacity skidders and forwarders, distance does not exert such a strong influence on production as in the past.

Labor is another variable often noted as exerting a great influence over smallwood harvesting profitability and job quality. Corley (1985) noted that the management of Rocky Creek Logging Company (RCLC)[2], an Alabama private contract firm, believed that their most important production factor was the quality of their crews. By promoting good worker attitudes, RCLC felt that they attained safer, higher quality, more cost efficient jobs than the average logger. In fact, an analysis of 72 pulpwood operations, the Battelle study, brought forth the opinion that, "crew aggressiveness can completely counteract all the other factors...stated as affecting harvesting cost" (Mackintosh and Bunn, 1976). The Battelle study was conducted in the 1960's and mainly dealt with manual harvesting systems. The findings may not be applicable to today's more mechanized operations.

Apart from crew outlook, labor still can exhibit a large effect on thinning/prelogging costs. Kerruish (1976) found that nearly 70 percent of total pulpwood harvest and transportation costs in Australia can be attributed to direct and indirect labor expenses. This high percentage is likely due to the need for manual delimbing of limby radiata pine (*Pinus radiata* D. Don) in Australia. A more reasonable estimate for labor costs in the South may be 30 percent. Pennanen and Farrar (1982) determined that, for a conventional thinning system, labor comprised 27.4 percent, while machines entailed 32.6 percent of total harvest costs. In any case, labor costs are forecast to climb at a more rapid rate than predicted production increases will be able to offset (Shartle, 1977). Unless labor requirements can be reduced (i.e. through increased mechanization), the products of thinning and prelogging may become so expensive to obtain that the costs will be considered too prohibitive to perform the operations (Kerruish, 1976; Shartle, 1977).

A study by the American Pulpwood Association Harvesting Research Project (APA-HRP) during the early 1970's found that important factors in operation success were goal setting and onsite supervision of the crew (Warren and Raburn, No date). These activities encouraged high pro-

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[2] The use of trade names in this paper does not constitute an official endorsement of the company or product; they are used for the convenience of the reader.

ductivity and low incidence of injuries. Goal setting included goals for crews and individuals for the short term and the long term. Supervision entailed remaining on the job site, providing explicit instructions and explanations, and training of crew members.

Production rates and, ultimately, profits can be determined by several other factors, but no factor has as great an effect as tree size. Some of these factors are harvest strategy (Biltonen, 1972; Walbridge and Stuart, 1980; Dunwoody, 1982), terrain conditions (Biltonen, 1972; Thienpont, 1976), volume to be removed per acre (Biltonen, 1972; Shartle, 1977; Lane, 1981), tree spacing (Biltonen, 1972; Shartle, 1977; Dunwoody, 1982), transportation and delivery point considerations (Thienpont, 1976; Lanford and Stokes, 1985), and number of machine functions per system (Spahr, 1983).

System Characteristics

In a mechanized smallwood system, as with any other logging system, the equipment performing the key elements should dictate system design (Granskog, 1978). For thinning and prelogging, the feller governs the production of the whole job, mainly through skid trail location and tree or bunch placement. Another relevant point is that job quality, in silvicultural terms, is mostly dependent upon tree selection decisions made by the felling operator (Corley, 1985). The additional labor and machine resources required therefore should be determined by expected felling productivity (Granskog, 1978).

Each individual system has its own unique features, even within system type classes, but there are general characteristics which should be common to most, if not all, successful smallwood harvesting operations. Hoffman (1982) broke down what he felt were the most desirable aspects of thinning/prelogging systems into four categories: 1) economic, 2) silvicultural, 3) equipment, and 4) harvest technique considerations. According to Hoffman, smallwood operations should involve the following characteristics:

Economic

- Low capital requirements
- Energy efficient
- Ergonomically efficient

Silvicultural

- Minimal site disturbance
- Tight operating paths
- Potential for individual tree selection

Equipment

- Low capital (small, light, simple machines)
- Narrow
- Low ground pressure
- Energy efficient
- Rapid cycle times for processors
- High load capacity-to-weight ratios for transporters

Techniques

- Better planning
- Minimize in-woods travel
- Minimize trail cutting
- Multiple piece handling
- Mechanical bunching and delimbing

These recommendations pertain specifically to northern small-tree systems, but should, in general, be practical for all thinning/prelogging applications. Additionally, small-tree harvesting equipment should provide sufficient productive capacity so as to be economically efficient.

It must be realized that major, new innovations in smallwood harvesting equipment do not appear to be on the near horizon. Current machinery may have to be refined so that it is more suitable for efficient production with small-diameter material, while restricting site and stand damage to acceptable levels. Furthermore, training of loggers to better acclimate them to the business and operating environments associated with thinning and prelogging jobs is essential and should be improved (Muckenfuss, 1985).

Current Harvest Methods

In selecting the most appropriate small-tree harvesting system, the logger must consider many facets of his expected operations. For instance, stand location, both in geographic terms and in connection with primary delivery yards, can influence equipment decisions in relation to hauling method. Between-stand move considerations are affected by the proposed harvest schedules of stands. Tract and stand characteristics (e.g. terrain, brush conditions, existing roads, tree spacing, volume per acre before and after treatment, and individual tree characteristics) may dictate machine specifications. Other factors, such as local market needs, product forms necessary to satisfy the markets, level of acceptable residual stand damage, or aesthetic and environmental concerns can also place limits on equipment types applicable to the operations (Strickland, 1980).

There are several factors which are particularly germane to southern equipment selection options. Timberland tracts, most of which are small and privately owned, are widely dispersed throughout the South. The present road systems and bridge laws restrict equipment dimensions and size of hauled loads enough to disqualify certain machinery from consideration. Also, many operators might find equipment purchasing funds difficult to obtain, which can preclude the use of capital intensive small-tree systems on a broad scale.

The trend in the South, however, appears to be toward mechanized operations. The total number of independent loggers has been dropping, but those that have remained in the business have increased their output sufficiently to increase total production (Weaver et al., 1981). Table 1 illustrates the shift from many smaller harvesting operations to fewer, more productive operations. One-fourth of the 1979 pulpwood harvesters in the South accomplished nearly two-thirds of that year's total production. In other words, 75 percent of the smallwood loggers produced only 35 percent of the total output or less than 50 cords per week apiece. This low output component of smallwood producers consisted mainly of bobtail truck shortwood operators (Weaver et al., 1981; Walbridge and Farrar, 1982). By 1985, shortwood systems still comprised two-thirds of the producer force, but the more highly mechanized longwood systems outproduced them in terms of weekly output (Lanford, 1985).

Through an informal phone survey of 22 of the South's largest plantation owners, Reisinger (1983) found that mechanized thinning systems are of more interest to the companies than manual methods, with their inherently lower production rates. The emphasis on mechanized systems is caused by a variety of factors. Probably the most important factor is the inadequate supply of smallwood loggers and woods labor, which necessitates the increased productivity of mechanical harvesting systems (Reisinger, 1983).

When full mechanization is not feasible and the costs of a partially mechanized system are similar to manual costs, there are still advantages associated with employing machinery to the extent possible. Labor supply problems can be significant with manual shortwood systems. Also, equipment can provide crew members with more protection from the operating environment (Pierrot, 1984).

Many studies have been conducted to determine the relative cost efficiencies of the various smallwood harvesting systems. Granskog (1978) found that both a shortwood harvester[3] and a tree length harvester system[4] produced more per man-day than either of two different full tree harvester systems[5]. The latter system types entailed lower costs per cord in slash pine stands, though, (assuming fixed skidding and hauling distances) because of lower capital investment-to-production ratios. A simulation study utilizing the Harvesting Analysis Technique, or HAT, computer package[6] compared shortwood harvester/forwarder, tree length harvester/grapple skidder, and feller

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[3] 1 shortwood feller-limber-bucker, 1 forwarder, 1 truck, 3 trailers, crew of 3

[4] 1 tree length feller-buncher-limber-topper, 1 grapple skidder, 1 loader, 2 trucks, 2 trailers, crew of 4

[5] Producing longwood: 1 feller-buncher, 2 chainsaw limber-toppers, 2 grapple skidders, 1 loader, 3 trucks, 3 trailers, crew of 8. Producing shortwood: 1 feller-buncher, 4 chainsaw limber-buckers, 2 forwarders, 2 trucks, 5 trailers, crew of 9

[6] See Stuart (1980) or Stuart (1981) for details

Table 1. Number of Southern Pulpwood Operations by Production Class

Annual Production (Cords)

Year	< 1000	1-5000	5-10,000	> 10,000	Total
1974	2902	2205	612	153	5872
1980	2083	1951	807	257	5098
Percent Change	-28	-12	+32	+68	-13

Adapted from Stuart and Shartle (1977)

buncher/grapple skidder/gate delimber systems on row thinning operations in a 6.5-inch average DBH slash pine stand. The feller-buncher system costs were lowest, while the costs for both the shortwood and tree length harvester systems were more than 10 percent higher (Cubbage and Granskog, 1982). Reisinger (1983) also used the HAT package to compare different thinning systems. On a volume or weight basis, costs were lowest with whole tree chip systems, intermediate with tree length (feller-buncher/grapple skidder/gate delimber) systems, and highest with shortwood (feller-buncher/forwarder) systems, although the lower value of whole tree chips when compared to roundwood acted to somewhat moderate the considerable differences in production.

Although production and costs seem to vary widely between system types, all types are still used in the South. A recent survey of American Pulpwood Association member companies in the Gulf States revealed that 32 percent of the 120 respondents thinned their lands with stump-to-stump bobtail truck systems, 31 percent utilized prehauler/forwarder systems, and 37 percent employed skidder systems (Lanford, 1985).

In addition to the equipment used, harvest strategy has an important role in the success or failure of an operation. Four basic patterns are used in thinning or prelogging operations. Individual tree selection is a method in which skid trails are formed, then trees are removed on the basis of either marking or operator selection (Dunwoody, 1982). Prelogging treatments are typically conducted in this fashion. Row thinning entails the extraction of all trees in certain rows of a plantation. Rows to be removed are chosen uniformly based on the prescribed residual stand density (i.e. harvest every third row). Row with selection thinning involves thinning from below in the area between removed rows. Similarly, in corridor thinning, trees in an eight to ten-foot swath are harvested and selective removal can be undertaken between corridors. This method is used in seeded and natural stands or in plantations where corridors are often laid out at an angle to planted rows (Dunwoody, 1982). The corridor thinning technique may seem to resemble individual tree selection. Corridors are spaced closer together than the skid trails used in pure selection cuts, however, so less travel through the residual stand is required.

From a strictly silvicultural standpoint, selection cutting is the most desirable method (Biltonen et al., 1976) because trees are individually evaluated as to whether or not their removal will benefit the residual stand (Dunwoody, 1982). The necessity of choosing which trees to cut, however, drastically reduces the feller's harvesting rate (Lane, 1981). Also, equipment operators must exercise a greater degree of caution when in the woods to avoid damaging the residual stand (Biltonen et al., 1976; Dunwoody, 1982).

Row thinning offers a more feasible opportunity for mechanized operations (Fries, 1973; Biltonen et al., 1976; Bailey and Pienaar, 1983) with the attendant production rise and reduction in harvesting costs per unit of volume. Also, thinnings can possibly be performed earlier in the rotation if complete rows are removed because the harvest samples uniformly across the diameter distribution rather than cutting only from the low end. Conceivably, earlier thinning may allow residual stand growth to accelerate sufficiently to shorten the rotation length (Wright, 1976). Obviously, when all trees in certain rows are harvested and other rows left intact, some possible sawtimber quality trees will be removed and some unacceptable trees will be left to grow (Wright, 1976; Dunwoody, 1982). This situation may affect the proportion of sawlogs and veneer logs to pulpwood, but by final harvest these effects should be minimal relative to selection cuts which retain comparable stand densities (Wright, 1976). However, strict row thinning is not a recommended practice in stands with a small number of potential crop trees per acre or stands which may have problems with windthrow (Wright, 1976; Dunwoody, 1982).

Row with selection thinning combines the properties of both of the methods previously discussed. Production is higher and costs lower than with pure selection cuts and silvicultural results are more acceptable than with row thinning (Biltonen et al., 1976; Blackwelder, 1982; Dunwoody, 1982). In fact, the combination technique is possibly the most common thinning strategy. Lanford (1985) found that 44 percent of questionnaire respondents conducted row plus selection thinnings, while 41 percent used selection cuts and only 15 percent performed row removals.

Corridor thinnings involve essentially the same operational advantages and disadvantages as row only or row with selection harvests depending upon whether tree selection is employed between corridors. Silviculturally, the use of corridors may be a more desirable method. Potential crop trees can be left in the stand since the corridors need not follow planted rows. For this reason, corridor thinning could replace row removal strategies as the dominant thinning method.

Regardless of the system/strategy combination adopted, management of the operation can exert a strong influence on production rates and profits. Table 2 reflects average weekly production rates and the ranges reported in a survey of southern thinning operations. The large amount of variability within and between system types reveals the chance of improving small-tree harvesting profitability through superior planning and organization of the harvests (Lanford, 1985).

Means of Reducing the Impact of Small Trees on Harvesting Operations

One branch of thinning/prelogging equipment development concentrated on combining several handling and harvesting functions into a main base machine (Dunwoody, 1982). Equipment designed to employ this ideology might include the TH-100, the TH-210, or the Propst harvester. The problem with this approach, however, is that, when designed to meet some particular application, these integrated machines are often not sufficiently versatile to profitably operate in other situations. In addition, the multiplying effect of mechanical availability on components resulted in very low utilization. Development contemporary with that discussed above focused attention on the design of specialized attachments which can be used on a variety of carriers already in production in order to best match equipment to the harvesting conditions encountered. In this way, carrier manufacturing costs can be extended over a greater number of machines and equipment flexibility can be obtained through interchange of attachments (Dunwoody, 1982).

Numerous other approaches have been proposed to reduce the effects of small-diameter harvested material. Decreasing time for machine work elements can allow the harvest of more trees per hour. This change in cycle time is bound by cost and mechanical availability constraints (Stuart, 1982). Designing equipment to more closely match the material handled (i.e. small, light weight) also has been suggested (Kantola, 1973; Stuart, 1982). Lanford and Stokes (1985) noted that appropriate operator training and harvest planning are essential if smallwood operations are to be successful. Felling productivity may be increased by allowing for operator selection in lieu of

Table 2. Production Rates of Southern Thinning Operations

System Type	Average Weekly Production (Cords)	Range Reported
Stump-to-stump	51	12-128
Prehauler/forwarder	109	45-265
Feller-buncher/ grapple skidder	265	82-750

From Lanford (1985)

timber marking, since the feller can move straight to the next tree to be cut instead of searching for marked trees (Corley, 1985).

The most promising method of coping with small trees may be to concentrate on equipment that has the ability to handle multiple stems rather than individual trees (Kantola, 1973; Conway 1977; Hypes, 1979; Stuart, 1982; Spahr, 1983). The capacity to process bunches of small stems seems to promote higher production and lower capital investment per unit of volume for the system (Spahr, 1983). The earlier individual trees can be aggregated into bunches, the more effectively the impacts of small-diameter material can be controlled. Loading and hauling times are relatively unaffected by material size, but productivity can be adversely affected by smaller piece lengths and volumes. Felling, limbing, topping, bucking, and skidding activities also can be influenced to varying degrees (Hypes, 1979).

The presence of an accumulator on feller-buncher shears to bunch trees before placing them on the ground may be the most important feature of the machines (Winsauer et al., 1984) because the material is bunched at the start of the operation. These attachments are especially important since the felling rate often limits the production of the entire system. Several Swedish studies have found that accumulating heads can decrease felling time per tree by 33 to 40 percent (Bredberg and Moberg, 1971; Sjunnesson and Santesson, 1972; Nilsson, 1978). In the United States, research has shown an increase of from 67 to 100 percent in the number of trees harvested per productive hour with an accumulator over single-stem felling heads (Walbridge and Stuart, 1980). These findings concur with a simulation study in which the production of both tree-to-tree and limited area feller-bunchers rose almost 100 percent when utilizing a bunching shear in a 5.6-inch average DBH stand (Hypes, 1979). Hiwassee Land Company experienced even more dramatic results. By incorporating accumulating shears into plantation thinning systems which previously used single-stem shears, feller-buncher productivity climbed threefold (Bryan, 1977b). In addition to raising the felling rate, accumulators can benefit skidding productivity by maximizing bunch size (Davidson, 1978; Winsauer et al., 1984).

Gate delimbers are another method of moderating the effects of small trees by processing the timber in bunches rather than individually. Bryan (1977) estimated cycle time for delimbing with a gate to be 1.0 to 1.5 minutes per turn. Since the entire bunch is treated at once, Bryan feels that single-tree delimbing techniques may not be able to compete efficiently with the gate. In fact, a South Carolina logging company crew chief noted that, "Experience...has shown that the gate can delimb more than twice as much as an experienced man with a powersaw" (Bryan, 1977).

The use of small trees for energy can make harvesting smaller diameter material more profitable (Strickland, 1980; Kluender et al., 1983). Logging residues can be accumulated through modification of common harvesting sequences. By limbing and topping at the deck rather than at the stump, usable material is aggregated in one location (King, 1981). These limbs and tops represent up to a 25 percent overrun compared to the utilization of bolewood only (Jolley, 1977) and can be used to produce energy. Through a simulation study, King (1981) found that systems altered to recover residues could harvest to a smaller average DBH profitably and more fully utilize the resource than conventional systems of the same makeup while average costs per unit of volume were lower. Although the simulation involved clearcutting systems, analysis concentrated on the costs of harvesting material 10 inches DBH and smaller.

Several benefits are associated with the use of whole tree chip systems in smallwood operations. Deformed trees which must be removed are chipped more easily than they can be hauled as solid wood (Kerruish, 1976) and, since the chips are to be used for fuel, restrictions on chip quality can be relaxed (Hakkila, 1981). Since the tops and branches of harvested trees are used, utilization of the tree can approach 100 percent (Young and Bowling, 1980) and yields per acre are greater than those obtained through traditional harvest methods (Kerruish, 1976; Bryan, 1977a). Also, by chipping this normally unused portion of the tree, logging residues are virtually eliminated from the stand, reducing fire and insect dangers (Bryan, 1977a), although site degradation may eventually result because of removal of nutrients contained in the slash.

Near rotation age, small tree effects can be lessened by prelogging. In Oklahoma, Weyerhaeuser harvested wood seven inches and less with a different system than used for the larger diameter portion of the stands and experienced a three percent savings in total logging costs (Conway, 1977). With the removal of small trees prior to subsequent final harvest, several benefits can be realized. In a South Carolina study by International Paper, a company harvesting foreman noted that final cut productivity rose 10 to 15 percent and machine upkeep costs declined when prelogging was conducted (Ford, 1982). Reductions in expenditures for site preparation are also possible (Ford, 1982). Small-tree removal operations provide landings and skidding pathways which can be used in the final cut as well. A problem that may be encountered if prelogging treatments are performed during improper ground conditions is that rutting can be severe enough to impair the skidding function in final harvests (Owens, 1968). Basically though, if preharvest extraction of small stems can be accomplished with a lower cost system than those used for the cutting of mature stands, the forest resource should be more completely utilized and final harvest equipment should become more cost efficient so that positive net returns can be maintained for logging operations (Owens, 1968).

Other methods of controlling the impacts of small timber have been implemented. Provisions for loading trailers butt-to-top with small trees allows hauling of payloads which are closer to the legal limit. The Virginia Cooperative Extension Service noted that loading by this method can allow up to 1.5 cords per load more than with conventional loading while remaining within legal height constraints (Anonymous, 1986). A problem with this approach is that wood-receiving yards must be equipped to remove the mixed load or to buck the load while on the truck, which some yards are not (Lanford and Stokes, 1985; Anonymous, 1986). A Washington logging firm has had success using a small, portable sawmill on the deck when thinning stands consisting mainly of Douglas-fir with some pine. They process 4.5 to 8.5 inch trees with the mill and can produce 8000 board feet of cants, studs, and dimension lumber plus two 25-ton loads of logs on an average day (Blackman, 1977).

Lanford and Stokes (1985) felt that the answer to smallwood operational problems may be forwarder systems consisting of small feller-bunchers, some type of limbing/bucking processors, and forwarders. They believed that, with some degree of individual tree selection, more desirable results can be obtained than with skidder systems. The processor's slash will provide a cushion which may reduce site damage and the residual stand could be less likely to be injured by a forwarder than by a skidder dragging a bundle of tree length material through the stand (Lanford and Stokes, 1985).

Damage to the Residual Site and Stand

A factor which must be considered when thinning is the level of residual stand and site damage that will be accepted[7]. Survey responses indicated that nearly half (46 percent) of the southern companies questioned experienced an appreciable amount of site and/or stand damage from thinning operations, but 39 percent reported negligible amounts (Lanford, 1985).

Extent of Damage and Its Effects

As small tree operations become more mechanized, the likelihood of tree damage tends to increase drastically. Heavy equipment may cause severance or exposure of roots, which will reduce tree vigor (Nilsson, 1978). Root damage by forest machinery has been found to impair pine and spruce growth by up to 12 percent (Bredberg and Wasterlund, 1983). Trees also can be scarred by collisions with machines, tires, or skidded loads. Susceptibility to disease or insect attack because of harvesting injuries to the trees may or may not be a problem, but the damage can adversely affect the value of the product eventually harvested from the residual stand (Nilsson, 1978).

In a thinning study conducted in northern hardwood stands, Biltonen et al. (1976) found that injuries to stems during the operations were the most prominent form of tree damage. Harvesting method exerted a strong influence on the occurrence of injuries. Mechanical row thinning caused an average of 63 incidences of bole damage per acre (18 percent of the remaining trees per acre), while chainsaw felling averaged only 6 (4 percent). Mechanical selection and row with selection methods injured 26 and 14 percent of the residual stand, respectively. Manual operations did not damage the roots to any extent, but mechanized selection and row with selection thinnings both injured the roots of 14 trees per acre on the average. Root damage was most common with row thinning, averaging 39 trees per acre (Biltonen et al., 1976), but root damage by all three mechanical

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[7] With prelogging, unlike thinning, damage to the remaining trees is not a major concern since the timber left standing will be harvested within a relatively short period of time.

methods was near 10 percent of the residual stand. Table 3 more fully details the results of this study. Differences between the deliquescent crown form of northern hardwoods and the excurrent form of southern pine and variations in branching habits may make interpretation of the absolute numbers and locations of damage from this study inapplicable to the southern pine forests. However, the trends which are apparent concerning the effect of harvest method on the incidence of tree damage may be pertinent to southern pine thinning operations.

Kluender (1985) felt that the most significant hazard imposed on the site by thinnings is soil compaction, since 95 percent of the roots of southern pine species exist in the upper five to six inches of soil. Compaction can slow tree growth by altering soil density and porosity which may retard root growth and limit water and nutrient dispersion (Burger et al., 1984). It should be noted, however, that little experimental evidence exists documenting the actual extent of growth impairment due to soil compaction.

In addition to compaction, rutting and erosion at the site may result from intermediate harvests. Also, when the thinning is relatively heavy, the level of the water table may climb, possibly leading to some unexpected problems (Kluender, 1985).

Factors Affecting the Incidence of Damage

The timber growing environment is so complex and varied that the interaction of a number of elements may determine the extent of stand and site damage. A Finnish study (Karkkainen, 1970) noted several factors which influence the amount of tree damage incurred. Bole damage seemed unrelated to season of the year, but root damage could occur up to three times more frequently in the summer as in the winter, probably due to the combined protective effect of frozen ground and large amounts of snow on the ground during Finnish winters. Skid trails which are too narrow also can increase the number of injuries sustained (Karkkainen, 1970). Spacing of the trees remaining in the stand will affect the percentage that are scarred by the operation (Biltonen et al., 1976; Stokes and Sirois, 1983). Factors which play key roles in the extent of tree damage are the levels of op-

Table 3. Occurrence of Thinning Damage by Harvest Method

Harvest Method	Residual TPA[1]	*Stem Injuries* TPA	Major[2] (%)	Minor (%)	*Root Injuries* TPA	Major (%)	Minor (%)
Manual							
Chainsaw	155	6	0	100	0	---	---
Mechanized							
Selection	137	35	9	91	14	50	50
Row plus selection	156	22	60	40	14	67	33
Row	350	63	40	60	39	33	67

From Biltonen et al. (1976)

[1] Trees per acre

[2] Major injuries consist of 50 square inches or more of stem or root cambium exposed.

erator skill and caution (Karkkainen, 1970; Biltonen et al., 1976), since the conscientious operator will exercise more care in performing the various harvesting functions.

Aside from injuries to the individual trees, disturbance of the soil and surface litter layer should be avoided as much as possible (Fries, 1973). Trail depth and soil breakage[8] were two properties used by Fries (1973) to illustrate the severity of site disturbance on a glaciated Scandinavian soil. Trail depth increased mainly during the initial passes, but became relatively uniform after later hauls. Soil breakage, on the other hand, became more pronounced with every pass. Compaction and changes in bulk density and porosity are more commonly used indicators of site damage in the South. Burger et al. (1984) found that compaction and bulk density increased and total porosity decreased as a function of the square root of the number of passes by either a skidder or crawler tractor on a Virginia sandy clay loam. The values of all of these measures continue to become less favorable for tree growth as the number of passes over a given path rises, indicating that, from a strictly damage prevention viewpoint, the amount of skidding along any one trail should be limited (Fries, 1973). However, increasing the number of skid trails in a stand to decrease the traffic on the individual trails may not be economically feasible nor silviculturally desirable.

Methods of Controlling Damage

Proper planning of the harvest is an invaluable tool in preventing residual stand and site damage. Apart from planning, there are certain operational tactics which have been suggested to reduce the impact of thinning operations. For instance, construction of corridors at an angle to, rather than following, the rows will decrease the likelihood of scarring the residual stems by avoiding any curves in the rows that may cause the dragged load to strike standing trees (Pierrot, 1984). Young and Bowling (1980) propose that laying out corridors at 45-degree angles to the rows will lessen the amount of damage to crop trees because the turn from the corridor towards the deck will not re-

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[8] Soil breakage refers to separation of the humus layer at the trail edge and the subsequent crushing of the portion in the trail.

quire the 90-degree curve that corridors arranged parallel with the rows would necessitate. For added protection, "turn" trees can be left on the inside edge of the curve from the corridor onto the main skid trail. These trees may be damaged as the load is skidded around the turn, but the injuries are restricted to fewer trees and they are cut at the end of the operation (Kantola, 1973; Pierrot, 1984). Also, formation of large bunches which cannot be dragged along the trail free of interference with residual stems should be avoided (Pierrot, 1984).

In order to protect the stand from the machines themselves, equipment width and residual tree spacing must be considered. The machines should not be so large that they cannot travel through the stand without the remaining trees acting as obstructions to travel (Kluender, 1985). To reduce the risk of stem and lateral root damage, Hoffman (1982) felt that trees should be spaced on the basis of equipment width plus 1.5 meters (4.5 feet). Figure 2 illustrates the premise behind this formula.

Tracked vehicles are often purported to reduce the site impact of harvesting activities. Actually, though, the argument for tracks, as opposed to tires, is valid only under certain ground conditions and can shift depending on the equipment under consideration, also. In Sweden, it was found that a large tractor with tracks caused markedly less site damage than the same machine with wheels when ground moisture content was high (Fries, 1973). Under drier conditions, trail depth was similar for both types. When differences were observed, the tracks were harsher on the humus layer, causing greater soil breakage than tires.

Burger et al. (1984) found no significant difference in soil damage between tires and tracks on a typical Piedmont soil. Soil bulk density, compaction, and porosity did not differ between machine types across all moisture content and traffic intensity levels observed, even though the wheeled skidder (John Deere 540B with 23.1-26 tires) exerted 3.7 times greater ground pressure than the crawler (Komatsu D53A with 19.8 x 91.2 inch tracks).

Fries (1973) and Kluender (1985) believed that the site could be protected by leaving the logging slash on the trails, although Kantola (1973) did not feel that this significantly deterred soil disturbance. Fries (1973) found that wheeled skidders caused double the trail depth and triple the amount of soil breakage when residues were not spread over skid paths. This work was conducted in

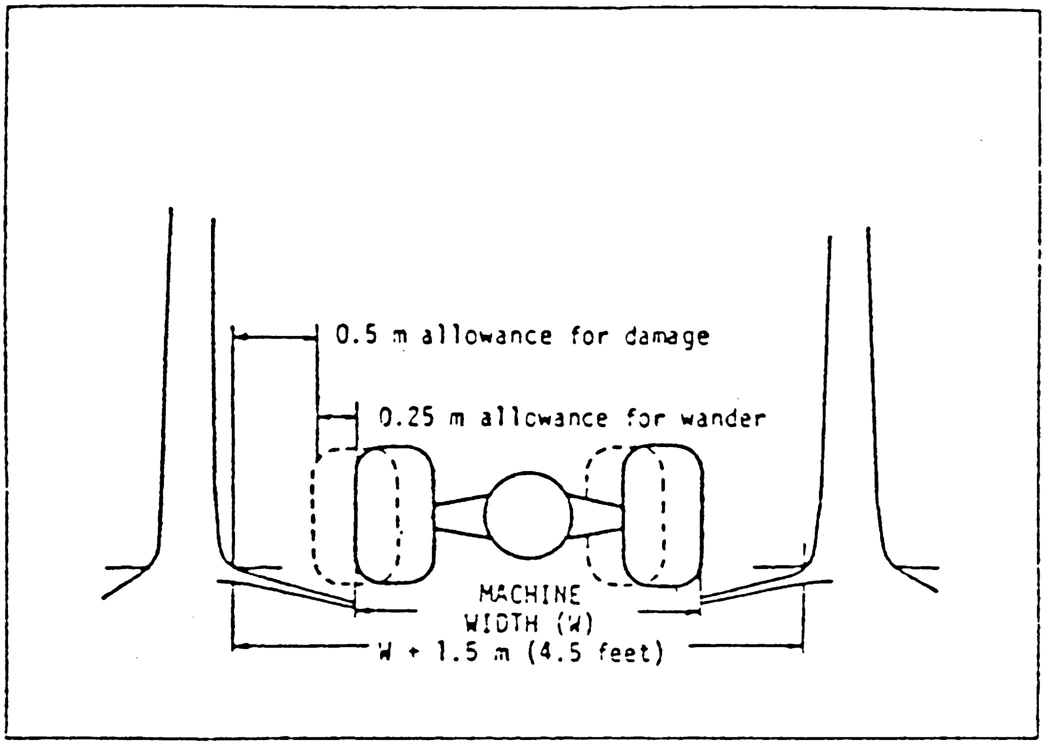

Figure 2. Consideration of Equipment Width in Determination of Residual Tree Spacing: From Hoffman (1982)

Scandinavia, where the glaciated soils with high organic matter content probably are affected more severely by harvesting operations than southern soils. The chance of root damage on the sandy or clayey soils of the South may be reduced by slash on the trail since the weight of the machine is distributed over a larger surface area (Kluender, 1985).

Protection of the site and stand can be afforded with minimal disruption of normal operating procedures, provided that harvests are properly scheduled and planned. Desired methods of decreasing the chance of damage can be determined during the initial planning of the harvest and, if carried out as intended, should prove effective.

Methods and Procedures

The identification of successful smallwood operations was accomplished through an industry survey. Determination of the importance of certain factors pertaining to smallwood harvesting operations was made by detailed field studies.

Industry Survey

In May, 1985, 81 sets of questionnaires were sent to woodlands managers and procurement foresters throughout the South. The purpose of the survey was to aid in identifying the "most promising" thinning and prelogging systems currently operating in the region. The information desired from the questionnaire included operation type and location, harvest method, stand data, equipment and crew composition, estimated weekly production, and a qualitative assessment of residual stand damage, if applicable, for each smallwood logger reported.

System Studies

Following receipt of the questionnaire responses, the data was compiled and summarized and led to more in-depth studies of selected systems. Portions of Sobhany's (1985) system evaluation technique were used to document the selected operations. The following categories of data were documented (Data collection form numbers used are included in parentheses):

Crew organization and safety (312.00)

- Crew description/tasks and skills (312.10, 312.11)
- System description/material flow (312.20, 312.21)

Machine description[9]

- Make, model, condition, price (312.22)
- Concept adequacy (370.01)
- Design adequacy (370.02)
- Service and repair considerations (370.03)
- Safety and comfort considerations (370.04)

Application

- Harvest strategy (306.51)
- Stand character and conditions (306.40, 306.52)
- Environment (306.10)
- Ground conditions (306.20)
- Working conditions (306.30)

Performance

- Periodic system productivity (352.0)
- Periodic machine expense elements (352.1)
- Periodic labor payments (312.12)

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[9] For an example of the type of data collected with forms 370.01 through 370.04, see Appendix A.

The performance criteria had to be generalized to avoid revealing details of the loggers' financial situations.

In addition to the aforementioned elements of the evaluation technique, supplementary knowledge concerning the material removed was also desired. If the information could not be obtained from the timberland owner, prism plot timber cruises were conducted in the stands to be logged (or comparable stands, if necessary) both before and following the thinning/prelogging treatments. These procedures provided a complete description of the stand conditions under which each system was operating.

A second method to substantiate the nature of the harvested timber was to tally sample trailer loads. The number of trees per load and the scale weight of those loads was obtained. Average weight per tree then was used to calculate a measure of tree size, the number of trees per ton.

Since felling is often the limiting factor in a system, each operation's felling equipment was observed in detail. Measurements were taken of the fellers' time per tree, time per accumulated bunch, and time per skidder bunch. This data provided information as to utilization and production of the felling equipment used in each operation. In addition, skidder turn times and the number of trees per turn were noted in order to determine the number of trees per minute delivered to the landing.

Discussions with timberland owners also provided useful data. Special circumstances or considerations for the logger were noted. Along with this, any jobs performed by the landowner which aided the operation (road building and maintenance, for example) and their impact on production and costs, if any, also were documented.

Residual Stand Damage Studies

Cruises were conducted to determine the extent of residual stand damage due to thinning operations. Random samples of the total number of crop trees and the number of damaged trees in an area were obtained. This process allowed a determination of a damage ratio or percentage for each operation. Damage was classified as either major or minor bole damage, depending on the area of bark removed. In accordance with a well-quantified study by Biltonen et al. (1976), 50 square inches of exposed cambium per damage location was the threshold between major and minor damage. Also, tops and large branches broken off during the felling cycle were considered damage.

To test the hypothesis that the probability of damage increases with increasing proximity to the landing, line plots were located randomly throughout the stands. Figure 3 depicts an example of the relationship between the timber and damage cruise plots. The corridor nearest to each timber cruise plot (see Plot 1 in Figure 3) was used as a border for the damage assessment area. An area one chain wide between corridors was examined (see shaded area in Figure 3). All crop trees in this area were tallied and the number of trees observed in each damage category was documented to derive a damage ratio. The line plots allowed random sampling for incidences of damage since they were based on the prism plots, which were randomly located throughout the stand. Measurement of the distance from the midpoint of the one-chain length in the corridor (Point A in Figure 3) to the landing, in combination with a damage ratio, provided data for testing the hypothesis.

The information obtained concerning the smallwood loggers' operations allowed calculation of relative costs and revenues for each system/harvest method combination and certain economic and productivity measures were calculated. The information derived through the evaluation method, the additional production and stand character data, and these monetary and production measures allowed comparisons between systems for the purpose of determining which features appeared to contribute to the operations' success.

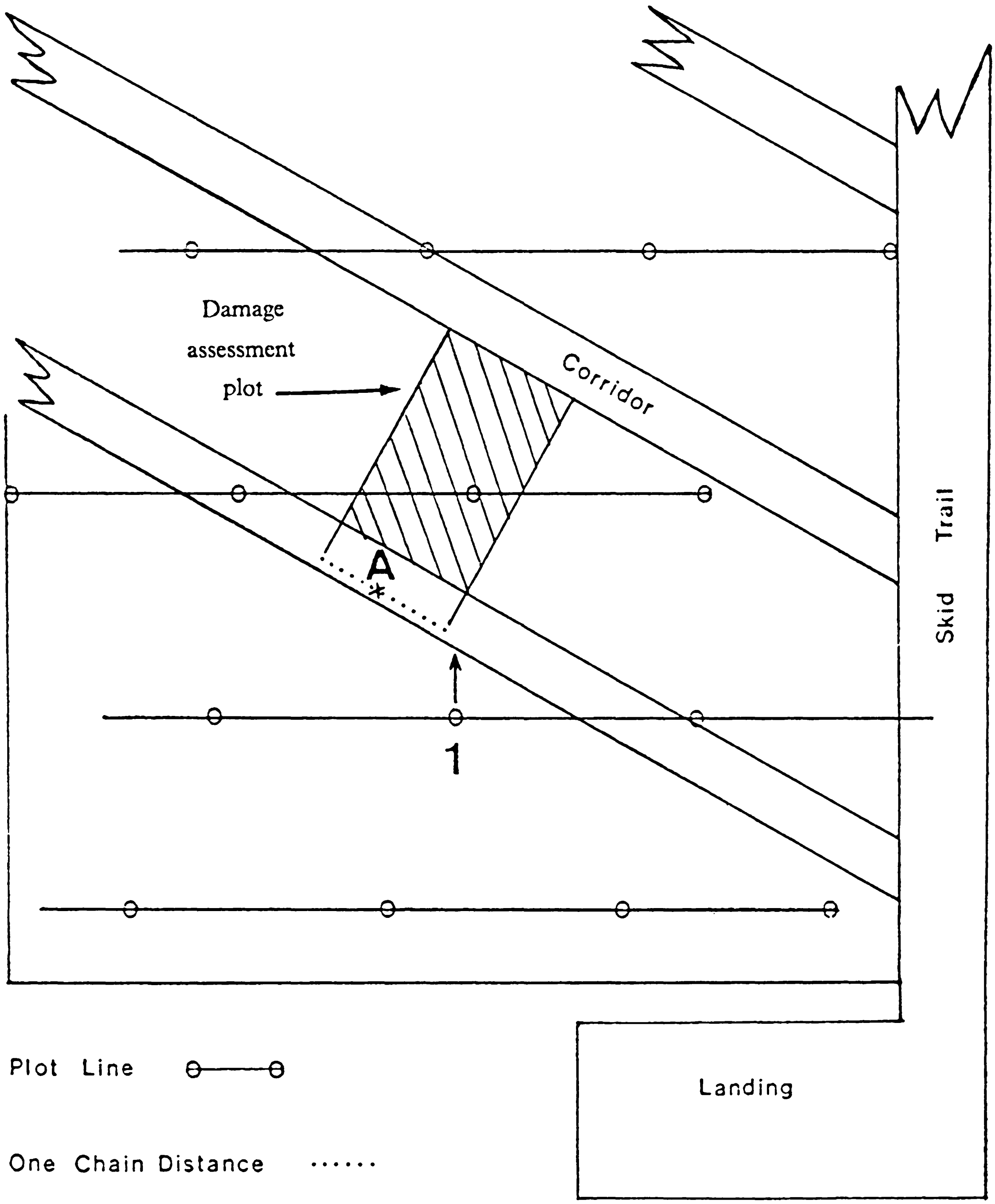

Figure 3. Example of the Relationship Between Timber and Damage Cruise Plot Locations

Results and Discussion

For clarity, the results of the analyses of the industry survey and the system studies are discussed separately.

Industry Survey

Of the 81 sets of surveys sent, 63 replies were received. Seventy eight percent of the respondents described operations which performed either thinning (48 percent), prelogging (8 percent), or both types of operations (22 percent). The remainder of the respondents did not conduct small-tree operations on their lands. The most prevalent system encountered consisted of rubber-tired feller-bunchers; rubber-tired, articulated grapple skidders; and hydraulic loaders (thinning) or whole tree chippers (prelogging), as shown in Table 4.

The numbers derived through the survey appear different than those from the survey discussed previously (Lanford, 1985) in which system types were roughly evenly divided between bobtail trucks, forwarders, and skidders. This is in part due to the fact that Lanford's survey was conducted mainly in the Deep South, where forwarders are more common than in other regions of the South. Responses to this project's survey were elicited South-wide. An additional criteria was that only information on systems deemed "successful" or "promising" by industry personnel was desired in this research rather than data concerning all thinning systems in use.

The small-tree operations predominantly produced tree length material, but those dedicated to prelogging produced whole tree chips. Hauling was mainly by trucks and trailers owned by the logger (86 percent) rather than by contract truckers (14 percent).

The average weekly production rates ranged widely across all system types and physiographic regions. The reported high was 760 cords per week (2000 tons) for a whole tree chipping prelogging operation in Alabama's Coastal Plain. The reported low was 50 cords per week for an operation that performed both thinning and prelogging in the Coastal Plain of Virginia.

Assumed capital investment, reported average weekly production, and crew size for each system were compared to average stand DBH to determine if system type was related to tree size. Because the survey data was used to identify systems only and because the quality of the data was uneven, statistical tests were not performed. Visual observation of the plots was felt to be adequate for the intended purpose of the survey results.

Figure 4 is the plot of capital investment against tree size. The high values on this graph represent whole tree chipping systems and the low values reflect motor-manual forwarder systems. The majority occurring between these extremes mainly depicts feller-buncher/grapple skidder systems. As seen in the plot, there is a slight separation of system types by capital investment level, but no predictable relationship between system type and tree size is apparent. Assumed machinery prices used for this plot are contained in Appendix B.

The diagram of weekly production versus DBH (Figure 5) reveals the same system type differentiation with whole tree chip systems in the high range and motor-manual forwarder systems on the low end. The largest portion of the systems, however, produced approximately 100 to 400 cords per week. Again, no reliable trend between system type and DBH is apparent.

Figure 6 is a graph of crew size versus tree size. Once again, no helpful relationship manifests itself. In this case, there is not even the system type separation observed in the previous plots.

Analysis of the survey results and consultation with the project sponsors resulted in a decision to conduct more in-depth studies of the most common system type (feller-buncher/grapple

Table 4. Survey Results-Equipment Types Used

Equipment Type	Number	Percent of Total
Felling		
Rubber-tired feller-bunchers	46	73
Tracked feller-bunchers	11	17
Chainsaw	6	10
Moving From Stump		
Grapple Skidders	77	94
Forwarders	5	6
Loading		
Hydraulic Loaders	40	82
Chippers	5	10
Manual	4	8

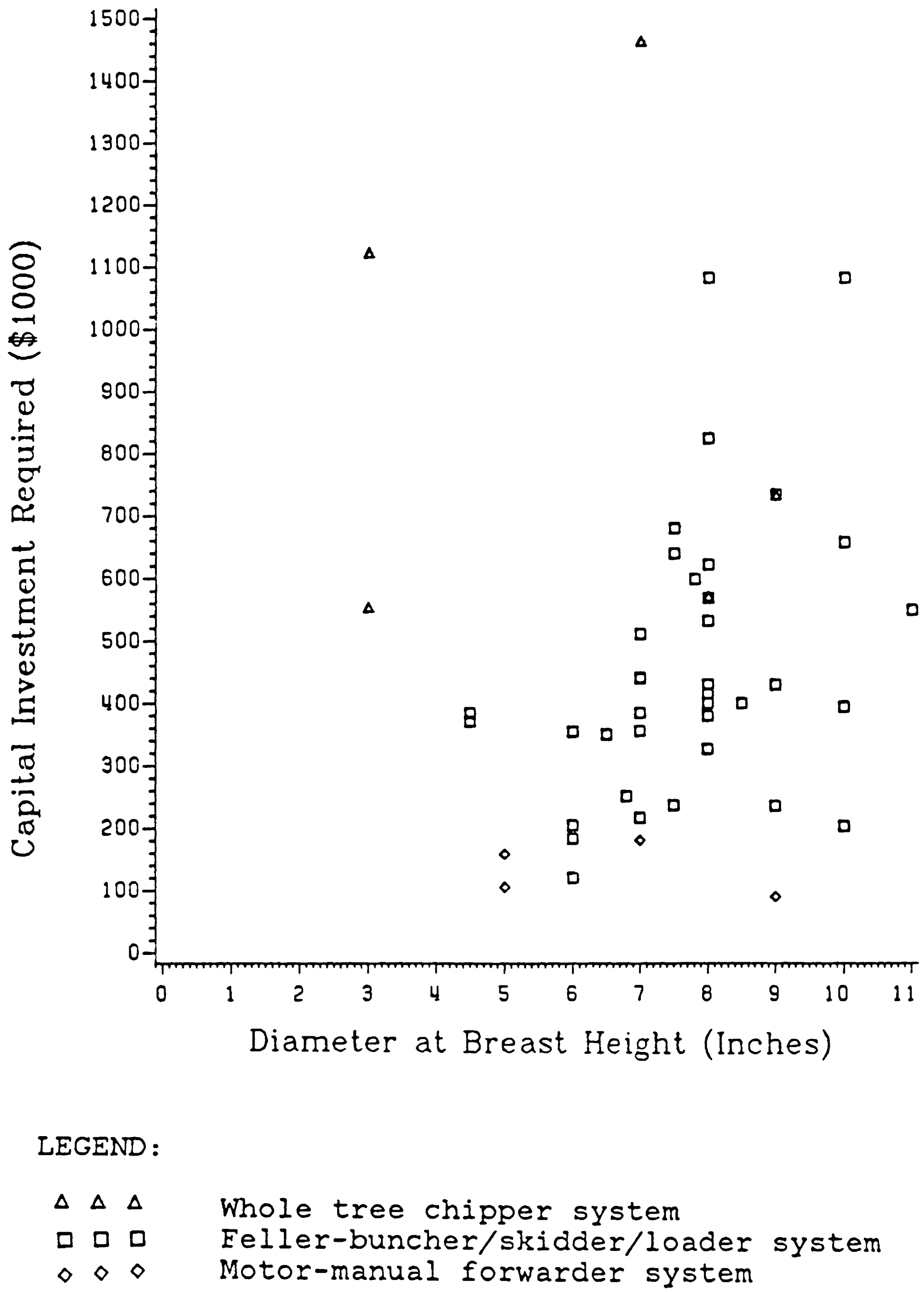

Figure 4. Survey Results-Assumed Capital Investment vs. DBH: Assumed capital investments do not include allowance for tools and spare parts.

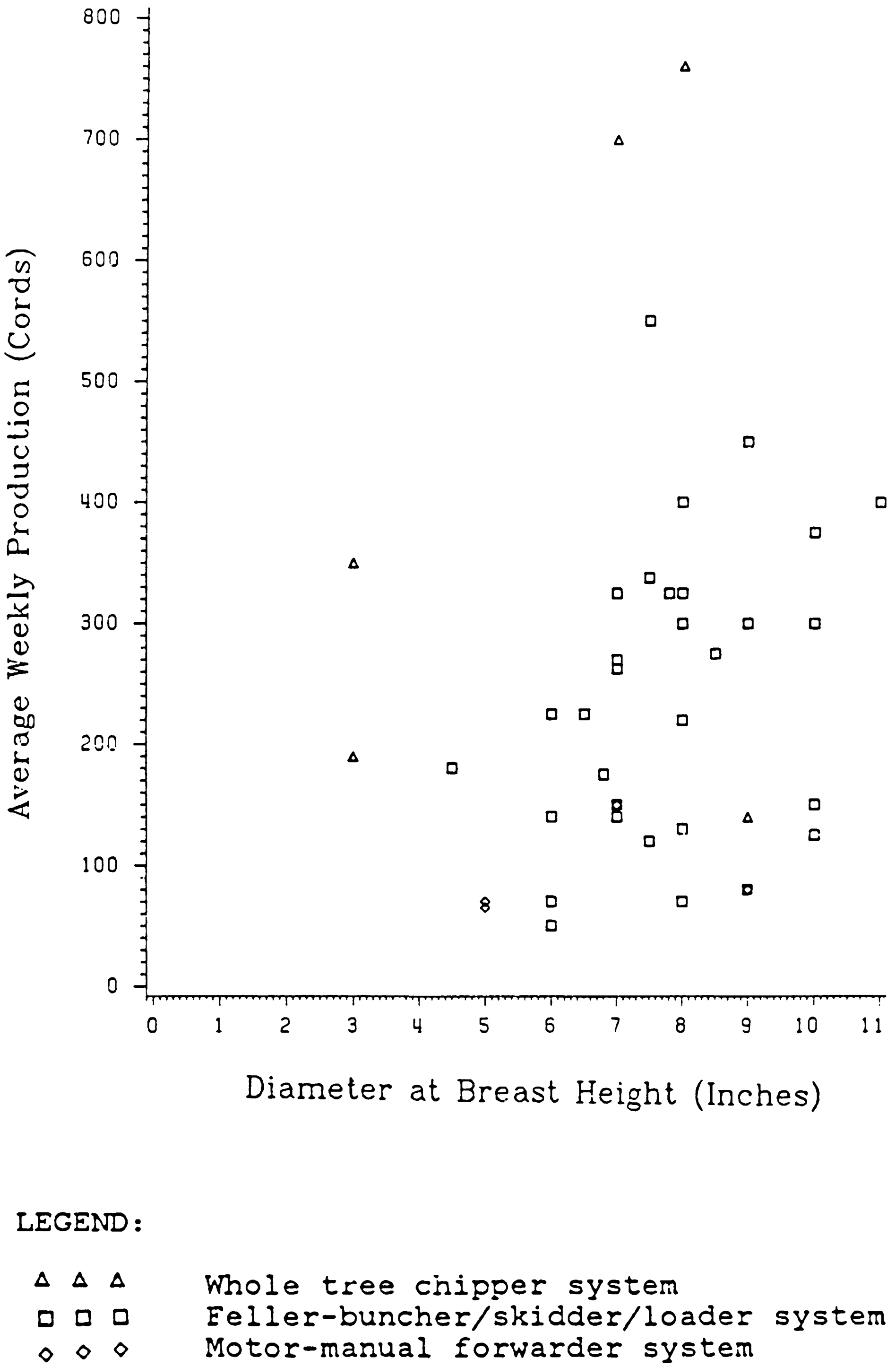

Figure 5. Survey Results-Average Weekly Production vs. DBH

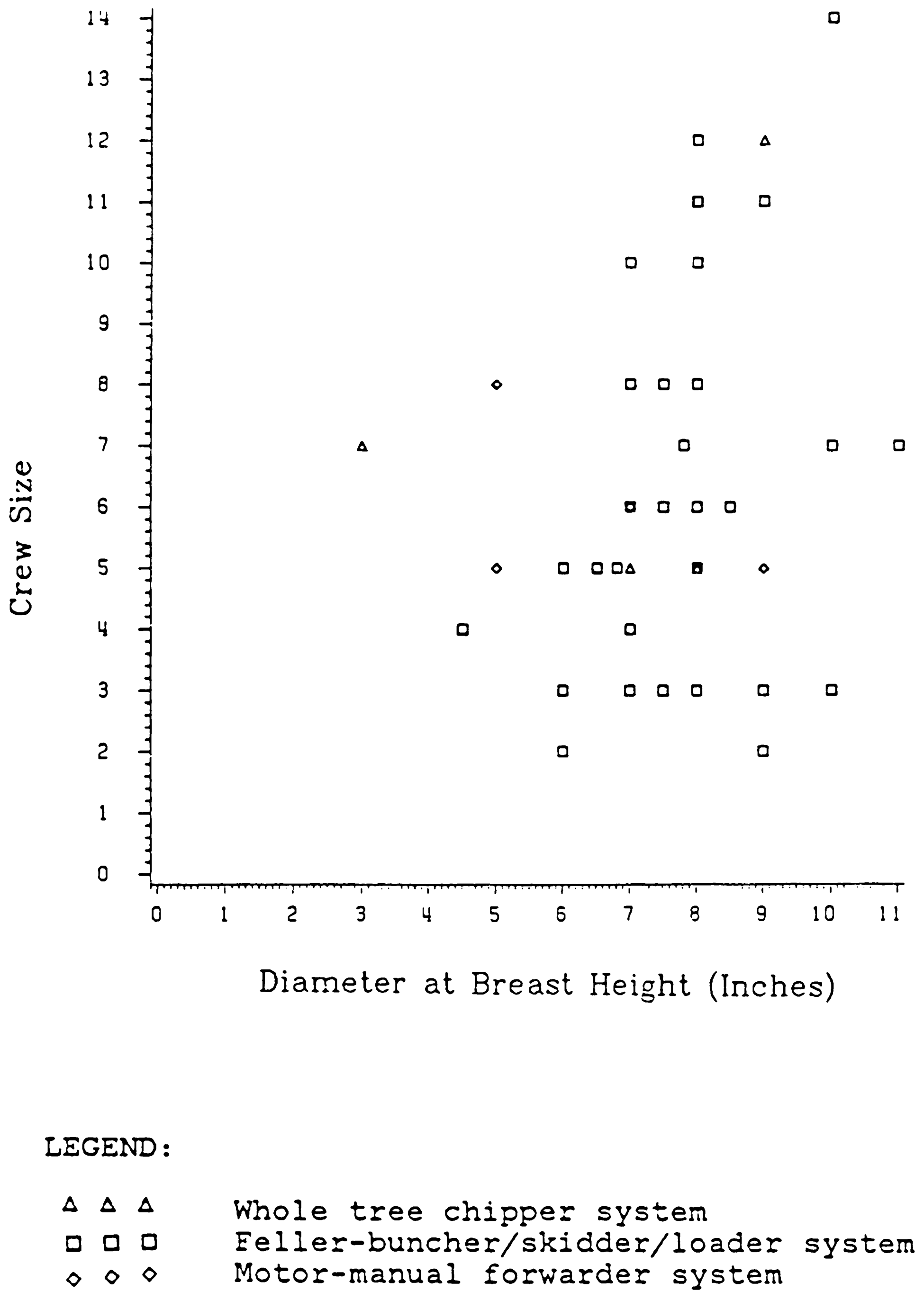

Figure 6. Survey Results-Crew Size vs. DBH

skidder/tree length hauling). These systems appeared to be the most widely applicable, most compatible with current markets, and required capital outlays achievable by independent contractors.

System Studies

Six feller-buncher/grapple skidder systems were selected for observation. These operations were chosen to be used as role models for contractors attempting to set up successful thinning/prelogging systems. Three of the observed operations were conducting thinnings, two were prelogging and producing tree length material, and one was prelogging and producing whole tree chips for energy.

Information was obtained pertaining to job history and operation, productivity of individual machines and systems, and residual stand damage of thinning operations. The field studies looked beyond simply equipment efficiency to system characteristics contributing to the operations' success. Abridged descriptions of the systems follow. For more detailed descriptions of the individual operations, see Appendices E through J.

System A

System A was a sole proprietorship which had been performing both thinning and prelogging operations for 15 months at the time of study. The material produced was tree length pulpwood, predominantly pine. The system spent the majority of time prelogging in the Upper Coastal Plain of Virginia, although thinnings were occasionally performed. The system operated in natural stands and plantations averaging four to eight inches DBH. When studied, the job was prelogging in a 30-year-old natural stand consisting of loblolly pine (*Pinus taeda* L.), with small amounts of Virginia pine (*Pinus virginiana* Mill.) and mixed hardwoods.

Figure 7 illustrates the material flow and crew organization. The feller-buncher was purchased new when the job started, while both the skidder and loader were bought used. The crew consisted of the owner and a hired operator, although there had been as many as four crew members in the past.

The feller-buncher opened a tract by cutting swaths through the stands starting at the deck and moving outward radially. Merchantable pine from within and between the swaths was cut and piled with the butts facing the landing to aid skidding. Hardwood stems of sapling size and larger were cut and piled to remove obstructions to travel and reduce the likelihood of hose damage. This practice invariably decreased felling productivity, but may have been partially compensated for by occasional delivery of the pulpwood-sized hardwoods to the yard. The bunches were moved by grapple skidder to the delimbing area adjacent to the landing, gate delimbed, and dropped near the loader. Wood was inventoried on the deck until the haul truck returned, at which time skidding ceased and the skidder operator moved to the loader.

Production averaged 92.1 cords per 35 to 40-hour week for the 10 months reported. The variation in weekly productivity is shown in Figure 8. After a high reached at the beginning of the year, production fluctuated very little on a week-to-week basis. However, productivity appears to be decreasing slightly over time rather than increasing with experience in small-tree harvesting. The forester contracting for this operation noted that system production was mainly constrained by quotas (120 to 150 cords per week) in the summer and by weather in the winter.

Trucking was well-coordinated with job productivity to minimize landing space and truck turnaround time. The 10-mile haul distance allowed for relatively fast turnaround time, even though the trucker hauled for another job before returning.

The timber owner built and maintained landings and roads for the operation, eliminating the need for the owner to purchase construction equipment while keeping the roads maintained to acceptable standards for contract truckers. The contract truckers in the area were not particularly eager to haul from the woods because of excessive wear and tear on their vehicles in comparison with over-the-road hauling. It was not determined if the contract rate for pulpwood was affected

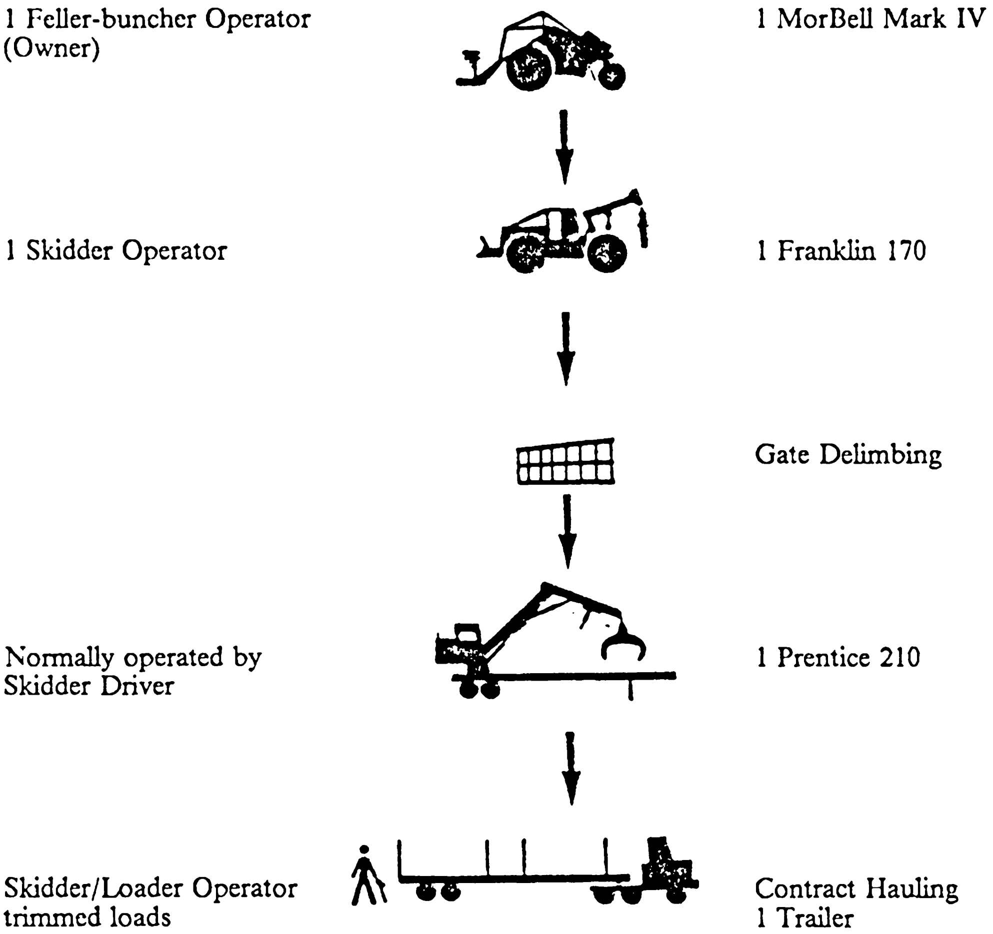

Figure 7. System A Material Flow and Crew Organization

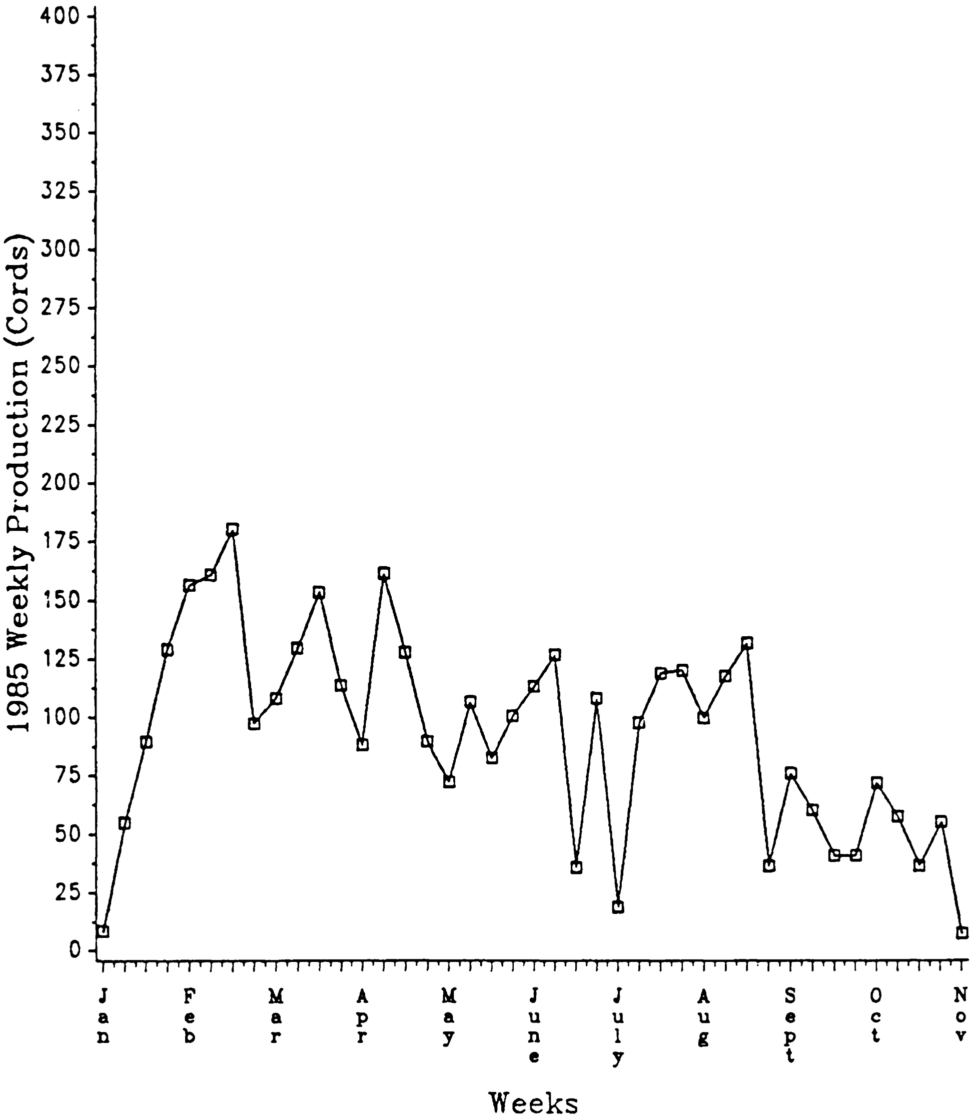

Figure 8. System A Weekly Production

because of the road and deck building service. The company purchasing wood also provided boundary marking in the stands and handled wood procurement activities for the contractor.

Labor turnover had been a problem for this crew. A reason for the high turnover was the incidence of chainsaw accidents while trimming on the landing or on the truck. Even though all crew members received safety training and safety equipment (hard hats, ear and eye protection) was required, injuries were fairly common.

The yard allowed trailers to be loaded butt-to-top. Although this practice would have increased load size, it was not done. The owner believed that butt-to-top loading would detain the haul truck at the landing for too long.

System B

System B, also a sole proprietorship, had been thinning for 18 months in Virginia's Piedmont region. The system normally operated in industry-owned pine plantations producing tree length pine pulpwood. At the time of study, the job site was located in a 19-year-old stand which averaged 8.3 inches DBH before thinning.

Figure 9 shows System B's harvest flow and the layout of the five-man crew. The feller-buncher was bought new when the job started. All other equipment on the operation was purchased second-hand.

The thinning technique used in this operation consisted of first clearing the main skid trail marked by the landowner. Next, corridors were cut about 60 feet apart in a herringbone fashion from the main skid trail. When the corridors had been cleared, the area between was thinned with the feller-buncher operator selecting trees for removal. The bunches were skidded to the landing, where they were gate delimbed, then brought to the loader. Trimming of remaining limbs was conducted by the deck man or truck driver.

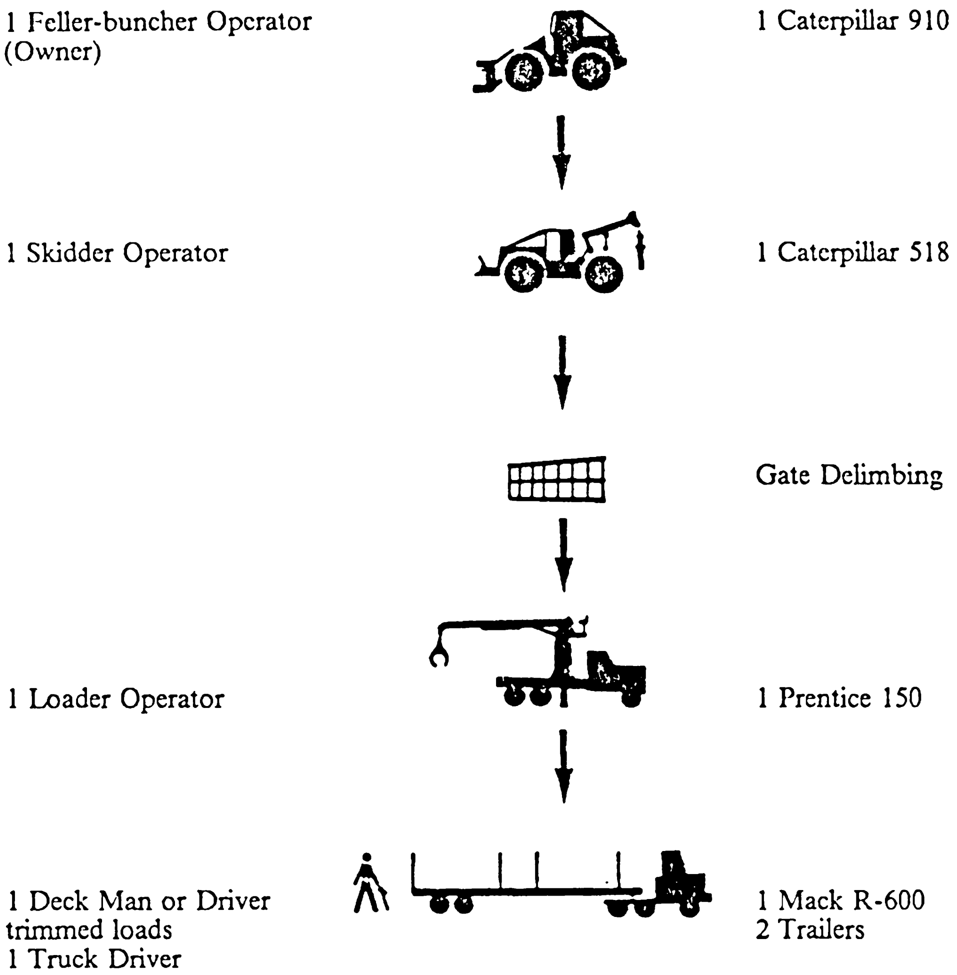

Figure 9. System B Material Flow and Crew Organization

System B's average production had been 105.9 cords per 30 to 50-hour week over the prior nine months. Weekly variation and a 1.5 to 2-month cyclical production trend is shown in Figure 10. Missing data points represent weeks when the system was clearcutting.

Several considerations affected the performance of the system. Allowances at the woodyard for butt-to-top loading permitted large load size on the haul truck (load tally average of 30.38 tons). An average of over 30 tons per load exceeded the gross vehicle weight (GVW) limit and possibly the legal height limit in Virginia. On short haul distances, the owner was willing to take the risk of overweight fines.

The landowner marked main skid trails and boundaries, constructed decks, and built and maintained roads for the operation. Again, it was undetermined if these services performed by the landowner affected the contract rate received for pulpwood. Also, the company occasionally offered clearcuts to the contractor to boost productivity.

A quota was imposed on weekly system production, but had not been strictly enforced in the past. However, as the company receiving the wood moved more loggers into the area, their production capability increased and enforcement of the quota became more stringent. The owner offered pay bonuses as a production incentive to the crew. When he could afford to, he would supplement their wages when production levels exceeded 20 to 25 loads per week. This practice was discontinued as the quota became more inflexible.

Several crew members could perform each job in the operation. Therefore, absenteeism, although not common, did not present a problem. The crew was a tight-knit group and had no difficulties with assuming additional tasks as required.

System C

System C was the only shortwood thinning operation studied. The owner, a sole proprietor, ran several other types of harvesting operations, a trucking service, and a chainsaw dealership. The operation had been thinning mostly industry-owned plantations for 10 months on the boundary

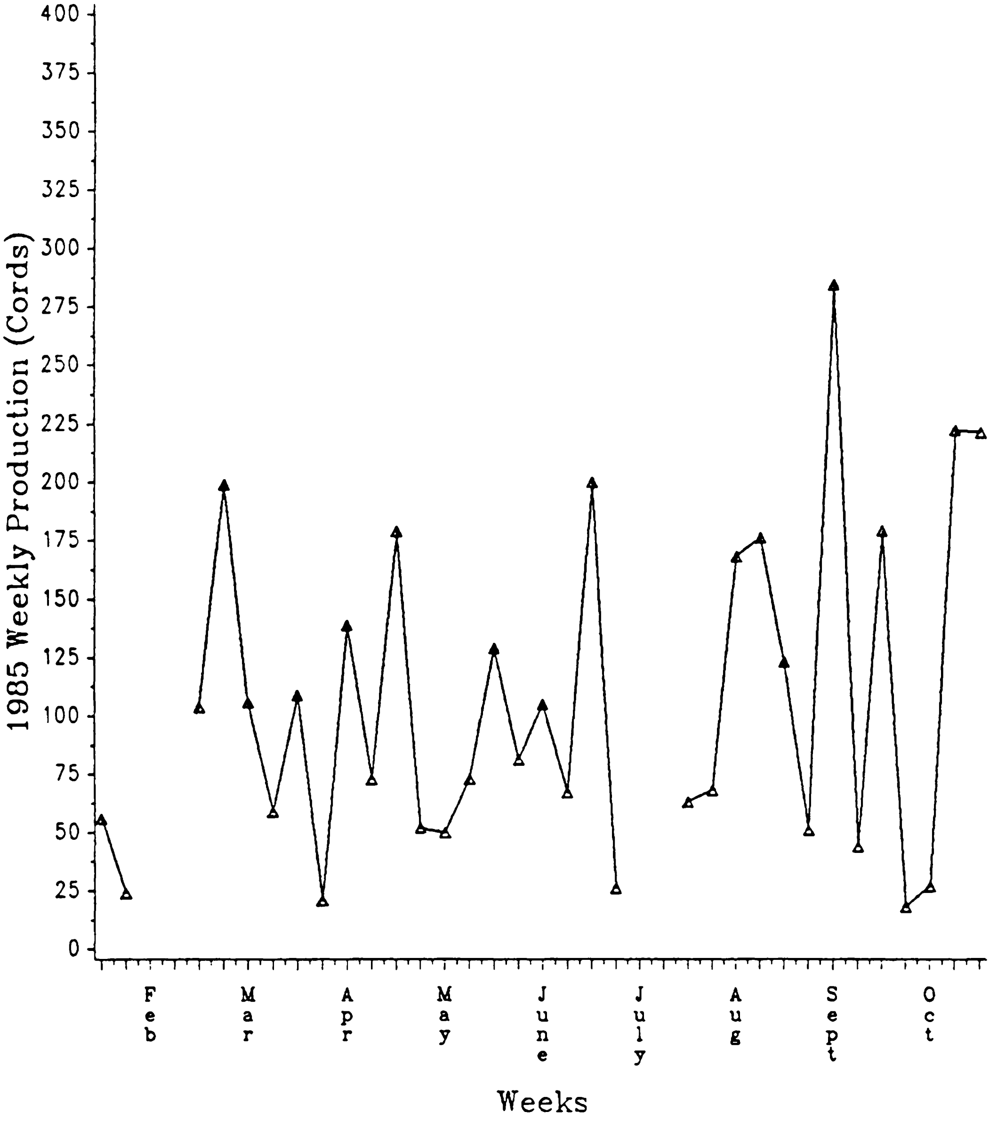

Figure 10. System B Weekly Production

between the Piedmont and Coastal Plain regions of Virginia and North Carolina, but also operated in privately-owned natural stands. The usual stands averaged about seven inches DBH. During the study, the operation was in a loblolly pine plantation averaging 6.5 inches DBH, slightly smaller than normal. In addition, the stand contained a moderate to heavy hardwood understory.

Figure 11 depicts the wood flow and crew composition of System C. The skidders and loader were purchased new for operation. All other equipment came from the owner's other operations. This crew, formed from a portion of a larger logging crew, consisted of from seven to nine people depending on the number of trucks required. At the time of study, eight members formed the crew.

The boundaries of stands to be thinned were marked by the timber owner. The contractor constructed decks and roads, when necessary, with a Fiat-Allis 10-B dozer assigned to this operation. Crew construction allowed placement and formation of decks to improve the operation. Decks and roads were kept clear and level with the dozer, although the timber owner would provide rock for roads if needed.

Where feasible, every fifth row was removed to begin a thinning operation. In tightly-spaced stands, natural stands, or when rows followed contours, 15 to 20-foot corridors were cut through the stand and spaced 30 to 35 feet apart to simulate a fifth row removal. Corridors were cut by a Franklin 105 with a directional shear. When the corridors or rows had been cut, selection between them was accomplished by a Franklin 105 with an accumulating feller-buncher head. The operator decided which trees to harvest. Under normal conditions, the bunches were manually delimbed in the corridors. If the bunches were laid down in a hazardous position for limbing, they were skidded to an intermediate deck first. Following delimbing, the bunches were skidded to the primary deck where they were bucked to five-foot lengths by a chainsaw slasher and loaded onto set-out trailers.

The crew usually reached their quota of 25 to 30 loads per week in 4 to 4.5 days (40 to 45 hours). Average productivity over the previous 10 months was 262.3 cords per week, as shown in Figure 12. After a one-month start-up phase, production became relatively stable. Fluctuations in quotas may account for the higher production rates observed in the fall and winter.

The mill contracting the operation was equipped to handle only shortwood. The owner saw this as a drawback, but it did allow the 10-cord capacity of the trailers to be more fully utilized when

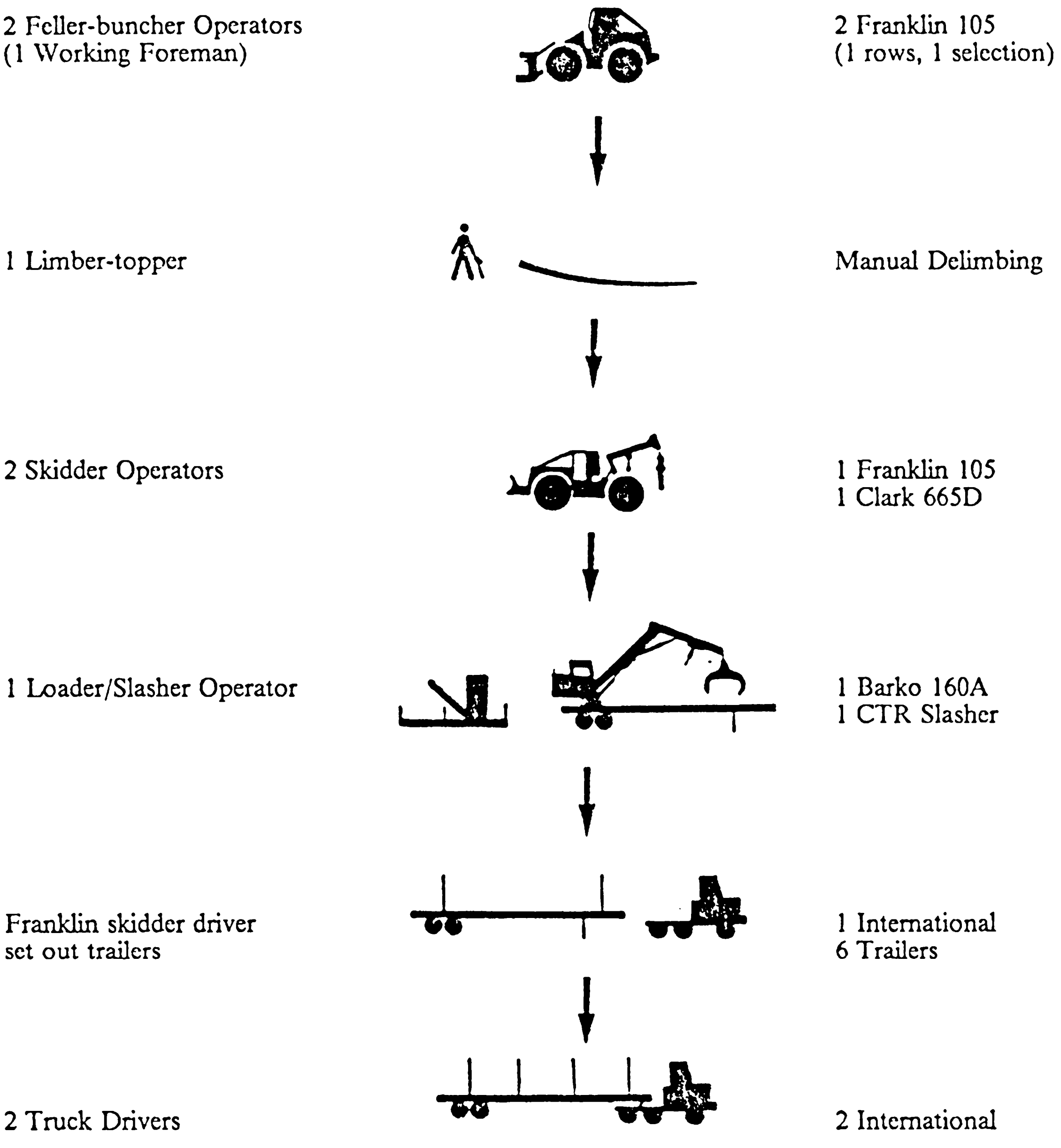

Figure 11. System C Material Flow and Crew Organization

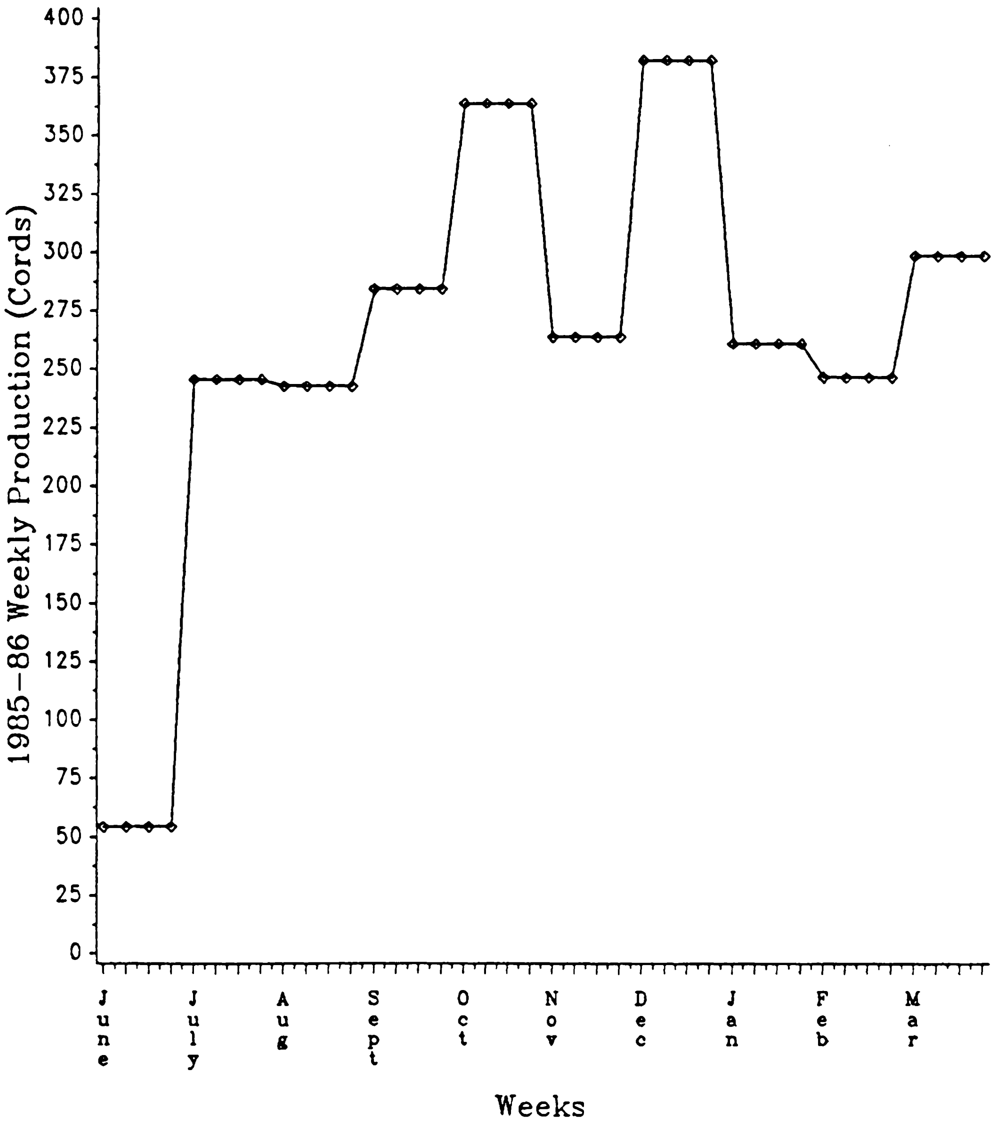

Figure 12. **System C Weekly Production:** Reported monthly production was transformed to weekly averages.

handling small trees than with conventional tree length loading techniques. The additional loading capacity was especially advantageous on longer hauls such as the 70 miles to the mill during the study.

Eagerness to learn and willingness to work were used as hiring criteria by this contractor, rather than harvesting experience. Hence, job turnover was very low in his crews. Nearly every crew member had worked for the owner on other operations prior to joining this crew.

The owner's operating philosophy was to accomplish a job that looked good first, then to work on increasing production. He felt that this led to good public relations. In fact, several industry personnel described stands thinned by this crew as looking "like a park." An attempt was made to remove all trees incapable of producing a good sawlog. Fewer trees may have been left than with other operations, but those that remained were usually the best trees.

Small pines, those not containing a 3.5-inch small end diameter stick, and all hardwoods were knocked down. This practice was time-consuming, especially in stands with large hardwood components, but was consistent with the owner's thinning philosophy.

Deliveries to the mill were consistently constrained by quotas. Paying the crew by the load served as an incentive to keep production at the quota level. Therefore, if the quota was met before the end of the work week, the crew could take the remainder of the week off while still receiving the same take-home pay.

System D

System D was a prelogging operation under the same owner as System C, a sole proprietor, which had been working with small trees for four years. Tree length pulpwood, mostly pine, was produced. The operation was located mainly in the Upper Coastal Plain of Virginia, but occasionally would move closer to the owner's headquarters and prelog in Virginia's Piedmont region. The system operated in both plantations and natural stands. At the time of study, the crew was in a 28-year-old stand of mixed natural and aerial-seeded origin with a moderate hardwood understory.

Pine in the stand averaged 7.4 inches DBH and commercial hardwoods averaged 8.8 inches DBH prior to harvest.

Figure 13 depicts System D's material flow and crew layout. All equipment was bought new for this system. The crew consisted of eight men who were drawn from throughout the owner's other crews.

The contractor's Fiat-Allis 10-B dozer was used to build roads and decks, when necessary. Cutting began at the deck and moved radially outward to boundaries marked by the timberland owner. The feller-bunchers moved through the stand harvesting all timber capable of producing a 12 to 15-foot stick with a 3.0-inch small end diameter. Trees up to nine inches DBH plus any crooked nine to ten-inch trees without a good 16-foot log were cut. Trees below the minimum specification were run over. Each skidder followed one of the feller-bunchers and dragged the felled material through the stand. Since the residual stand was to be removed in a second pass following prelogging, moderate bark removal damage was acceptable. Clumps of trees were left in the stand and the skidders backed their loads through the clumps, breaking off many of the branches to aid the limber-topper. The bunches were skidded to an intermediate deck for manual limbing and topping. After dropping a partially delimbed bunch at the intermediate deck, the skidders picked up a completed bunch and dragged it to the main deck for loading.

The crew normally worked 45 hours a week in producing an average of 272.0 cords per week over the prior six months. The reported production for that time period had been fairly consistent, as illustrated in Figure 14. This is probably a function of the crew's relatively long experience with small trees (four years) and minimal interference from quotas.

The mill receiving the wood was equipped to handle material loaded butt-to-top. Normally, full loads could be achieved with butt-forward loading only. Shorter material was separated and cold decked until a truckload of material requiring butt-to-top loading was accumulated. The loads were moved over the 47-mile haul by two contractor-owned tractor-trailers.

This operation parallelled System C in that the crew was paid on a per-load basis and several crew members were cross-trained for each task in the operation. They were an aggressive, tightly-knit work force who took pride in the appearance of their work.

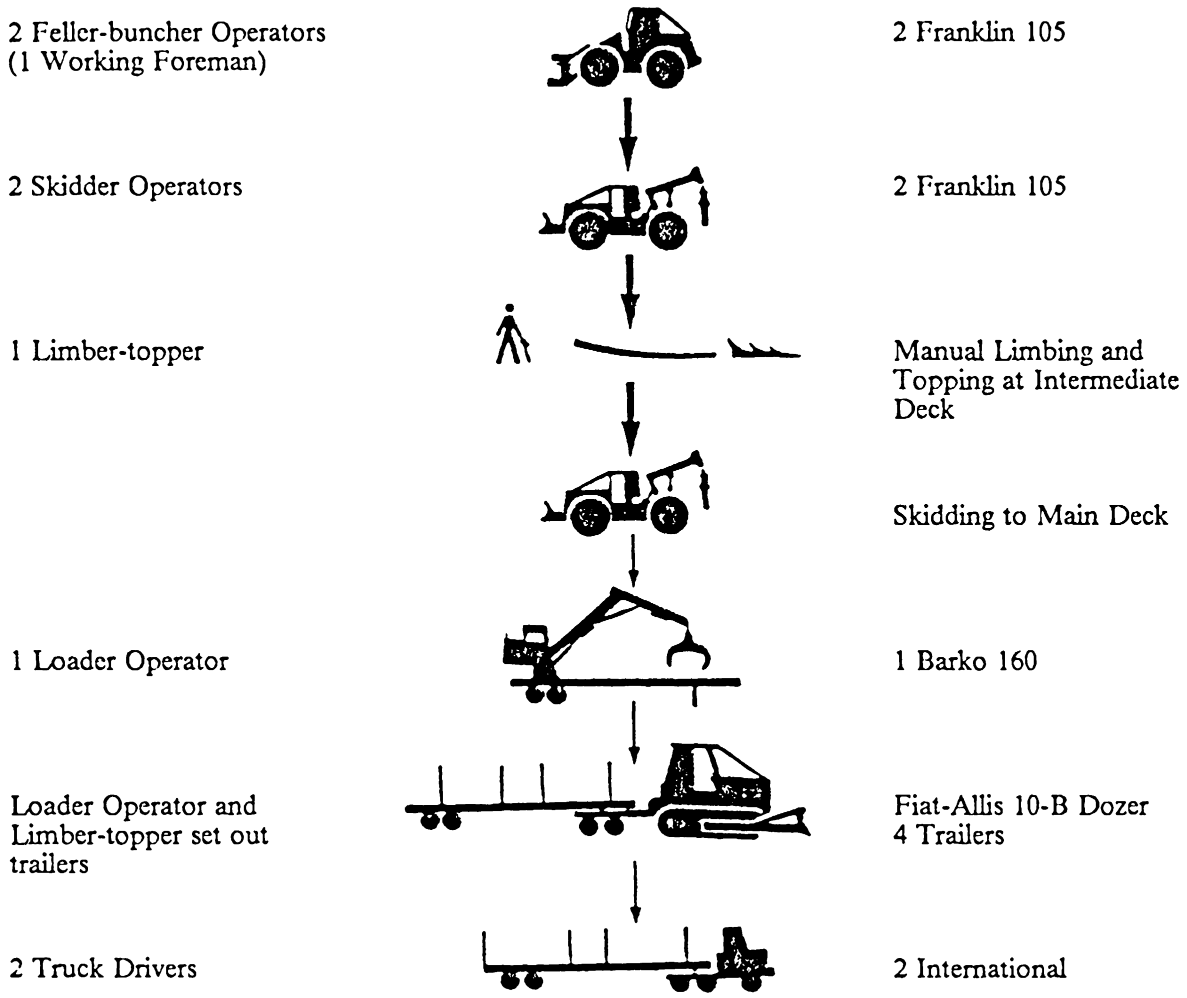

Figure 13. System D Material Flow and Crew Organization

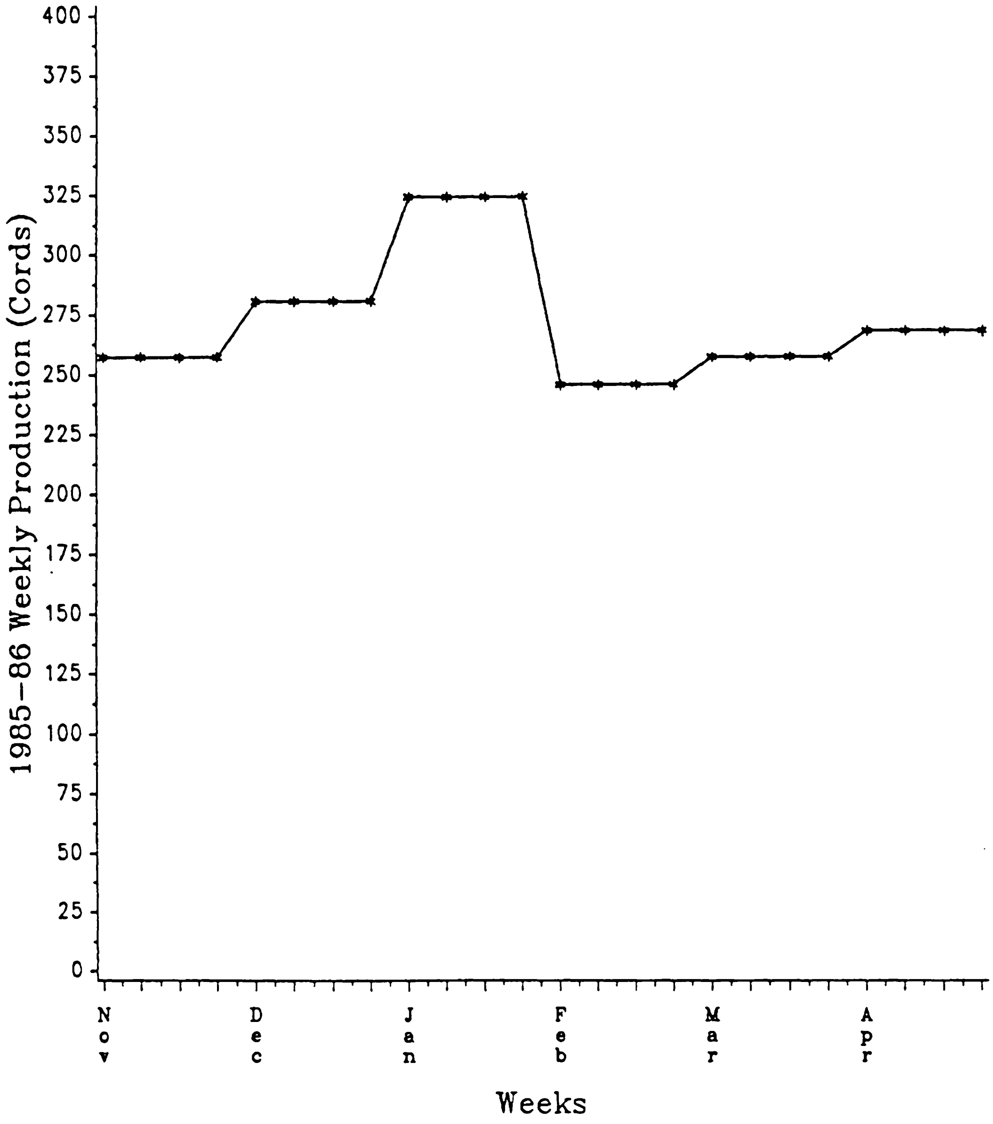

Figure 14. System D Weekly Production: Reported monthly production was transformed to weekly averages.

System E

System E, the only operation owned by a wood dealer who also leased equipment to four independent contractors, had performed thinnings for 16 months in the Lower Coastal Plain of South Carolina at the time of study. The operation usually produced tree length pine pulpwood from industry-owned plantations, but would contract for thinnings on private lands occasionally. The tract thinned during the study was similar to the previous four sales which averaged 7.8 inches DBH and 19.5 years old when thinned.

Figure 15 shows the wood flow and crew organization of System E. The feller-buncher and skidder were purchased new for the operation, the loader was bought used from the mill. The owner did not take an active role in job management, leaving this to an associate and a working foreman. At the time of study, the system consisted of three men and a contract trucker. However, the owner was attempting to hire a fourth man to relieve the foreman of operating responsibilities.

Boundaries and skid trails usually were not marked for this operation. The timberland owner, however, would build and maintain roads and decks, when necessary. The main skid trail was cut perpendicular to the rows to initiate a thinning. Next, two or three corridors were cleared on 30 to 50-foot centers at an obtuse angle to the skid trail and the rows. Operator selection was conducted between the corridors, removing only small and poorly-formed pines to confrom to the company's basal area per acre thinning prescription. This process was continued until the stand had been thinned. An attempt was made to run over or cut and leave hardwoods. The bunches were skidded to the edge of the deck, gate delimbed, then dropped near the loader where final trimming was done with a chainsaw. The deck man cold decked material to keep the skidway clear until the contract trucker returned, at which time the trucker loaded his own loads. The skidder would pick up a grapple load of the residues which had accumulated around the gate and slowly release them as it travelled back through the stand. The owner believed that this practice lessened the site impact of the harvesting activities. The 27-mile haul on company, county, and state roads allowed the trucker to keep pace with job productivity.

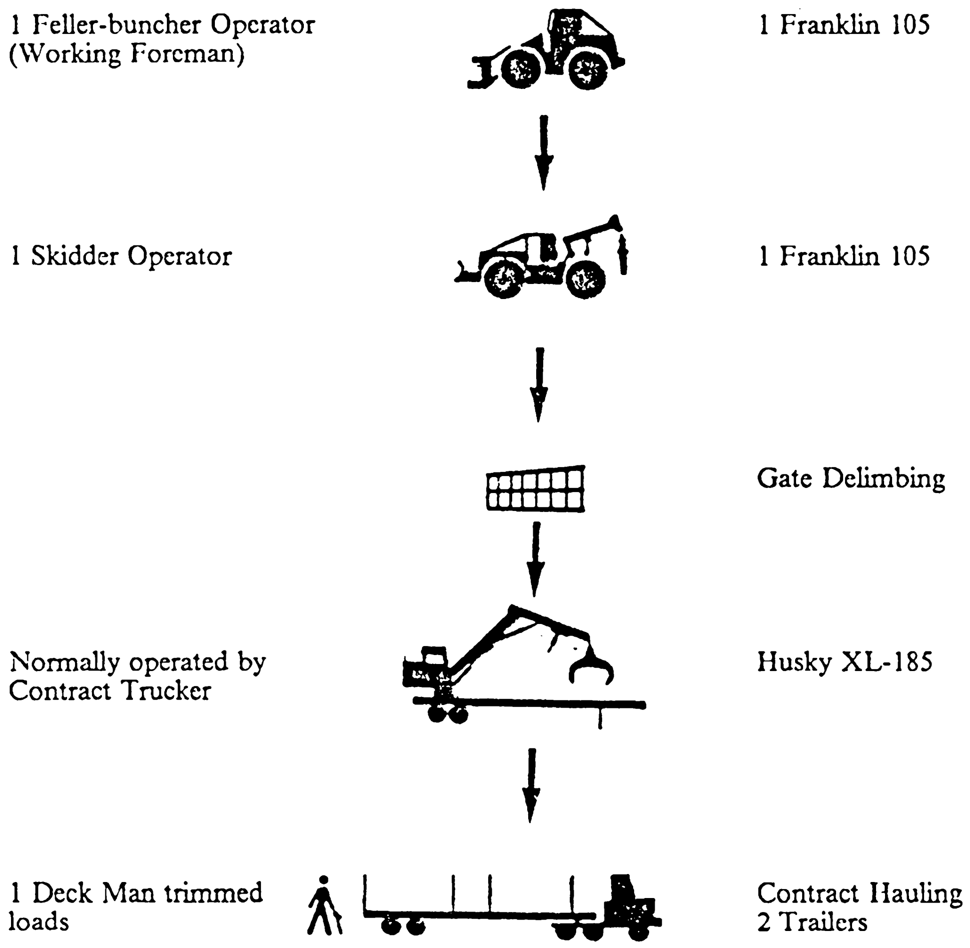

Figure 15. System E Material Flow and Crew Organization

The crew worked 40 to 45 hours per week producing an average of 133.6 cords per week over the six months preceding the study, as shown in Figure 16. Missing data points represent weeks shut down or performing other harvests. Production increased through the summer, then declined during the fall.

The owner had a good, long-established business relationship with the timberlands and mill divisions of the company. He had owned a contract trucking company moving wood from outlying yards to the mill before establishing his wood dealership. In fact, the corporation had encouraged the owner to enter into the dealership and was very interested in the success of his small-tree harvesting endeavors. Flexibility was granted through relaxation of minimum diameter limits, absence of quotas, and a thinning budget of 5000 acres per year.

The working foreman (feller-buncher operator) and skidder operator were drawn from the owner's previous trucking and lawn and garden businesses. The contract trucker serving this job also had been employed on the owner's trucking operation. Only the deck man was hired specifically for this thinning operation. The owner looked for integrity and a desire to work in the person when hiring crew members or contractors. Previous harvesting experience did not carry much weight. He preferred a person with little or no harvesting experience over someone who had worked extensively in a high production-oriented operation. He felt that an inexperienced crew member could be trained from the start to thin stands in an appropriate manner, whereas a person with previous experience on a clearcutting system had difficulty in changing old habits. Again, this was a tightly-knit group who took great pride in their work. Crew members were also cross-trained so that each piece of equipment had at least two capable operators.

System F

System F, one of a number of company whole tree chipping wood energy crews for a large southern forest products corporation, had been prelogging in the Coastal Plain of Alabama for six years when studied. The system operated in both natural stands and plantations with time divided

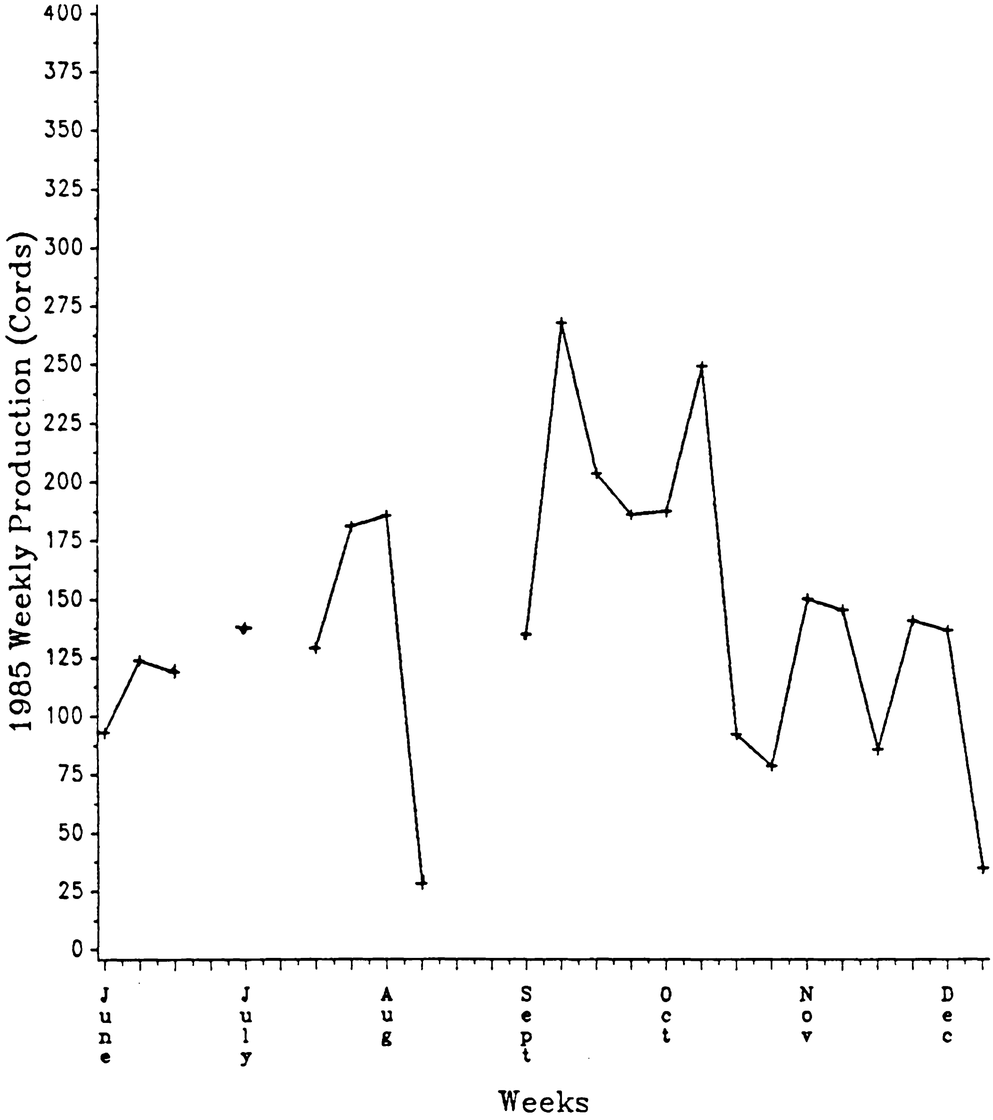

Figure 16. System E Weekly Production

evenly between company and private lands. During the study, the operation was in a privately-owned 20-year-old natural stand of mixed pine and hardwood.

System F's material flow and crew composition are represented in Figure 17. All equipment was purchased new for this operation. The crew itself consisted of seven men plus one company truck driver and two contract truckers. Trucking capacity varied with haul distance.

A company unit manager was responsible for job scheduling, harvest preparation, and procurement activities for the crew. A harvestable volume of 22 to 23 tons per acre (8.7 to 9.3 cord equivalents) was quoted by the unit manager as a minimum for System F to operate efficiently. Below this limit, the feasibility of harvesting a stand was at the discretion of the unit manager, the feller-buncher operators, and/or the foreman. When conventional pulpwood was bought from a private timberland owner, a separate bond was written to obtain the energy wood at no additional cost, if the owner was agreeable. The private landowners were usually willing to allow removal of small and malformed trees and brush since it cleaned up the stand and could decrease site preparation costs.

When necessary, roads were built in the tracts by a separate company crew. The feller-bunchers opened stands by cutting swaths from the road to the back boundary, removing all stems between one and eight inches DBH and assembling large, single grapple load bunches for subsequent skidding. Most brushy material was removed during felling and much of it was sent through the chipper, also. An attempt was made to keep the feller-bunchers about a week's work ahead of the skidders. This was impossible during the study, however, since two of the three feller-bunchers were not operating.

The chipper was moved roughly twice a day to hold skid distances to a minimum (an average of about 400 feet). The grapple skidders were closely coordinated with the chipper and transported previously assembled bunches through the stand. However, the bulkiness of the brushy bunches sometimes forced the skidders to be held up at the chipper until enough room was cleared for them to drop their loads within reach of the boom.

A set-out system of two Internationals was used with the nine vans serving the operation. As a van was loaded and set out by one chipper operator, the other operator parked the next van by

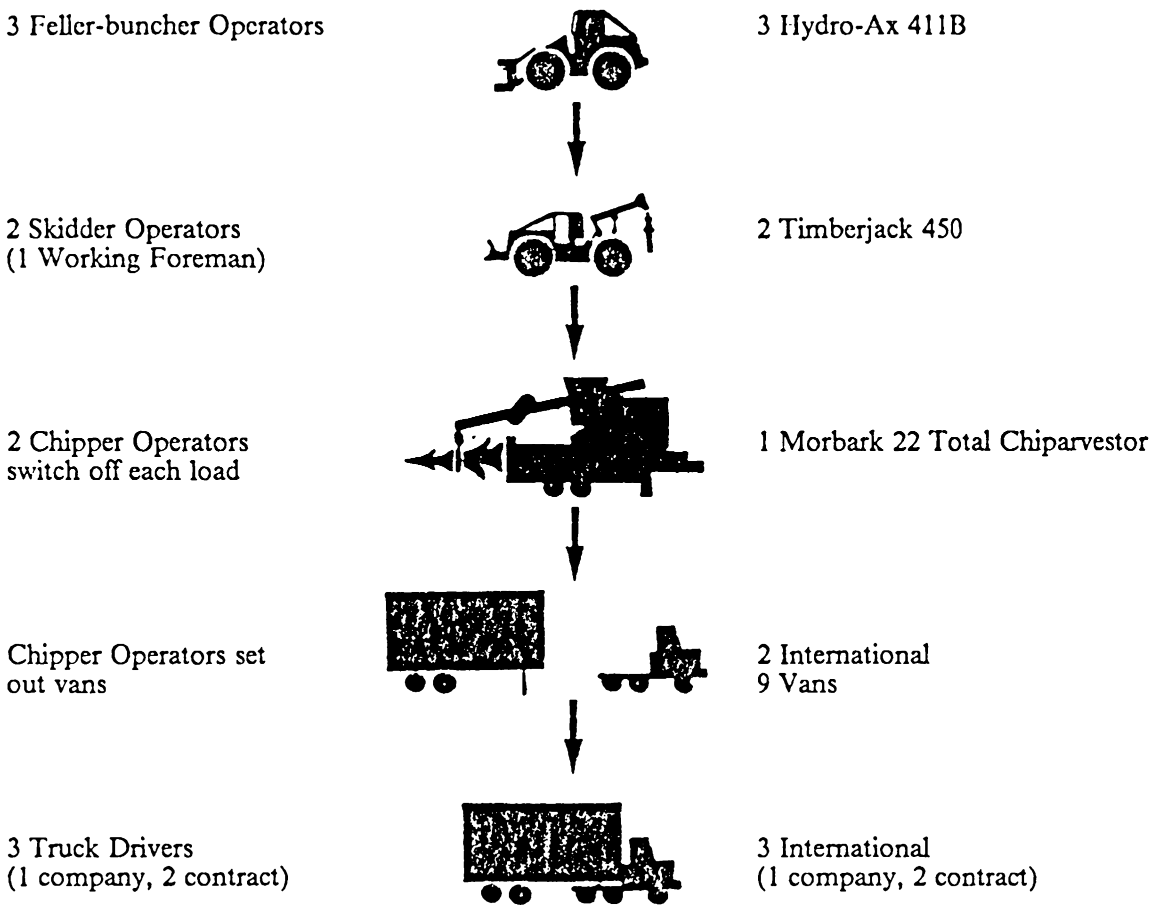

Figure 17. System F Material Flow and Crew Organization

the chipper and began loading. With this method, the chipper was in operation almost constantly, barring down time, and the operators got a break between loads.

Woods-loaded haul trucks which did not travel on interstates were allowed 88,000 pounds GVW in Alabama, a situation which would be expected to decrease trucking costs per ton-mile relative to the other systems studied. This permitted the crew to load to an average GVW of 80,000 pounds during the study. Normally, however, the average GVW was 4000 to 6000 pounds more.

The unit manager was not comfortable disclosing exact production figures. He did, however, report that System F had produced an average of 1000 tons per 45 to 50-hour week for the prior six months.

System F was the only operation studied in which safety awareness was an integral part of the job. All crew members received Red Cross first aid training and were required to wear hard hats, ear protection, and hard-toed boots. There were no chainsaws on the job and every crew member was inside the cab of a piece of equipment rather than on the ground.

Unlike the other systems studied, the crew members in this system were trained for only one piece of equipment in the operation. Each person performed his own mechanical work rather than one member acting as crew mechanic. The virtually non-existent job turnover within the energy crew was attributed by the unit manager and foreman to the high wage rate paid to crew members. The group did not seem to be as tightly knit as in the other systems studied. This may be because the crew members were employees of a large corporation rather than a small business. They were, however, proud of the appearance of their work and were able to work together very efficiently.

Comments and Observations

Responses of the equipment owners and operators indicated that they were generally satisfied with the concept and design adequacy, safety and comfort considerations, and maintenance and repair considerations of their machinery. Table 5 lists the most common suggestions for equipment improvement. Most equipment operators, especially the skidder operators, desired closed-in cabs (i.e. removable plexiglas plates inside the wire cage) for added protection from entry of foreign material and vapors. Not surprisingly, all operators would have preferred air conditioning in their machines. Virtually all the operators noted that their equipment lacked a temperature guage and/or low oil level warning in the hydraulic systems. Other suggestions were concerned mainly with difficulty in accessing service points, excessive vibration and noise, improvement of seat design, and increased protection of hydraulic hoses and wiring. Several feller-bunchers had modifications, usually to the felling head, to satisfy the operators' perceived needs in their normal operating environment.

Crew characteristics are compared in Table 6. Crew size (excluding hauling personnel) ranged from two to seven. The small crew sizes seemed to promote a sense of comraderie and pride in work among the members. The crews were composed mainly of people under 35 years old. No system had a crew member less than 20 years old and four of the six systems had at least one member over 45 years old. Median ages ranged from 24 to 34. All crews employed a working foreman/supervisor.

Even though some systems had relatively low median years of harvesting experience, all crews had at least one member who had spent at least 15 years in the woods, with the exception of System A. These people were not necessarily foremen. In fact, often they were other men with the ability to fill in for any equipment operator on the crew when needed.

Comparing system longevity and the time that individual workers had been with the crew indicates that turnover was relatively low on these jobs. Each operation had at least one member who had been on the crew when it originated. Both the mean and median values of time with crew are at least 70 percent of system longevity. Crew members, therefore, knew what was expected of them in the operation and were familiar with the work habits of the others. These values are lower for System D because of movement of crew members among the owner's other operations.

Years of harvesting experience is broken down by job type in Table 7. Forty percent of the feller-buncher operators, 33 percent of the skidder and loader operators, all of the limber-toppers, and none of the deck men had less than five years of harvesting experience. Extensive years of experience need not be prerequisite to efficient operation within a small-tree harvesting system. The

Table 5. Owners' and Operators' Most Common Suggestions for Equipment Improvement

FELLER-BUNCHERS
1. Install air conditioning in cab. 2. Enclose or increase protection of hosing, lines, wiring, and shafts. 3. Enclose cab to minimize entry of foreign materials and vapors. 4. Include temperature guage in hydraulic oil tank. 5. Include warning system for low hydraulic oil level.
SKIDDERS
1. Install air conditioning in cab. 2. Enclose cab to minimize entry of foreign materials and vapors. 3. Improve noise protection in cab. 4. Include warning system for low hydraulic oil level. 5. Provide seat adjustments to accommodate normal range of operators. 6. Place labels on high voltage points.
LOADERS
1. Install air conditioning in cab. 2. Provide arm and head rests. 3. Provide seat belts. 4. Design machine such that vibration is at a minimum and separated from cab. 5. Include temperature guage in hydraulic oil tank. 6. Provide seat adjustments to accommodate normal range of operators. 7. Consider mechanic comfort and protection when designing machine.

Table 6. All Systems' Crew Characteristics

SYSTEM

	A	B	C	D	E	F
Crew Size[1]	2	4	6	6	3	7
Age (Years)						
Mean	24.0	29.5	34.8	26.3	38.3	37.3
Median	24.0	26.0	32.5	24.5	34.0	32.0
Range	21-27	21-45	25-45	20-35	22-59	27-50
Harvesting Experience (Years)						
Mean	2.00	9.25	11.42	6.95	13.75	19.00
Median	2.00	3.00	12.00	5.50	2.00	13.00
Range	.5-3.5	1-30	2.5-18	.67-17	1.25-38	8-35
System Longevity (Months)	15	18	10	48	15	72
Time with Crew (Months)						
Mean	10.5	13.5	9.0	16.7	13.0	59.1
Median	10.5	15.0	10.0	10.0	12.0	72.0
Range	6-15	6-18	4-10	7-48	12-15	24-72

[1] All values in table calculated exclusive of transportation personnel.

least amount of experience was found with the limber-toppers since the job requires the least amount of quality control and is the least production-limiting activity. The deck men were the most experienced on their crews. As noted earlier, these men could substitute on at least some of the equipment, when necessary.

Table 8 compares production-related characteristics of the systems. Four of the systems produced tree length pulpwood, one produced shortwood pulpwood, and one produced whole tree chips for energy.

Average weekly production ranged from 92.1 cords in System A to 333.3 cord equivalents (1000 tons) in System F. Production varied directly with crew size. However, another contributing factor may be that the higher-producing operations often were composed of more experienced crew members.

Cords per man-day (excluding transportation personnel) ranged from 10.5 in System A to 5.3 in System B and from 7.0 in A to 4.2 in B when haul truck drivers were included in the calculations. Tree size undoubtedly played a role in the production differences. However, System F, the whole tree chipping operation, had productivity per man-day of roughly 80 percent of the highest value (System A). System F achieved this productivity harvesting timber that averaged less than half the size of that cut by System A (13.48 trees per ton compared to 5.22), indicating that other factors must have had an impact. Equipment selection and operation management compensated for some of the small-tree effects, as shown by the fact that five of the six operations had productivity greater than eight cords per man-day.

The conventional prelogging systems harvested about 13 cords per acre. The Virginia and North Carolina thinning operations recovered between 5 and 7 cords per acre, while the South Carolina thinning job harvested about 12 cords per acre. A harvest of 22 tons (7.3 cord equivalents) per acre was reported as the minimum acceptable for the whole tree chipping system to operate efficiently on a continuing basis.

Table 9 presents equipment ages for each type of equipment in order to observe age in relation to system longevity. In this way, it could be determined whether equipment was new or used when put into use on the operations. It appears that feller-bunchers were generally new when introduced

Table 7. Harvesting Experience by Position

Position	Number	Harvesting Experience (Years)	Mean	Median
Feller-buncher Operator	10	.67, 1.33, 3.5, 4, 8, 9, 11, 12, 13, 15	7.75	8.50
Skidder Operator	9	.5, 2, 2, 5, 9, 15, 17, 32, 35	13.05	9.00
Loader or Chipper Operator	6	.5, 1, 6, 8, 18, 25	9.75	7.00
Limber-topper	2	2, 2.5	2.25	2.25
Deck Man	2	30, 38	34.00	34.00

Table 8. Production-Related System Characteristics

	SYSTEM					
	A	B	C	D	E	F
Product	Tree Length	Tree Length	Short-wood	Tree Length	Tree Length	Whole Tree Chips
Average Weekly Production (Cords)	92.1	105.9	262.3	272.0	133.6	333.3
Cords/Man-day On-board Truck[1]	10.5	5.3	8.7	8.1	8.9	8.3
Cords/Man-day to Delivery Point[2]	7.0	4.2	6.6	6.1	6.7	5.8
Size of Trees Harvested[3] Trees/Ton	5.22	7.01	9.17	5.09	6.51	13.48
Pounds/Tree	383.1	285.3	218.1	392.9	307.2	148.4
Volume Removed Per Acre (Cords)	13.4	6.3	5.0, 6.4[4]	12.9	12.1	7.3

[1] Excluding transportation personnel.

[2] Including transportation personnel.

[3] Averages as indicated by the load tallies.

[4] The data indicated that a greater volume per acre was removed from a level portion of the stand than from a hillier section.

into the systems, indicating that equipment better-suited to the operating environment was purchased. The majority of skidders also were bought new. The ages of the loader and chipper category, on the other hand, indicated that they were normally used when put into the systems.

Appendix C contains tables of observed felling and skidding productivity data across all systems studied. The Kolmogorov-Smirnov test was used to determine if the distributions of cycle times were significantly different from each other. The results of this statistical test are also tabulated in Appendix C. Care must be taken to consider associated machines when referring to the data contained in the appendix.

Feller-buncher C2, which performed only selection cuts between corridors on a thinning operation, had cycle times which took significantly longer than all other feller-bunchers. As an illustrative example, Figure 18 shows a comparison of Feller-buncher C2's cumulative relative frequency distribution of cycle times with that of Feller-buncher E, also a Franklin 105, which performed mixed corridor and selection thinnings. System C was removing only about half of the volume and was working in timber one-third smaller than was System E. Contrasting operating strategies also will influence cycle times. Feller-buncher C2 created large bunches to enhance skidder productivity, thus lengthening felling cycles. Feller-buncher E, on the other hand, accumulated small bunches, shortening its cycle times, but affecting skidder production. The skidders from both of these systems exhibited roughly similar distributions of trees per bunch, indicating that Skidder E was forced to collect several small bunches rather than one larger bunch to utilize grapple capacity.

Significant differences occurred between a number of the skidders observed. Since skidder productivity is so closely related to felling, harvest method, delimbing method, tree and bunch size, and skidway and landing management, it was not possible to determine which factors caused these differences without more intensive studies of each individual machine.

Table 9. Equipment Age (Months) by Type

SYSTEM

	A	B	C	D	E	F	Mean	Median
System Longevity	15	18	10	48	16	72	29.83	17.00
Equipment								
Feller-buncher	14	12	12 30	24 42	16	8 8 40	20.60	15.00
Skidder	24	144	6 10	16 18	16	48 48	36.67	18.00
Loader or Chipper	72	84	1	24	60	36	46.17	30.00

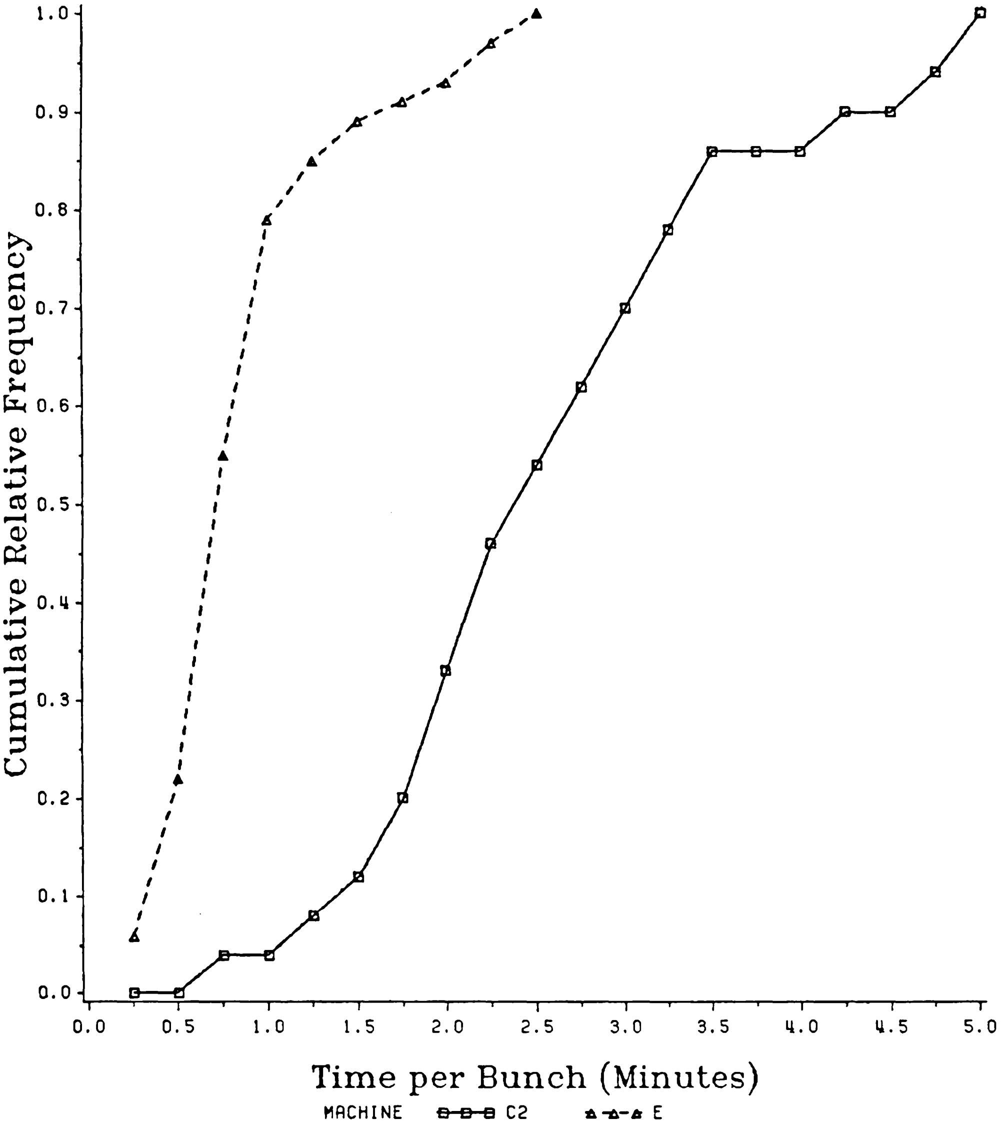

Figure 18. Comparison of Cycle Time Distributions for Feller-bunchers C2 and E

Economic Analysis

The data collected in the field studies was used to calculate the indicators of system efficiency and profitability listed in Table 10. Trucking was not included in this section because of the variability between systems and between the various southern states' regulations.

The systems' capital investment was figured assuming new equipment as shown in Appendix B. The systems split into three capital investment classes. Systems A, B, and E were in the $200,000 to $250,000 range. Systems C and D, both owned by the same man, required capital investments assumed around $500,000 and the whole tree chipper operation, System F, was the most capital intensive system at over three-quarters of a million dollars.

Annual production per $1000 of capital investment was determined for each operation as a measure of capital utilization efficiency. Systems E and D were at the high end of the range. Medium scale production per $1000 was obtained by Systems C and F. Systems A and B, two of the smaller operations, were in the bottom portion of the range. This may illustrate that smaller, lower production operations can have difficulty making efficient use of capital and may be best served by employing used equipment, especially when the contractor has limited management experience.

System costs were determined based on the assumptions outlined in Appendix D. All expenses were calculated and put on a weekly basis. Seventy five percent of purchase price financed at 12 percent annual percentage rate (APR) for three years determined equipment payments. A percentage of average fixed investment (AFI) represented taxes, insurance, and licenses. Owner/operators were treated as salaried foremen for costing purposes. Likewise, owner/supervisors and absentee owners were given a salary equal to that of their foremen. Salary payments were treated as fixed costs because of the short-term nature of the cost analyses. All other labor was assumed paid per scheduled hour to simplify calculations, although in reality, some crews were paid by the load. The cost of labor was based on reported number of hours worked per week. Equipment supply costs were based on assumed utilization, hourly consumption, and hours worked per week. Equipment maintenance and repair was estimated at 60 percent of depreciation (calculated on a straight line basis for five-year equipment lives). Information was not obtained con-

Table 10. Economic Comparisons

	SYSTEM					
	A	B	C	D	E	F
Assumed Capital Investment[1] ($1000)	217.5	253.5	506.6	440.6	203.5	766.5
Annual Production Per $1000 of Capital Investment (Cords)	19.5	18.8	23.3	27.8	29.5	21.7
Cost Per Cord ($)	32.21	39.25	30.25	27.16	26.56	34.15
Assumed Revenue Per Cord[2] ($)	40.00	40.00	40.00	40.00	40.00	42.00[3]
Margin Per Cord ($)	7.79	.75	9.75	12.84	13.44	7.85

[1] All equipment assumed new when purchased.

[2] Since all equipment was assumed new, assumed revenue per cord may be higher than is common in the industry.

[3] $14 per ton which equates to $42 per cord equivalent.

cerning overhead costs associated with the operations, so these costs were not included in the analyses. Dividing the summed weekly expenses by average weekly production provided average costs per cord.

The lowest calculated wood cost was by System E, while System B's was the highest. Production costs of the other operations were spread throughout the range. The average costs of thinning versus prelogging may appear similar, but thinning costs exhibited a much higher degree of variability. The substantial influence that operation management can exert on system efficiency and profitability was indicated by the large differences in production per $1000 of capital investment and cost per cord between Systems B and E. The extensive business management experience of System E's owner may have had an important role. For instance, although both systems performed thinnings, System E entailed only 80 percent of the assumed capital investment of System B. System E also was allowed to harvest almost twice as much volume per acre as System B.

Systems A through E's margins per cord were calculated based on an assumed revenue of $40 per cord of pulpwood. Although System F was a company operation, a price of $14 per ton of fuel chips ($42 per cord equivalent) was assigned to its output for comparative purposes. These revenues may be higher than the usual contract rates in the industry, but the net revenues calculated were for comparison purposes only. The net returns ranged from $13.44 per cord for System E to System B's $.75 per cord. It should be noted that these figures do not reflect overhead costs associated with maintaining a large spare parts inventory, shop, office, or other business expenses, which may be significant in the cases of Systems C, D, E, and F.

Table 11 shows the price per cord necessary to realize selected rates of return on AFI based on the assumptions used and the operating conditions at the time of observation. These prices per cord do not allow for overhead or trucking costs. They were used to provide relative rankings among the systems. System E achieved each observed rate of return at the lowest price per cord and System B at the highest.

Based on the preceding analysis, System E appears to have become a very desirable small-tree harvesting system. It was consistently ranked first in the comparative economic indices calculated. The equipment spread required minimal capital investment when compared to other mechanized

Table 11. Price per Cord Necessary to Achieve a Given Percent Rate of Return on AFI

SYSTEM

Target Rate of Return (%)	A	B	C	D	E	F
15	$27.35	$43.07	$31.76	$30.06	$25.16	$32.96
20	29.09	44.88	33.22	31.28	26.31	34.52
25	30.84	46.69	34.68	32.51	27.47	36.08

systems. The crew was comprised of men experienced in the forest industry who had melded into a stable group with good esprit and pride in their work. The owner had a long history of business management and had developed good relations with landowners and timber buyers.

Residual Stand Damage Analysis

Cruises were conducted at each of the thinning operations (Systems B, C, and E) in order to observe the extent of residual stand damage. In all, 71 plots containing 1093 trees were examined. The total number of crop trees and the number in each damage class (major, minor, and broken tops) were tallied at each plot. Each tree's location in relation to the corridor and the distance from each plot midpoint to the deck were recorded.

Table 12 relates the numbers derived from the damage cruises. Eighty six (7.9 percent) of the 1093 trees had incurred some form of injury. This figure was comprised of 1.6 percent major damage[10], 6.2 percent minor damage, and 0.1 percent broken tops. Over 75 percent of the injuries were inflicted on trees located along the corridors, while less than 25 percent occurred within the selection areas. This was expected because trees on the corridors were exposed to traffic by both the feller-bunchers and the skidders, but those between corridors faced only feller-buncher traffic.

Each operation's individual damage percentages are also shown in Table 12. The cruise conducted at System B's job site revealed that 16 of the 186 trees examined, or 8.6 percent, were damaged. Major damage was inflicted on twice as many trees as minor damage and one tree had its top broken off. Trees along the corridors accounted for 81.3 percent of the total. Fifty one (8.4 percent) of the 608 trees observed at System C's site were damaged. Seven trees had major damage, 44 had minor injuries. Forty of the 51 damaged trees were located on the corridors. At System E's thinning site, 299 trees were tallied. Nineteen of the trees (6.4 percent) had damage, all minor. Twelve of these trees were on the corridors, seven were situated between corridors. The broken top

[10] Major damage consisted of 50 square inches or more of exposed cambium.

damage class was excluded from the remainder of the analysis, since only one tree out of 1093 had this form of injury.

Differences in the levels of damage could be attributable to differences in the amount of timber removed per acre. Systems B and C removed about six cords per acre and involved very similar damage levels. System E removed twice as much volume and inflicted slightly less damage (two percent) on the residual stand. The thinning prescriptions, however, were comparable on a basal area per acre basis. Systems B and E entered stands containing about 100 square feet per acre. System C's stands averaged 120 square feet per acre. All three systems left 60 to 70 square feet per acre following thinning.

An objective of the stand damage analysis was to determine whether the distance a tree was situated from the deck was a significant predictor of the probability of incurring damage. For this purpose, the data was stratified into 100-foot intervals from zero to 600 feet from the deck. An analysis-of-variance (ANOVA) procedure then was conducted with the cruise data. Table 13 shows the ANOVA results and damage percentages in terms of distance from the deck for all three thinning systems combined.
Distance was not a significant predictor of total, major, or minor damage at a .05 alpha level[11]. The first 100 feet from the deck incurred the highest percent of both major and minor damage, but the percent damage did not always show a decrease with increasing distance from the landing.

Table 14, Table 15, and Table 16 relate the ANOVA results and damage percentages for each individual operation. With System B, distance again was not significant in predicting the likelihood of any type of damage. The majority of trees damaged had at least 50 square inches of cambium exposed, as mentioned earlier. In fact, although every interval had some trees injured, only the intervals from 100 to 300 feet had trees with minor damage. The interval from 100 to 200 feet from the deck had the highest damage percentage, having more than twice as many trees injured than any other interval.

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[11] Probability of rejecting a true null hypothesis

Table 12. Thinning Systems' Stand Damage by Class and Location

Damage Class	Number of Trees Damaged	Damage Percentage
	All Thinning Systems	
Major	17	1.6
Minor	68	6.2
Broken Top	1	0.1
All Types	86	7.9
	System B	
Major	10	5.4
Minor	5	2.7
Broken Top	1	0.5
All Types	16	8.6
	System C	
Major	7	1.2
Minor	44	7.2
Broken Top	--	---
All Types	51	8.4
	System E	
Major	--	---
Minor	19	6.4
Broken Top	--	---
All Types	19	6.4

Damage Location	Number of Trees Damaged	Damage Percentage
	All Thinning Systems	
Along Corridors	65	6.0
Between Corridors	21	1.9
	System B	
Along Corridors	13	7.0
Between Corridors	3	1.6
	System C	
Along Corridors	40	6.6
Between Corridors	11	1.8
	System E	
Along Corridors	12	4.0
Between Corridors	7	2.4

All systems: 1093 trees tallied.
System B: 186 trees tallied.
System C: 608 trees tallied.
System E: 299 trees tallied.

Table 13. All Thinning Systems Stand Damage Percentages by Distance from Deck and ANOVA Results

Distance from Deck (Feet)	Number of Trees Tallied	Number of Trees Damaged	Percent Major Damage	Percent Minor Damage	Percent All Types Damage[1]
0-100	203	24	3.0	8.9	11.8
100-200	220	17	2.7	5.0	7.7
200-300	218	14	0.5	6.0	6.4
300-400	145	6	0.7	3.4	4.1
400-500	203	18	1.0	7.9	8.7
500-600	104	6	1.0	4.8	5.8
Total	1092[2]	85			

Test Statistic	Major Damage	Minor Damage	All Types Damage
F value	1.54	1.25	1.75
p-value	.1747	.2827	.1191

[1] Major + Minor may not equal All Types due to rounding.

[2] 1093 minus one tree with broken top.

Table 14. System B Stand Damage Percentages by Distance from Deck and ANOVA Results

Distance from Deck[1] (Feet)	Number of Trees Tallied	Number of Trees Damaged	Percent Major Damage	Percent Minor Damage	Percent All Types Damage
0-100	25	2	8.0	---	8.0
100-200	76	8	6.6	3.9	10.5
200-300	46	3	2.2	4.3	6.5
300-400	25	1	4.0	---	4.0
400-500	13	1	7.7	---	7.7
Total	185[2]	15			

Test Statistic	Major Damage	Minor Damage	All Types Damage
F value	.41	.66	.46
p-value	.7987	.6240	.7627

[1] Due to the randomness of the cruise, no samples were obtained from the 500 to 600-foot interval.

[2] 186 minus one tree with broken top.

Distance was found to be a significant predictor of total damage for System C, although it was non-significant in predicting any particular damage category. The significance was probably because of the high number of injuries in the zero to 100 and 400 to 500-foot distance intervals in comparison with the other levels. Nearly all damaged trees received minor injuries. Not a single major injury was observed between 200 and 400 feet from the deck.

Analysis of the cruise data from System E indicated that distance was not a significant predictor of damage probability. Since no major damage was observed, the figures derived for total and minor damage are identical. Note that the 400 to 500-foot interval had a larger percentage of trees injured than the closer 200 to 300-foot interval.

The hypothesis that delimbing method influenced the amount of residual stand damage was tested. System C normally delimbed the trees in-woods, while Systems B and E gate delimbed at the deck after dragging the trees through the stand. As shown in Table 17, the in-woods delimbing led to a higher percentage of stand damage than when the trees were delimbed at the deck. The difference in the amount of injuries between delimbing methods, though, was not statistically significant. It must be recognized that a variety of factors could have masked the effects of delimbing method. Among these was the use of "turn" trees, which were removed after harvest, by Systems B and E, but not C. Other important factors were differences in skidder operators, felling considerations, and stand characteristics. Because of the interaction of these elements, levels of damage could not be attributed to delimbing method. Proper management and supervision of the operations appeared to be the paramount factor in limiting stand damage.

The stand damage studies demonstrate that mechanical thinning with selection is possible with minimal damage. Very little major damage was exhibited and the amount of all types of damage was below nine percent for all systems studied. These operations used common harvesting machinery, indicating that equipment currently available can be used to conduct thinnings while holding damage to acceptable levels.

Table 15. System C Stand Damage Percentages by Distance from Deck and ANOVA Results

Distance from Deck (Feet)	Number of Trees Tallied	Number of Trees Damaged	Percent Major Damage	Percent Minor Damage	Percent All Types Damage[1]
0-100	108	17	3.7	12.0	15.7
100-200	88	5	1.1	4.5	5.7
200-300	90	7	---	7.8	7.8
300-400	120	5	---	4.2	4.2
400-500	98	11	1.0	10.2	11.2
500-600	104	6	1.0	4.8	5.8
Total	608	51			

Test Statistic	Major Damage	Minor Damage	All Types Damage
F value	1.74	1.72	2.68
p-value	.1216	.1260	.0210

[1] Major + Minor may not equal All Types due to rounding.

Table 16. System E Stand Damage Percentages by Distance from Deck and ANOVA Results

Distance from Deck[1] (Feet)	Number of Trees Tallied	Number of Trees Damaged	Percent Major Damage	Percent Minor Damage	Percent All Types Damage
0-100	70	5	---	7.1	7.1
100-200	55	4	---	7.3	7.3
200-300	82	4	---	4.9	4.9
400-500	92	6	---	6.5	6.5
Total	299	19			

Test Statistic	Major Damage	Minor Damage	All Types Damage
F value	----	.15	.15
p-value	----	.9263	.9263

[1] Due to the randomness of the cruise, no samples were obtained from either the 300 to 400 or the 500 to 660-foot intervals.

Table 17. Damage Percentage by Class and Delimbing Method

	Damage Percentage	
Damage Class	In-woods Delimbing[1]	Delimbing at Deck[2]
Total	8.4	7.0
Major	1.2	2.0
Minor	7.2	5.0

[1] 608 trees tallied (System C)

[2] 484 trees tallied (Systems B and E)

Recommendations

A number of characteristics which could affect the success of small-tree handling and harvesting systems were revealed through intensive studies of the six operations. Some factors were common throughout most or all of the operations. Others, however, were unique to individual systems, but should be feasible to other thinning/prelogging jobs as well. The major characteristics of success which became apparent through this research suggest that:

- The contractor should have prior experience operating some sort of business enterprise.

The base of any operation is the owner because good management seems paramount to an operation's success. The owners had considerable experience managing businesses of their own prior to initiating their thinning/prelogging operations in the majority of systems (C,D,E, and F). The owner of System B had been an independent logger for one year before establishing his thinning operation. A previous background in business may not be essential, especially in smaller operations. However, given the differences in productivity and profitability between Systems B and E, System E's owner's extensive prior business experience could have played a large role. The experience does not necessarily have to be in timber harvesting. It appears that just exposure to the management of people and money in a business environment can be beneficial in operating small-tree harvesting systems.

- The contractor should act as an owner/supervisor, possibly with some production responsibilities, rather than as an owner/operator.

When a piece of equipment must be shut down so that the owner/operator can conduct other elements of his business (e.g. contract negotiation, stand reconnaissance, parts replacement), production is lost. The contractor is available to leave the job site, smooth production, fill in as an equipment operator, and/or perform mechanic's duties if he is not faced with specific operating responsibilities. The owners of Systems C, D, E, and F did not participate directly in production. Three of these operations, C, D, and E, had the highest margins per cord of wood produced. It may not be possible for the owner to act in a purely supervisory capacity at the outset of the operation, but the sooner the move can be accomplished, the better. Of course, the owner's ability to leave the job site is contingent upon the presence of a capable foreman who can keep the job running smoothly.

- The crew must be given an opportunity to solve shakedown problems and stabilize.

It may take up to a year before a crew is assembled which is stable enough to work together efficiently and profitably. Advantages can be realized by the contractor assembling a crew comprised of personnel that he is familiar with from prior work experience. All of the crews consisted of a majority of people who had worked with the owner in one capacity or another for a number of years, except Systems A and B. Most of the crew members of System B, however, had been acquainted for much of their lives. The use of people known from other experience is not absolutely essential, but the contractor should, at the very least, be a good judge of people. In this way, problems with job turnover can be minimized and good working relationships can be promoted to maximize production with a minimum of operational problems.

- The crew should include at least one person with extensive forest harvesting experience.

The presence of at least one crew member who had spent a large portion of his working life in the forest industry was a feature of every system studied with the exception of System A, the two-man operation. On the smaller operations, this person was a deck man with at least 30 years of timber harvesting experience. The larger crews had a minimum of three members with over 10 years of logging and/or woodyard experience. These people, with their many years of exposure to the forest industry, seemed to aid the foremen in keeping the jobs running efficiently. A related characteristic was that, in each system, a number of people could run every piece of equipment. This cross-training minimized the impact of absent crew members.

- The contractor can be successful with equipment currently on the market, but should be sure to select equipment which is flexible in application.

Harvesting equipment now available can be used efficiently and economically on small-tree operations when utilized properly. The equipment owners and operators generally seemed satisfied with the performance of their machines in the thinning/prelogging environments. Suggestions regarding improvement mainly involved operator comfort and ease of maintenance. The residual stand damage studies evidenced that stem injuries can be minimized if equipment is operated conscientiously. Although the majority of time may be spent thinning or prelogging, equipment should be versatile enough to handle occasional clearcutting or other opportunities which can be encountered. For instance, System B conducted clearfelling operations during the breaks in its production history shown in Figure 10.

- The contractor should attempt to obtain used equipment when initiating an operation or, if necessary, be selective in new purchases.

The contractor should try to purchase good used equipment, if available, rather than all new when creating the system, since most thinning/prelogging operations work on a slim profit margin. This is especially true for smaller systems where funds for equipment purchases may be tighter than for larger, higher-production systems. If good used equipment is unavailable or must be replaced, the priority for new equipment purchases should be feller-buncher first, then skidder, followed by loader or truck. In each system studied, the feller-buncher was new or virtually new when purchased for the operation. Skidders were also bought new, except for two of the smaller operations, A and B. Loaders and trucks were more commonly bought used. The contractor should not overburden himself with excessive equipment financing costs because of the problems which may be encountered with assembling a reliable crew at the start of an operation.

- The operation should subcontract hauling duties at least until crew shakedown and other problems have been solved.

In systems that owned trucks and trailers or vans, Systems B, C, D, and F, investment in hauling equipment entailed from 20 to nearly 30 percent of capital investment (all equipment assumed new). The system ranking best in most comparisons, System E, relied totally on contract hauling. Absence of truck maintenance costs and greater flexibility during periods of production or quota fluctuations are possible when hauling is subcontracted. Also, the contractor or foreman can focus his management efforts on the in-woods portion of harvests. Therefore, if an amenable agreement can be reached, system owners should subcontract their hauling at least until the operations are stabilized and working at the desired output levels.

- Operations which do not employ set-out trailers and full-time haul truck drivers should seek to harvest tracts which require short haul distances.

The haul distance between the job site and delivery point can exert an impact on operation profitability. In this project, the smaller, lower production systems enjoyed considerably shorter haul distances. Systems A, B, and E hauled one-way distances of 10, 5, and 27 miles, respectively, when observed. The other operations hauled from 40 to 70 miles one way. These shorter distances, which allowed quicker turnaround times, were probably necessary for the small operations to deliver sufficient loads to remain profitable without requiring excessive amounts of overtime work. Short haul distances would be especially helpful in cases where the truck driver has responsibilities in addition to hauling, such as trimming and other deck man duties or loading, and/or when set-out trailers are not used. Longer hauls would be more tolerable when a full-time driver and set-out trailers are involved, so long as production is not limited by an insufficient number of trucks and trailers for the distance faced.

- Residual stand damage can be minimized through preharvest planning, job layout, and crew supervision.

Residual stand damage was found to be less than 10 percent for the thinning operations studied, an amount likely within acceptable limits for intermediate harvests in the South. Good planning of the harvest prior to entering the stand seemed to aid in controlling stand damage. All three thinning crews, Systems B, C, and E, discussed specific harvest techniques before cutting began, whether that meant use of "turn" trees or just the most appropriate method to employ on a particular stand. At least as important as good planning is that the contractor must be genuinely concerned with minimizing injuries to the remaining crop trees. This concern must be emphasized to every member of the crew to ensure that the proper care and attention are given to preventing damage. The three contractors and their crews took great pride in the appearance of their finished work. A lack of concern on the contractor's part could be remedied by implementation of monetary or other forms of performance rewards or penalties.

- A medium should be established for the exchange of information concerning successful harvest methods and techniques.

Small-tree contractors could benefit from the sharing of successful ideas between operations. If a certain operating procedure works well for one system, it may or may not work with other systems, operation types, or in other regions. However, the knowledge should be made available for individual contractors so that they may decide whether methods which have proven feasible for others would work for them. Improved training in efficient thinning and prelogging techniques for contractors and their crews is essential. Additionally, allowing contractors more input into job layout at the planning stage would seem to facilitate efficiency. For example, landings were built for System B by the landowner, but it was often necessary for the crew to expand their landing space substantially during the course of thinning operations. Unproductive time spent enlarging landings could have been reduced or eliminated through interaction between the contractor and landowner before the harvests.

- Small-tree operations should be afforded procurement flexibility by timber buyers.

It is important to make small-tree harvesting operations more attractive to loggers so that desired stand treatments can be conducted. Obviously, increasing the contract rate for pulpwood would prompt interest among timber harvesters, but non-monetary incentives are possible, also. For instance, allowances for flexibility in tree size accepted or quotas, to which small-tree operations are especially sensitive, could result in increased interest in thinning and prelogging among conventional loggers. System E did not face quotas on their deliveries to the mill and minimum diameter limits were lenient. Another possibility is the incentive of occasional clearcuts, such as those offered to System B, to enhance the lower productivity achieved in small-tree operations.

- The burden of support activities should be removed from small-tree harvesting operations by the landowner or timber buyer.

Because of the nature of small-tree operations, the overhead costs of procurement activities, road building and maintenance, boundary marking, and landowner relations are more easily borne by landowners and timber buyers than by contractors. All of these services were performed for Systems A, B, and F. The bulk of these activities were also performed for the other operations, although, as a wood dealer, System E's owner procured some wood on his own. Also, boundaries were not marked for his operation. Systems C and D built and maintained their own roads and decks, when necessary. In the cases where the owner and crew can devote their efforts mainly to the stand treatment, the more satisfactory the results should be from both the landowner's and contractor's points of view.

- Small-tree harvesting systems should be added to existing operations rather than established as single-system contractorships.

By establishing thinning/prelogging systems as subsidiaries to larger operations, overhead costs of support equipment, large spare parts inventories, shops, and offices are spread over a greater number of operations. Systems C and D were operations initiated as parts of an established multiple-system contractorship. System E was managed by a wood dealer who contracted for several other crews, as well. System F was one of a number of company operations. The single-system contractor has no other means of economic survival during times of decreased demand for his product. By operating several, preferably different types of systems, the contractor's risk from one individual system is minimized.

Summary and Conclusions

The objectives of this research project were to identify small tree harvesting systems deemed successful by industry personnel, to document and analyze characteristics of selected systems to determine their effects on system performance, and to study which factors affect damage to the residual stands following thinning treatments. Two separate types of studies were used to accomplish these objectives.

A South-wide survey of procurement foresters and woodlands managers was used to identify promising systems. The data gathered contained information concerning operation type and location, products produced, tree size harvested, crew and equipment layout, average weekly production, and a qualitative measure of residual stand damage (where applicable). Three system types, motor-manual forwarder, feller-buncher/grapple skidder/hydraulic loader, and whole tree chipper, were identified as successful systems. A vast majority of the operations cited employed the feller-buncher/grapple skidder system type.

Following analysis of the survey results, it was felt that the appropriate direction for the project was to base the research on the most common system type. Therefore, six feller-buncher/grapple skidder systems (three which conducted thinnings and three which carried out prelogging treatments) were selected to be more intensively studied. One of the prelogging systems was a whole tree chipping wood energy operation which was chosen for comparative purposes. The systems selected covered a range of ownership types (sole proprietorship, dealer crew, company crew) and the three physiographic regions of the South.

The field studies included documentation of many details of each operation. Basically, five areas of information were collected. System application (i.e. harvest strategy and operating conditions) was noted. Data concerning crew organization and background was obtained. Complete machine descriptions, including owner and operator opinions concerning equipment suitability, were documented. Also, information was obtained pertaining to system performance, such as production and expense histories and general equipment time studies. Finally, any special considerations provided to the operations by the landowners or timber buyers were noted. Residual stand damage cruises were also conducted on each of the thinning operations.

The data was analyzed case by case and comparatively. The following information was documented as being the key to success of one or more of the systems:

- System owners should have some form of prior business management experience (not necessarily forestry-related business) to aid in running efficient, profitable operations.
- The contractor should be in the position of owner/supervisor rather than owner/operator as soon as possible after system initiation to allow him to conduct all elements of his business without hindering system production.
- The crew must be given an opportunity to stabilize, possibly up to a year. In order to minimize shakedown problems, the contractor can either hire people known from other work experience or at least have the ability to judge a person's willingness to work effectively in the operation.
- The crew should contain at least one crew member with a good deal of timber harvesting experience Also, cross-training of equipment operators helps in the smooth running of the operations.
- Equipment selected must be flexible enough to handle any harvesting opportunities which may be encountered. Suggestions for improvement mainly concerned operator comfort and ease of maintenance.

- If at all possible, good used equipment should be purchased rather than new machinery because of slim profit margins and possible crew shakedown problems during system initiation.
- When haul truck drivers have additional responsibilities and/or set-out trailers are not used, contractors should seek to harvest tracts requiring short haul distances.
- System owners should subcontract hauling duties, at least until the operation stabilizes, because of the large amounts of capital involved with the purchase of timber hauling equipment and the increased flexibility allowed by subcontracting.
- Residual stand damage can be held to acceptable levels through good pre-harvest planning and contractor/crew concern over job quality.
- Knowledge of harvest methods which have proven successful should be made available among other thinning/prelogging operations. Also, improved training at all levels and more contractor input into harvest planning will aid in operation success.
- Concessions for small-tree contractors (e.g. flexibility in size or amount of material accepted by the mill and/or occasional clearcut opportunities) are necessary to attract logger interest in thinning/prelogging operations.
- Landowners or timber buyers should bear the burden of support activities to permit profitable operations and to promote good business relationships.
- Small-tree systems should be established in conjunction with existing operations to minimize risk and overhead costs.

All of these suggestions may not be practical for every operation or situation. However, the implementation of as many as possible should prove helpful in terms of operation profitability and intermediate stand treatment acceptability.

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Appendix A. Data Collection Form 370.02

Each applicable category was evaluated and given a grade of from 1 (lowest) to 10 (highest).

Study ID ____________

Date ________________

New ____, Revised ____

370.02 General Design Adequacy

370.021 Overall Considerations

021.1 ___ Machine dimensions appropraite for timber, terrain, and transport.

021.2 ___ Machine construction appropriately robust for task.

021.3 ___ The use of exotic or non-standard components has been minimized.

021.31 ___ Exotic or non-standard parts can be easily replaced by more familiar or readily available components.

021.32 ___ Exotic or non-standard parts have been sufficiently tested or have sufficient history in related fields to warrant inclusion.

021.4 ___ The machine design is built up from modules of related components.

021.41 ___ Repair by component replacement facilitated.

021.411 ___ Components can be altered or redesigned without unduly affecting machine integrity.

021.412 ___ Possibility of using alternative engines to get advanyage of local service, if necessary.

021.413 ___ Ease of unit replacement of all major hydraulic components.

370.022 ___ Power, power transmission, and similar components adequate for local conditions.

022.1 ___ Components can be selected to meet needs.

022.2 ___ Gear ranges adequate for local soils and terrain.

370.023 ___ Chassis and undercarriage adequate for expected application.

023.1 ___ Sufficient flotation for expected condition.

023.2 ___ Tipping angle greater than expected operating condition.

023.3 ___ Steering and protection adequate for the environment and application.

023.4 ___ Tires or tracks sufficiently robust for application.

023.5 ___ Sufficient clearance around tires and tracks to allow installation of chains, service, replacement, or repair.

370.024 ___ Cab design, location, and access adequate.

370.025 ___ Machine is sufficiently shielded and protected for work environment.

025.1 ___ Design is "clean." Components are mutually protected. Pockets, flats, and openings have been avoided.

025.2 ___ Hosing, lines, wiring, shafts enclosed or protected.

025.3 ___ Electrical system adequately protected and fused.

025.4 ___ Exhaust system designed and located to reduce fire hazards.

025.5 ___ Fire prevention and suppression consideration adequate.

025.6 ___ Good exhaust location to prevent debris accumulation.

025.29 ___ Other

370.026 Hydraulic system design considerations

026.1 Adequacy of hydraulic compon

11 ___ Durability

12 ___ Reliability

13 ___ Cold weather

14 ___ Oil contamination

19 ___ Other

026.2 ___ Standard thread used for hydraulic components.

026.3 ___ Adequate controls and trouble shooting considerations with regard to hydraulic system.

026.31 ___ Possibility of checking pressure at each important hydraulic component.

026.32 ___ Inclusion of a warning system for a low hydraulic oil level and overheating.

026.33 ___ Inclusion of a temperature guage in the hydraulic oil tank.

026.4 ___ Hydraulic tank size adequate for cooling and conditioning before recirculation.

026.5 ___ Drip tray arrangement for all major hydraulic components to drain the leaks outside the machine and to permit repair without oil spilling over the machine.

026.6 ___ Standardization of hose sizes and lengths.

026.7 ___ Hoses and plumbing well arranged and anchored to prevent loosening and damage to fittings due to machine movement.

026.71 ___ All hydraulic hoses adequately covered with heavy duty rubber.

026.72 ___ Adequate protective shielding for all points of hose abrasion.

026.73 ___ Guards provided for hydraulic hoses wherever the danger of damage from terrain or trees is expected.

026.74 ___ High quality steel tubing and fittings used throughout the design.

370.027 Steel section, built up, and welded parts

027.1 ___ All welds of good workmanship and quality.

027.2 ___ Wear plates used where appropriate.

027.3 ___ Section subject to damage and repair can be easily replaced.

029 ___ Other

Appendix B. Assumed Equipment Prices

FELLER-BUNCHERS

Bobcat	
843	$ 65,000
1075	75,000
1080	75,000
Caterpillar 910	85,000
Drott 40	188,200
Franklin	
105	65,000
170	100,000
HydroAx	
311	85,000
411	100,000
MorBell Mark IV	60,000

SKIDDERS

Caterpillar 518	$ 90,000
Clark 665	85,000
Franklin	
105	50,000
170	85,000
John Deere	
440	85,000
540	100,000
640	140,000
MorBell Logger	53,500
MRS	89,200
Timberjack	
230	70,500
240	80,000
350	90,000
380	95,000
450	105,000
Tree Farmer C-5	90,000

FORWARDERS

Gafner Iron Mule	$ 63,500
Soderhamm	63,500

CHIPPERS

Morbark

20	$230,000
22	178,500
27	224,000
Omark Blu Ox	229,000

LOADERS

Barko

160	$ 60,000
250	110,000
Caterpillar	60,000
Dunham Log Hog Z-160	60,000
HyHoe	60,000
Husky	
185	60,000
240	100,000
John Deere 6009	60,000
Prentice	
150	45,000
180	50,000
210	60,000
410	90,000
Ronan Log Loader	60,000

MISCELLANEOUS

Chainsaw	$ 550
Chip Van	14,000
Crew Truck	25,000
Dozer	90,000
Gate Delimber	2,400
Lowboy	14,000
Parts Truck	9,000
Pickup	9,000
Service Truck	30,000
Set-out Truck	14,000
Shortwood Truck	19,500
Slasher	11,500
Tractor (over-the-road)	65,000
Trailer (frame type)	10,000

* Prices obtained from Morbark catalog, Werblow and Cubbage (1986), and quotations or recent purchases by loggers and dealers

Appendix C. Observed Machine Performance Data

The equipment listed below corresponds to the system and equipment numbers in the following tables.

Feller-bunchers

System A: MorBell Mark IV

System B: Caterpillar 910

System C: 1 = Franklin 105 (rows), 2 = Franklin 105 (selection)

System D: 1 and 2 = Franklin 105

System E: Franklin 105

System F: Hydro-Ax 411B

Skidders

System A: Franklin 170

System B: Caterpillar 518

System C: 1 = Franklin 105, 2 = Clark 665D

System D: 1 and 2 = Franklin 105

System E: Franklin 105

System F: 1 and 2 = Timberjack 450

Table 18. Observed Feller-buncher Times per Bunch Across All Systems

Time per Bunch Interval Midpoint (Minutes)	Relative Frequency								Cumulative Relative Frequency							
System and → Feller-buncher No.	A	B	C1	C2	D1	D2	E	F	A	B	C1	C2	D1	D2	E	F
.25	.04	.03	---	---	---	---	.06	.05	.04	.04	---	---	---	---	.06	.05
.50	.16	.14	---	---	.07	---	.16	.05	.20	.17	---	---	.07	---	.22	.10
.75	.24	.14	---	.04	.07	.15	.33	---	.44	.31	---	.04	.14	.15	.55	.10
1.00	.22	.14	.20	---	.20	.27	.24	.27	.66	.45	.20	.04	.34	.42	.79	.37
1.25	.16	.17	.40	.04	.15	.33	.06	.14	.82	.62	.60	.08	.49	.75	.85	.51
1.50	.16	.14	.10	.04	.33	.07	.04	.23	.98	.76	.70	.12	.82	.82	.89	.74
1.75	.02	.10	.20	.08	.15	.15	.02	.18	1.00	.86	.90	.20	.97	.97	.91	.92
2.00		.10	.10	.13	---	.07	.02	.05		.96	1.00	.33	.97	1.04	.93	.97
2.25		.03		.13	.07		.04	.05		.99		.46	1.04		.97	1.02
2.50				.08			.02					.54			.99	
2.75				.08								.62				
3.00				.08								.70				
3.25				.08								.78				
3.50				.08								.86				
3.75				---								.86				
4.00				---								.86				
4.25				.04								.90				
4.50				---								.90				
4.75				.04								.94				
5.00				.04								.98				
Number of Cycles	45	29	10	24	15	15	49	22								

Cumulative frequencies may not total exactly 1.00 due to rounding.

Table 19. Observed Feller-buncher Trees per Bunch Across All Systems

Trees per Bunch	Relative Frequency								Cumulative Relative Frequency							
System and → Feller-buncher No.	A	B	C1	C2	D1	D2	E	F	A	B	C1	C2	D1	D2	E	F
1	.31	.10	---	---	.07	---	.27	---	.31	.10	---	---	.07	---	.27	---
2	.24	.17	---	.08	.07	---	.37	.09	.55	.27	---	.08	.14	---	.64	.09
3	.36	.14	---	.04	.33	.33	.33	---	.91	.41	---	.12	.47	.33	.97	.09
4	.04	.24	.20	.25	.40	.33	.04	.05	.95	.65	.20	.37	.87	.66	1.01	.14
5	---	.24	.30	.33	---	.33		.05	.95	.89	.50	.70	.87	.99		.19
6	.04	.10	.10	.17	.07			.09	.99	.99	.60	.87	.94			.28
7			.40	---	.07			.14			1.00	.87	1.01			.42
8				.08				.14				.95				.56
9				---				.18				.95				.74
10				.04				.05				.99				.79
11								.05								.84
12								.05								.89
> 12								.14[1]								1.03
Number of Cycles	45	29	10	24	15	15	49	22								

[1] Two bunches contained 13 trees, one bunch contained 18 trees.

Cumulative frequencies may not total exactly 1.00 due to rounding.

Table 20. Observed Skidder Times per Turn Across All Systems

Time per Turn	Relative Frequency									Cumulative Relative Frequency								
System and → Skidder No.	A	B	C1	C2	D1	D2	E	F1	F2	A	B	C1	C2	D1	D2	E	F1	F2
2	.07	---	.05	---	---	---	---	.04	.05	.07	---	.05	---	---	---	---	.04	.05
3	.07	.14	.09	.10	---	.06	---	.07	---	.14	.14	.14	.10	---	.06	---	.11	.05
4	.43	.19	.14	.05	.07	---	---	.07	.18	.57	.33	.28	.15	.07	.06	---	.18	.23
5	.36	.24	.18	.05	.14	.06	.21	.43	---	.93	.57	.46	.20	.21	.12	.21	.61	.23
6	.07	.19	.18	.19	.14	.06	.21	.14	.27	1.00	.76	.64	.39	.35	.18	.42	.75	.50
7	---	.10	.09	.19	.14	.31	.21	.04	.18		.86	.73	.58	.49	.49	.63	.79	.68
8		.05	.05	---	---	.06	.21	.11	.09		.91	.78	.58	.49	.55	.84	.90	.77
9		---	.09	.05	.14	---	---	.04	.14		.91	.87	.63	.63	.55	.84	.94	.91
10		.05	---	.05	.14	.06	---	---	.05		.96	.87	.68	.77	.61	.84	.94	.96
11		---	.05	.05	.07	.19	.07	.04	---		.96	.92	.73	.84	.80	.91	.98	.96
12		.05	.05	.14	.07	.06	---	---	---		1.01	.97	.87	.91	.86	.91	.98	.96
13			---	.05	---	.13	.07	---	.05			.97	.92	.91	.99	.98	.98	1.01
> 13			.05[1]	.10[2]	.07[3]			.04[4]				1.02	1.02	.98			1.02	
Number of Cycles	28	21	22	21	14	16	14	28	22									

[1] One turn in the 17 minute interval.
[2] One turn each in the 16 and 20 minute intervals.
[3] One turn in the 16 minute interval.
[4] One turn in the 14 minute interval.

Cumulative frequencies may not total exactly 1.00 due to rounding.

Table 21. Observed Skidder Trees per Turn Across All Systems

Trees per Turn	Relative Frequency								Cumulative Relative Frequency							
System and → Skidder No.	A	B	C1	C2	D1	D2	E	F[1]	A	B	C1	C2	D1	D2	E	F
< 5	---	.10[2]	---	---	---	---	---	---	---	.10	---	---	---	---	---	---
5	---	---	.05	---	---	---	---	---	---	.10	.05	---	---	---	---	---
6	.18	.10	---	.05	---	---	---	---	.18	.20	.05	.05	---	---	---	---
7	.04	.10	.05	---	---	---	---	---	.22	.30	.10	.05	---	---	---	---
8	.11	.19	---	---	.07	---	---	---	.33	.49	.10	.05	.07	---	---	---
9	.18	.14	.05	---	---	---	.07	---	.51	.63	.15	.05	.07	---	.07	---
10	.21	.05	.05	.05	.07	---	.07	---	.72	.68	.20	.10	.14	---	.14	---
11	.11	.14	.09	.19	.07	---	.21	---	.83	.82	.29	.29	.21	---	.35	---
12	.11	.10	.09	.10	.14	.25	.21	---	.94	.92	.38	.39	.35	.25	.56	---
13	.07	.05	.05	.10	---	.06	.14	---	1.01	.97	.43	.49	.35	.31	.70	---
14		.05	.05	.05	.07	.06	---	---		1.02	.48	.54	.42	.37	.70	---
15			.18	.10	.21	.25	.14	---			.66	.64	.63	.62	.84	---
16			---	.05	.14	.06	.07	---			.66	.69	.77	.68	.91	---
17			.14	.14	.07	.13	---	---			.80	.83	.84	.81	.91	---
18			.05	.05	.14	.06	---	.04			.85	.88	.98	.87	.91	.04
19			---	---		.06	---	.08			.85	.88		.93	.91	.12
20			.14	---		---	---	.12			.99	.88		.93	.91	.24
21			.05	.05		.06	.07	---			1.04	.93		.99	.98	.24
22				---				.04				.93				.28
23				---				.04				.93				.32
24				.05				.08				.98				.40
25				---				.12				.98				.52
26				---				.04				.98				.56
27				---				.08				.98				.64
28				---				.08				.98				.72
> 28				.05[3]				.28[4]				1.03				1.00
Number of Cycles	28	21	22	21	14	16	14	25								

[1] Bunches tallied while on the ground.
[2] Two turns containing 2 and 4 trees.
[3] One turn contained 39 trees.
[4] One turn each of 33, 34, and 47 trees. Two turns each of 35 and 36 trees.

Cumulative frequencies may not total exactly 1.00 due to rounding.

Table 22. Results of Kolmogorov-Smirnov Tests for Differences in Cycle Time Distributions

Results are tabulated below dashed lines.

FELLER-BUNCHERS								
	A	B	C1	C2	D1	D2	E	F
A	--------							
B		--------						
C1			--------					
C2	**	**	*	--------				
D1				**	--------			
D2				**		--------		
E			**	**	**	*	--------	
F		**		**				--------

SKIDDERS									
	A	B	C1	C2	D1	D2	E	F1	F2
A	--------								
B	**	--------							
C1			--------						
C2	*	**	*	--------					
D1	*				--------				
D2	*	*				--------			
E	*			**			--------		
F1					**	*		--------	
F2		*		**					--------

* = significant at .05 alpha level
** = significant at .005 alpha level

Appendix D. Cost Assumptions

Trucking costs were excluded from the cost calculations for reasons explained in the Economic Analysis section. Equipment was assumed to have a five-year useful life. Support equipment may well remain productive beyond this time, but was set up on the same basis to maintain consistency.

Fixed Costs (FC)

Foreman/owner salary (F) = \$15000 per year

Equipment - 25% down, remainder financed at 12% annual percentage rate (APR) for 3 years

$$AP = .75 \times P \times \left[\frac{.12}{1 - (1.12)^{-3}}\right] \cong .31^{*} \times P$$

Where:
AP = Annual equipment payment
P = Equipment purchase price
* Actual value = .3112261735

Yearly insurance, taxes, and licenses (ITL) = 18% of average fixed investment

$$AFI = \frac{(P - S) \times (L + 1)}{2 \times L} + S = .68 \times P$$

Where:
AFI = Average fixed investment (for a 3-year loan)
P = Equipment purchase price
S = Equipment salvage value (20% of purchase price)
L = Equipment life in years

$$\text{Weekly FC} = \frac{(F + AP + ITL)}{52 \text{ weeks per year}}$$

F = 2F for systems with an owner/supervisor or absentee owner

Operating Costs (OC)

Reported number of hours worked per week (H) and weeks worked per year (W):

System A: H = 35, W = 46
System B: H = 40, W = 45
System C: H = 40, W = 45
System D: H = 45, W = 45
System E: H = 40, W = 45
System F: H = 45, W = 50

Engine Consumption
(Gallons per Operating Hour)

	60-90 Hp	90-110 Hp	110-130 Hp	600 Hp
Fuel	2.5	3.0	3.5	17.5
Engine oil	.012	.016	.020	1.5% of fuel cost
Hydraulic oil-constant at .004 gallons per operating hour				

Fuel price = \$.61 per gallon
Fuel cost (C_f) = Hourly fuel consumption × Fuel price

Engine oil price = \$3.16 per gallon
Engine oil cost (C_e) = Hourly engine oil consumption × Engine oil price

Hydraulic oil price = \$6.76 per gallon
Hydraulic oil cost (C_h) = Hourly hydraulic oil consumption × Hydraulic oil price

Lubricant cost = 50% of engine oil cost

Chipper knife allowance (C_c) = \$.12 per operating hour

Maintenance and repair (MR) = 60% of depreciation

$$D = \frac{P - S}{L} = .16 \times P$$

Where:
D = Annual depreciation on equipment (for a 5-year life)
P = Equipment purchase price
S = Equipment salvage value (20% of purchase price)
L = Equipment life in years

Estimated equipment utilization (U):

Feller-bunchers = 60%
Skidders = 70%
Loaders = 50%
Chippers = 60%
Dozers = 15%

- System A's skidder and loader were operated by the same crew member. Utilization of this equipment was adjusted accordingly (Skidder = 50%, Loader = 30%).
- Utilization of equipment operated by crew mechanic was decreased by 10% to account for other responsibilities.
- Utilization of System F's equipment was decreased by 5% since each crew member performed his own mechanic work.

Labor rate (LR) = $6.00 per hour + 50% fringe and call-up

$$\text{Weekly OC} = \{[C_f + (C_e \times 1.5) + C_h] \times U \times H\} \text{ for each machine}$$
$$+ [LR \times (\text{Crew size} - 1) \times H] + \frac{MR}{W}$$

Add ($C_c \times U \times H$) to weekly OC of System F

Total Costs (TC)

Weekly TC = Weekly OC + Weekly FC

Appendix E. Detailed Description of System A

System A was a sole proprietorship which had been performing both thinning and prelogging operations for 15 months at the time of study. The primary material being produced was tree length pine pulpwood. Although thinnings were occasionally performed, the majority of time the system was used to prelog in the Upper Coastal Plain of Virginia.

System A operated in natural stands and plantations which averaged four to eight inches DBH. When studied, the system was conducting prelogging in a 30-year-old natural stand consisting of loblolly pine, with small amounts of Virginia pine and hardwood. A conventional timber cruise by the landowner estimated that 11 cords of pulpwood and 1200 board feet of sawtimber per acre were present on the tract prior to harvest. Through careful merchandising and the fact that System A was located on a better than average portion of the tract, 12.7 cords of pine pulpwood and posts and .7 cords of hardwood pulpwood were removed per acre through prelogging of 191 acres.

Figure 19 illustrates the material flow of System A. The felling equipment used was a MorBell Mark IV equipped with a 15-inch Morbark shear. The material was skidded from the woods with a Franklin 170 grapple skidder. A trailer-mounted Prentice 210 loader with a fixed heel and pulpwood grapple was operated by the skidder operator in this system. Hauling for System A was handled by a contract trucker who hauled for another job at the same time. A single truck and trailer were used. The loads were hauled as tree lengths to the woodyard where they were bucked on-board with a Curry Cost Cutter. Table 23 notes System A's equipment condition when observed.

The crew consisted of the owner and a hired operator, although there had been as many as four crew members in the past. The owner (Employee 1) was a college graduate with a forestry degree. Employee 2, the hired operator, had a two-year forest technician degree. His job had been subject to high turnover in the past. Table 24 summarizes the crew's personal data. Their responsibilities with the operation are noted in Table 25.

Prelogging treatments began with the feller-buncher cutting swaths through the stands starting at the deck and moving outward radially. Hardwoods were cut and piled to prevent hose breakage from driving over scattered trees on the ground and because many hardwood saplings could not be run over with the MorBell. This practice invariably decreased felling productivity, but may have been partially compensated for by occasional delivery of the pulpwood-sized hardwoods to the yard. The wood was all laid in one direction, with the butts facing the landing in order to aid skidding. The bunches were gate delimbed and skidded to the deck. Once enough wood for a trailer load was on the deck the skidder operator moved to the loader, provided that the haul truck was present.

System A had produced 92.1 cords per week, on the average, for the 10 months reported with the crew working 35 to 40 hours per week. Figure 20 is a plot of the weekly production reported. After a high reached at the beginning of the year, weekly production seems fairly stable. Interestingly, though, the trend appears to be decreasing slightly rather than increasing with experience in small-tree harvesting.

System A's MorBell feller-buncher was observed accumulating 45 bunches during the study. Table 26 shows the distribution of times and trees per bunch. The times ranged from .30 to 1.78 minutes per bunch. Sixty percent of the accumulated loads took less than one minute to collect and over 90 percent required less than 1.5 minutes. As shown, 41 of the 45 bunches (91 percent) contained three trees or fewer.

Productivity of the Franklin 170 also was examined. The times of 28 skidder turns, along with the number of trees per turn, were recorded and their distribution is related in Table 27. The cycles observed centered around four to five minutes and were fairly evenly divided around either side of

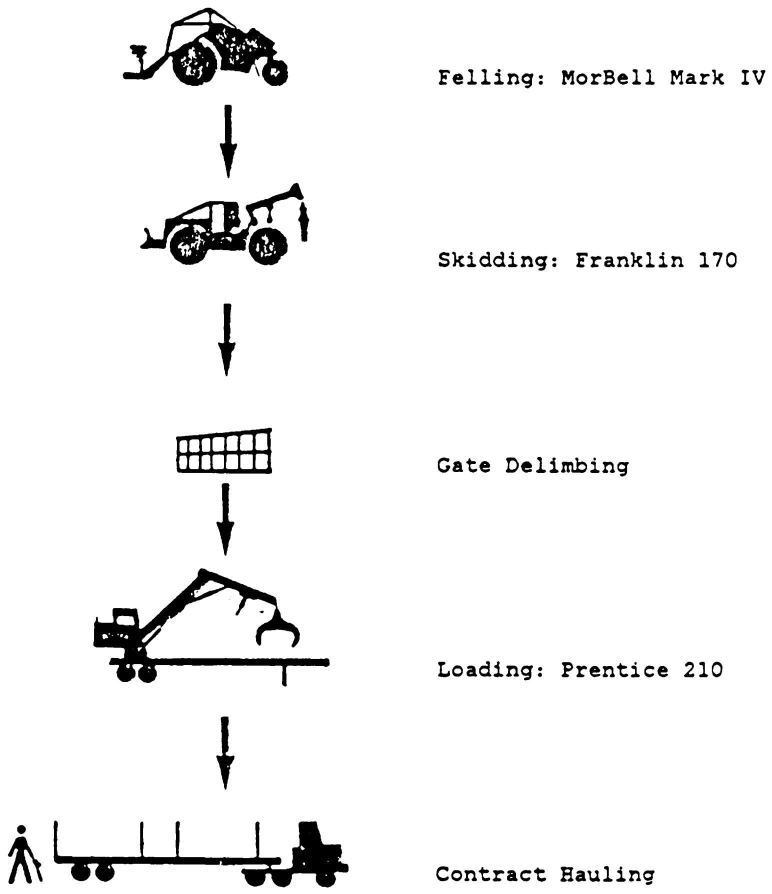

Figure 19. System A Material Flow

Table 23. System A Equipment Condition

Equipment	Age (Months)	Approximate Engine Hours	Condition[1]
MorBell Mark IV	14	1200	Very good
Franklin 170 skidder	24	1000	Good
Prentice 210	72	3800	Good

[1] For descriptions of condition classes see Appendix K.

Table 24. System A Crew Characteristics

		Work Experience (Years)		
Employee Number	Age (Years)	With Crew	All Timber Harvesting	Other
1[1]	27	3.5	3.5	4.5 college
2	21	.5	.5	2 technical school

[1] Owner/foreman

Table 25. System A Crew Responsibilities

Employee Number	Feller-Buncher	Skidder	Loader	Mechanic
1	1		X[1]	1
2		1	1[2]	

1 = Primary Responsibility(s)
X = Other Responsibilities

[1] Since it was desired to keep the feller-buncher one to two days' work ahead of the skidder, Employee 1 would operate the loader only if sufficient inventory was on the ground for the skidder.

[2] Included trimming and binding trailer loads.

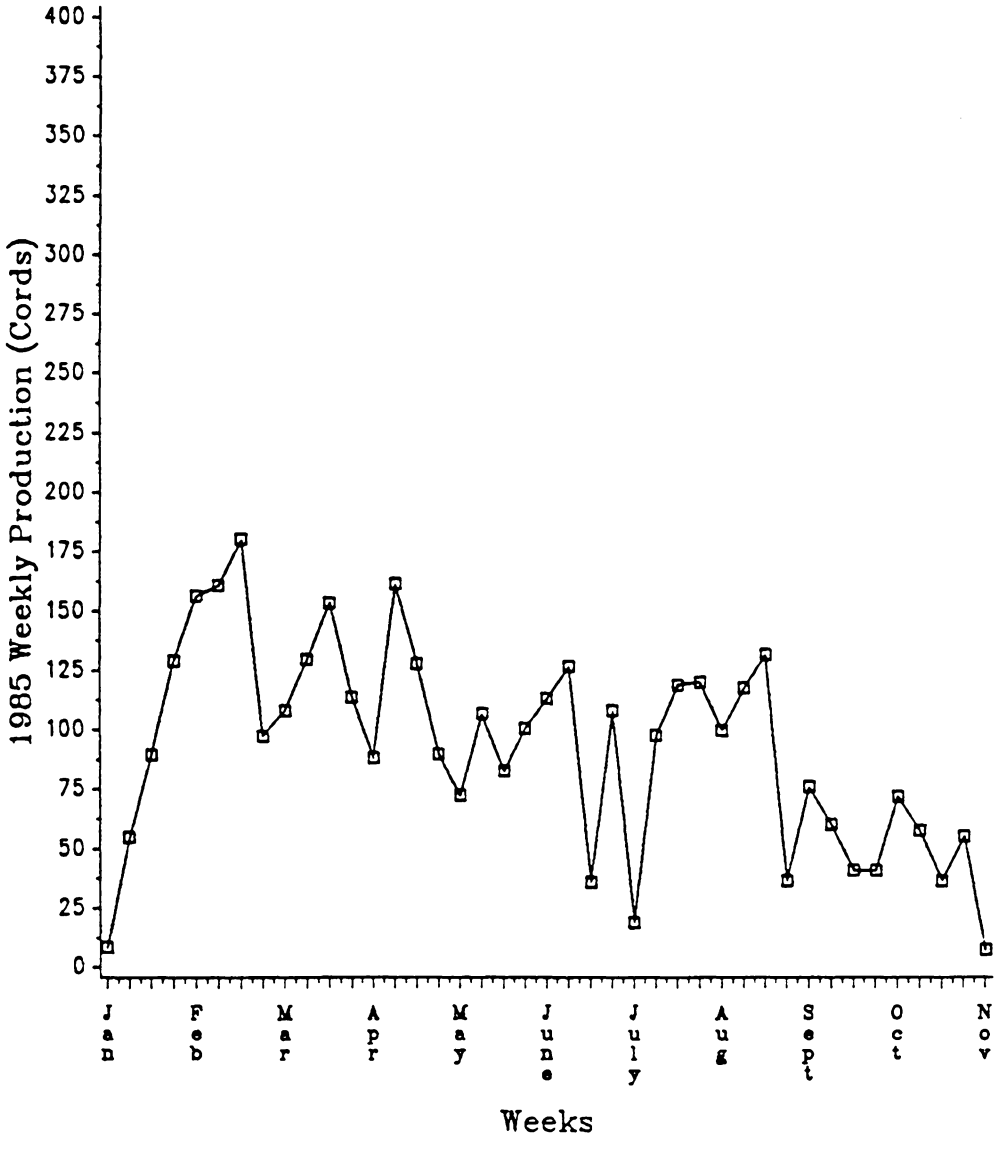

Figure 20. System A Weekly Production

Table 26. System A Observed Feller-buncher Productivity Data

Time per Bunch Interval Midpoint (Minutes)	Relative Frequency	Cumulative Relative Frequency	Trees per Bunch	Relative Frequency	Cumulative Relative Frequency
.25	.04	.04	1	.31	.31
.50	.16	.20	2	.24	.55
.75	.24	.44	3	.36	.91
1.00	.22	.66	4	.04	.95
1.25	.16	.82	5	---	.95
1.50	.16	.98	6	.04	.99
1.75	.02	1.00			

* 45 cycles recorded

the middle interval from 2.02 to 6.07 minutes. The grapple loads contained from six to 13 trees with the majority consisting of eight to 11 pieces.

Five trailers were sampled for the load tally (Table 28). Load size ranged from 90 trees and a weight of 18.69 tons to 121 trees weighing 20.62 tons. Interestingly, the trailer containing the heaviest payload with the most and the smallest trees took the least time to load.

After loading, the trailers were hauled about 10 miles to the woodyard. The beginning of the haul consisted of 1.6 miles on a Class 3 permanent woods road[12]. From that point, 8.5 miles on a Class 2 public road brought the loads to the yard entrance.

A number of factors affected the productivity and profitability of System A. Use of the MorBell feller-buncher revealed several difficulties. The operator felt that both terrain and tree size may have imposed performance penalties which, in turn, decreased the machine's flexibility in application; the three-wheeled vehicle was not as stable as its four-wheeled counterparts and, because of its small size, could not easily push over the larger hardwood saplings it encountered. The machine's design, however, did provide for excellent maneuverability, even in dense stands. Problems had been experienced with replacement of exotic hydraulic components and with an inordinate amount of hydraulic hose wear due to inadequate protection at some points. Also, some periodic maintenance, most notably with the hydraulic oil reservoir and filter, required the operator to assume uncomfortable positions. Excessive noise levels during engine operation were felt to interfere with crew communication and to adversely affect operator comfort, even with ear protection. Dust and debris, along with obstructions in the cab which caused blind spots, led to operator visibility which was far less than ideal. Some of these problems may have reduced the productivity of the MorBell, while the others dealt with hazard reduction and maintenance of operation.

Lack of climate control in the cab of the Franklin skidder was believed by the operator to be a hindrance to his productivity, as was the sound intensity of the machine, with or without noise protection. Also, the driver would have preferred more cushion from shock in the seat. He felt that some service could not be accomplished without getting unduly wet or dirty. These opinions all

[12] See Appendix L for descriptions of the different road type classes.

Table 27. System A Observed Skidder Productivity Data

Time per Turn Interval Midpoint (Minutes)	Relative Frequency	Cumulative Relative Frequency	Trees per Turn	Relative Frequency	Cumulative Relative Frequency
2	.07	.07	6	.18	.18
3	.07	.14	7	.04	.22
4	.43	.57	8	.11	.33
5	.36	.93	9	.18	.51
6	.07	1.00	10	.21	.72
			11	.11	.83
			12	.11	.94
			13	.07	1.01

* 28 cycles recorded

Table 28. System A Load Tally Results

Load Number	Time to Load (Minutes)	Number of Trees	Load Weight (Tons)	Trees per Ton
1	43.25	90	18.69	4.82
2	60.00	96	19.38	4.95
3	44.50	100	19.28	5.12
4	40.00	93	17.39	5.35
5	32.00	121	20.62	5.87
Mean	43.95	100	19.07	5.22

dealt with operator comfort, but they could have been attributable to unfamiliarity with mechanical timber harvesting equipment and typical working conditions facing loggers.

The owner felt that the operator should have had more experience with the Prentice loader so that he could achieve the skill level that he had on the skidder. The operator had found that lack of arm and head rests and what he felt was excessive vibration in the cab caused him discomfort and may have decreased his productivity. The machine's robustness and size, however, were deemed appropriate for the size of timber handled.

The 10-mile haul distance allowed for relatively fast turnaround time, even though the trucker hauled for another job before returning. The contract truckers in the area were not particularly eager to haul from the woods. Therefore, the logging roads had to be very well built and well maintained.

The timber-owning company built and maintained decks and roads for the operation, eliminating the need for the owner to purchase construction equipment. It was not determined if the price he was paid for the pulpwood he delivered was lower because of this service. The company also provided boundary marking in the stands. The forester responsible for this operation noted that system production was mainly constrained by quotas (120 to 150 cords per week) in the summer and by weather in the winter.

Labor turnover had been a problem on this crew, as mentioned previously. A reason for the high turnover was the danger involved with logging. Even though all crew members had received safety training and some safety equipment (hard hats, ear and eye protection) was required, injuries had been fairly common.

The yard allowed trailers to be loaded butt-to-top. Although this practice would have increased load size, it was not done. The owner believed that butt-to-top loading at the landing would detain the haul truck for too long.

Appendix F. Detailed Description of System B

Thinning on industry land was the primary activity undertaken by System B, a sole proprietorship. When observed, the system had been in operation for 18 months. The system was equipped to produce tree length pine pulpwood in Virginia's Piedmont region.

System B normally operated in industry pine plantations. On the preceding contract an average of 6.3 cords per acre on 178 acres were harvested. At the time of study, the job site was located in a 19-year-old stand which averaged 8.3 inches DBH before thinning. Moderate amounts of brush were present in the stand, possibly impeding feller-buncher performance at the stump.

Figure 21 shows System B's harvest flow. The feller-buncher used in System B was a Caterpillar 910 with a Fleco 15-inch accumulating head. A Caterpillar 518 grapple skidder was used to skid and a Prentice 150 loader equipped with a pulpwood grapple and mounted on an old truck was used to load the trailers. The loader was a repossession which was purchased second hand. The hauling was accomplished with a 12-year-old Mack truck and two 10-cord frame trailers. The condition of System B's equipment when studied is related in Table 29.

The crew was made up of five people. Their ages and experience are related in Table 30. The four younger crew members grew up in the same town and had been friends since attending high school. In addition to work experience, the owner (Employee 1) had some vocational-agricultural training. The skidder operator (Employee 2) had spent much of his working life as a taxi driver in

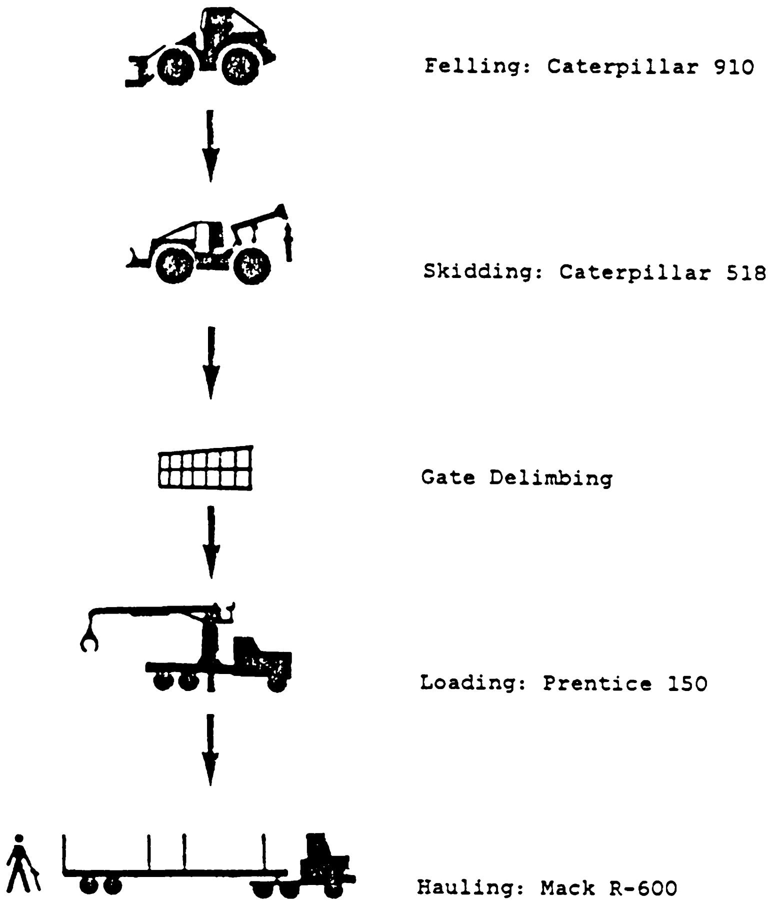

Figure 21. System B Material Flow

Table 29. System B Equipment Condition

Equipment	Age (Months)	Approximate Engine Hours	Condition
Caterpillar 910	12	990	Excellent
Caterpillar 518	144	850[1]	Good
Prentice 150	84	2600	Very good

[1] Engine had been rebuilt several times.

a large city. Loading in this operation was normally undertaken by the wife of the owner (Employee 3). System B's deck hand (Employee 4) was the oldest crew member. He was the only member not with the group since high school. High turnover of truck drivers had plagued the operation until the driver present at the time of study (Employee 5) joined the crew. The duties of each crew member are shown in Table 31.

The thinning technique used in this operation consisted of first clearing the main skid trail marked by the company which owned the timberlands. Next, parallel corridors were cut about 60 feet apart in a herringbone fashion. When the corridors had been cleared, the area between was thinned with the feller-buncher operator selecting which trees to take and leave. The bunches were skidded to the landing, where they were gate delimbed, then brought to the loader. The skidder often pushed the slash from around the gate and loader off to the side of the deck to aid traffic flow.

Over the prior nine months, System B's average production had been 105.9 cords per week. Figure 22 reflects the operation's reported thinning production. It is interesting to note that production seems somewhat cyclical. Every 1.5 to 2 months a peak level was reached, followed by a proportionally large drop in cords produced per week. Missing data points represent weeks when System B was not thinning. In attaining this production, the crew worked 30 to 50 hours per week, usually towards the middle or lower end of this range.

The Caterpillar 910's felling and accumulating cycles were timed. Their distribution is shown in Table 32. The times per bunch ranged from .27 to 2.27 minutes. Less than one minute was taken to acquire and drop a bunch in 37.9 percent of the 29 cycles recorded and less than two minutes were required 93.1 percent of the time. Between one and six trees per bunch were accumulated before being released, although nearly 50 percent of the bunches contained either four or five trees. The observed numbers of trees per bunch are also depicted in Table 32.

While observing the skidder, 21 turns were recorded. The times and number of trees per turn are shown in Table 33. The turns took from 2.87 to 11.52 minutes to complete with a median value of 4.96 minutes. The Caterpillar 518 needed less than seven minutes to finish a cycle in 85.7 percent of the cases observed. The number of trees brought to the landing per turn was from 2 to 14. However, a vast majority of the skidder bunches consisted of from six to 12 trees.

Table 30. System B Crew Characteristics

		Work Experience (Years)		
Employee Number	Age	With Crew	All Timber Harvesting	Other
1[1]	24	1.5	2 shortwood 1 clearcutting[2] 1.5 thinning	1 auto mechanic
2	28	1.5	.5 shortwood 1.5 thinning	6 taxi driver
3	21	1	1 thinning	2 factory
4	45	.5	30 various jobs	
5	23	1	3 shortwood 1 hauling	

[1] Owner/foreman

[2] Experience as an independent logger.

Table 31. System B Crew Responsibilities

Employee Number	Feller-Buncher	Skidder	Loader	Deck Man	Haul Truck	Mechanic
1	1	X	X		X	1
2	X	1				X
3			1			
4	X	X	X	1	X	
5	X	X		X	1	

1 = Primary responsibility(s)
X = Other responsibilities

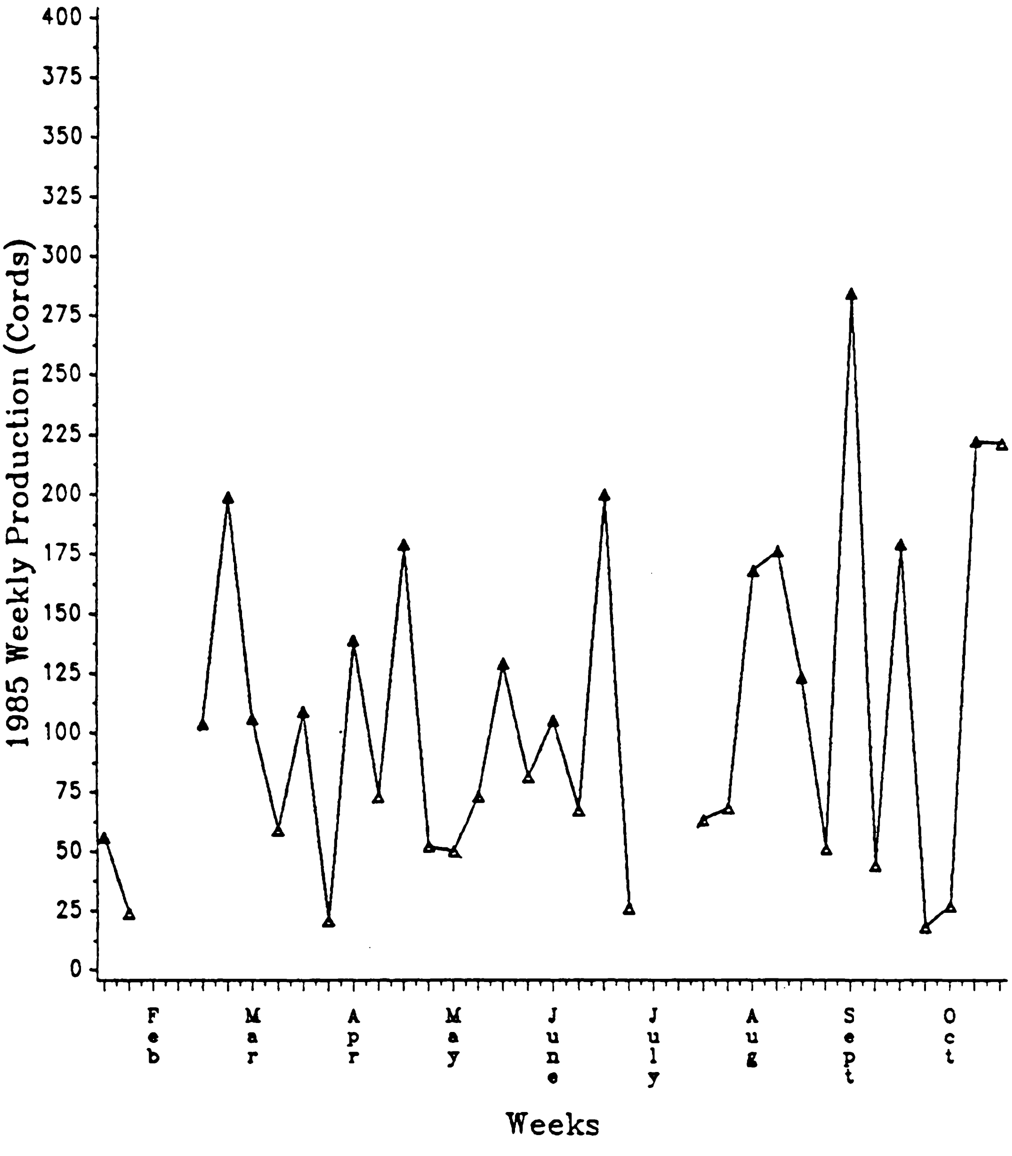

Figure 22. System B Weekly Production

Table 32. System B Observed Feller-buncher Productivity Data

Time per Bunch Interval Midpoint (Minutes)	Relative Frequency	Cumulative Relative Frequency	Trees per Bunch	Relative Frequency	Cumulative Relative Frequency
.25	.03	.03	1	.10	.10
.50	.14	.17	2	.17	.27
.75	.14	.31	3	.14	.41
1.00	.14	.45	4	.24	.65
1.25	.17	.62	5	.24	.89
1.50	.14	.76	6	.10	.99
1.75	.10	.86			
2.00	.10	.96			
2.25	.03	.99			

* 29 cycles recorded

Table 33. System B Observed Skidder Productivity Data

Time per Turn Interval Midpoint (Minutes)	Relative Frequency	Cumulative Relative Frequency	Trees per Turn	Relative Frequency	Cumulative Relative Frequency
3	.14	.14	2	.05	.05
4	.19	.33	3	---	.05
5	.24	.57	4	.05	.10
6	.19	.76	5	---	.10
7	.10	.86	6	.10	.20
8	.05	.91	7	.10	.30
9	---	.91	8	.19	.49
10	.05	.96	9	.14	.63
11	---	.96	10	.05	.68
12	.05	1.01	11	.14	.82
			12	.10	.92
			13	.05	.97
			14	.05	1.02

* 21 cycles recorded

Table 34 gives the results of the load tallies of four trailers. From 182 to 246 trees were placed on the trailers in from 37.87 to 54.42 minutes. The highest net weight observed was 32.43 tons, the lowest was 29.13 tons.

During the study, loads were hauled only 5.0 miles to the woodyard. The first 1.0 mile was a Class 3 permanent woods road. The remainder of the haul was on a Class 3 public road.

The feller-buncher operator believed that both weather and soils could adversely affect the machine's performance, which necessitated some special scheduling considerations. Hydraulic hoses often shook loose, and this, along with the arrangement of the drip tray, led to relatively frequent hazards of spillage of hot hydraulic oil over the machine. Also, the operator felt that the location of the exhaust system was conducive to debris accumulation and subsequent risk of fire. The presence of dust and vapors in the cab and lack of climate control bothered the operator enough to make it necessary to take breaks more often than would otherwise be needed, reducing productivity.

The skidder driver also felt that soils and weather could constrain productivity to a certain extent, but not to the degree that the feller-buncher was affected. Service and repair was an area of concern for the operator. Difficulty in access to the fuel tank was an annoyance to him. He also thought that inadequate considerations were provided for mechanic comfort and protection. Also, protective shields and bellypans were a problem to open or remove. The cab was another problem area, according to the driver. Sharp angles, entry of foreign materials and fumes, obstructions to view, and what was felt to be excessive vibration due to seat design all caused the operator discomfort and/or restricted efficient skidding. A positive aspect was that both the owner and operator were impressed with the power capabilities of the machine.

The loader operator felt that cold weather was detrimental to the performance of some hydraulic components of the Prentice 150. The owner, who conducted most of the service on the machine, believed that hydraulic hose protection was inadequate. Some safety considerations were a cause for concern. The operator would have preferred non-slip surfaces on the steps leading to, and railings around, the seat. The seat itself did not suit the operator because it had no belt, no armrests or headrests, and the vibration caused excessive fatigue. Hearing protection was necessary

Table 34. System B Load Tally Results

Load Number	Time to Load (Minutes)	Number of Trees	Load Weight (Tons)	Trees per Ton
1	37.87	182	29.32	6.21
2	43.25	226	30.63	7.38
3	38.90	200	29.13	6.87
4	54.42	246	32.43	7.59
Mean	43.61	214	30.38	7.01

during operation, which affected communication with the rest of the crew. Since the loader was mounted on an inoperable truck, the entire set-up had to be hauled around by the skidder. Transportation between jobs caused problems, especially when highway travel was involved because the driver felt that the skidder's steering was unstable at highway speeds.

The large load size on the haul truck was accomplished through allowances at the woodyard for butt-to-top loading. However, an average of over 30 tons on a trailer pushed the gross vehicle weight (GVW) of the tractor-trailer over the legal limit and possibly over the legal height limit, also. The owner felt that the short haul to the yard on back roads decreased the likelihood of overweight tickets sufficiently to face the risks.

In addition to marking the main skid trails, the company marked boundaries, constructed decks, and built and maintained roads for the operation. As with System A, these conveniences performed by the company may or may not have affected the contract rate received for pulpwood. Also, the company occasionally offered clearcuts to the owner to boost productivity.

Several other considerations affected the performance of System B. A quota was imposed on weekly system production, but was not strictly adhered to. As more loggers moved into the area, though, enforcement of the quota became more stringent.

As a production incentive, the owner offered pay bonuses to the crew. When he could afford to, he would supplement their wages for delivery of 20 to 25 loads per week to the yard. As the quota became more inflexible, the owner stopped giving bonuses.

As indicated previously in Table 31, several crew members could perform each job in the operation. Therefore, absenteeism, although not common, did not present a problem. The crew was a tight-knit group and had no qualms about covering for each other when necessary.

A continual problem for the contractor was vandalism of equipment. The equipment had to be parked in the stand rather than on the deck. This still left the haul truck to be damaged. When the individual thought to be responsible for the vandalism was arrested, this problem ceased.

Appendix G. Detailed Description of System C

System C was a shortwood thinning operation. The system was operated by a sole proprietor who ran several other operations, as well as being a chainsaw dealer. His other operations consisted of another thinning crew, a prelogging crew, a logging crew, and a trucking service for a local woodyard. When observed, System C had been thinning for 10 months on the boundary between the Piedmont and Coastal Plain regions of Virginia and North Carolina.

System C normally thinned industry-owned plantations, but did operate in natural stands sometimes when on private land. The usual stands averaged about seven inches DBH. During the study, the plantation averaged 6.5 inches DBH and was comprised of loblolly pine with fair amounts of hardwood. The tract contained 15 cords per acre on 149 acres before treatment. One portion of the stand had 6.4 cords per acre removed, while a rockier, more hilly part had only 5.0 cords per acre harvested. The stand was of relatively low basal area for commercial thinning (98 square feet per acre), but the timber owners wanted the stand treated. A previous thinning in a 7.1-inch DBH stand removed 10.4 cords per acre on 122 acres.

Figure 23 depicts the wood flow of System C. A working foreman (Employee 1) operated one feller-buncher, a Franklin 105 with a 14-inch Tidewater head, and performed the selection cuttings between corridors or rows which had been cleared. A Franklin 105 with a Morbark 14-inch Rapid Buncher head, was used by Employee 2 to cut the corridors or rows. One of the system's skidder operators (Employee 3) also drove the spot truck. The skidder operated by this crew member was a Franklin 170. A Clark 665D skidder (driven by Employee 4) also was used to drag the wood to the deck. Employee 5 operated the loader, a new Barko 160A with a fixed heel and pulpwood grapple. It replaced a Barko 250 which was moved to the logging job because it was larger than necessary on the pulpwood operation. A CTR slasher was connected to the loader and was used to buck the material to shortwood size before loading. The trees were manually delimbed by Employee 6. Both drivers (Employees 7 and 8) had hauled for this operation since it began except when haul distance was short enough for one truck to manage. Two trucks, 1981 and 1982 Internationals, were used to transport the pulpwood to the mill when studied. Six 10-cord pulpwood trailers were on the site. Table 35 notes the condition of System C's equipment during the study.

When hiring crew members the owner looked for a willingness to work and thus, job turnover was very low in his crews. He did not feel that harvesting experience was too important as a hiring criterion, as long as the person was eager to learn and work. Formed from a portion of a larger logging crew, this particular crew consisted of from seven to nine people depending on the number of trucks needed for the haul distance at hand. At the time of study, eight members formed the crew. Table 36 details the crew members' ages and experience. Note that nearly every crew member had worked for the owner on other operations for a period of time. The crew's tasks with the operation are outlined in Table 37.

The boundaries of stands to be thinned were marked by the company which had bought the timber. To begin a thinning operation, every fifth row was removed if enough room was available to maneuver without damaging the remaining trees. If not, corridors were cut perpendicular to the rows and spaced 30 to 35 feet apart to assimilate a fifth row removal. Corridors were placed so that felling was downhill (across contours) when significant slopes were faced. This way the possibility of equipment rollover was lessened. When the corridors or rows had been cut, selection between them was done by the other feller-buncher with the operator deciding which trees to remove. The bunches were normally manually delimbed in the woods, but sometimes were skidded to an intermediate deck first. Following delimbing, the bunches were skidded to the deck where they were bucked to five-foot lengths by the slasher and loaded onto trailers.

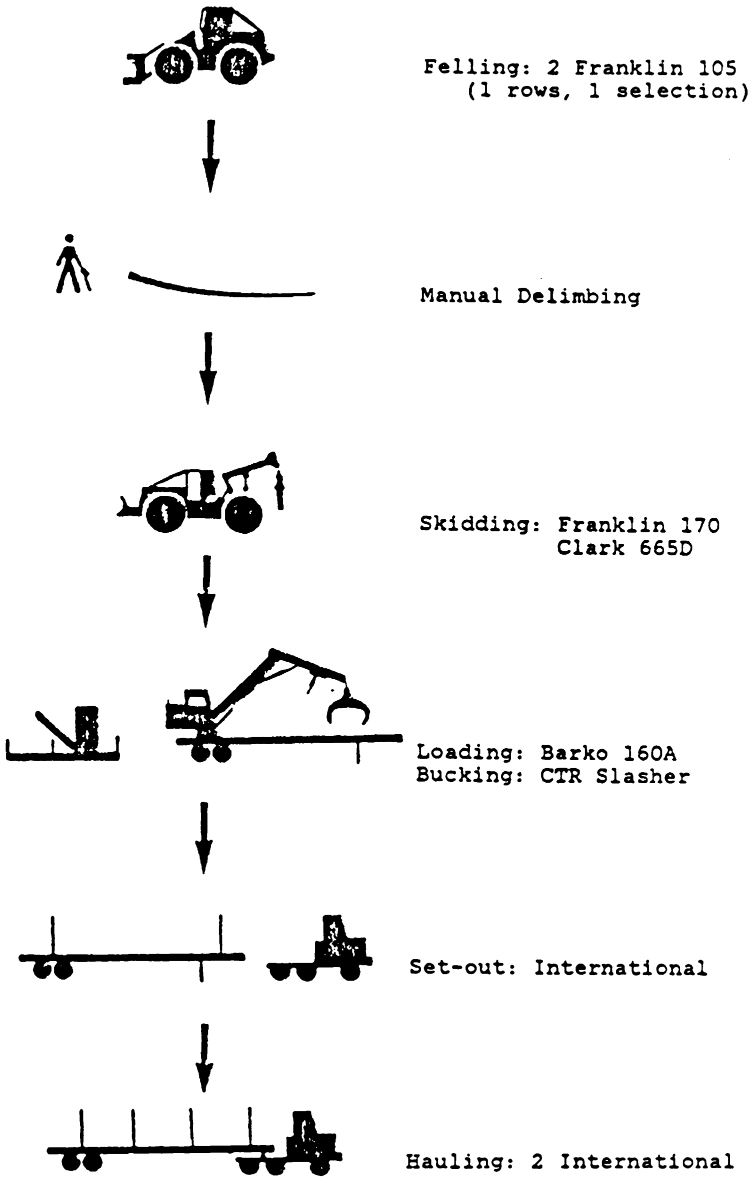

Figure 23. System C Material Flow

Table 35. System C Equipment Condition

Equipment	Age (Months)	Approximate Engine Hours	Condition
Franklin 105 feller-buncher (selection)	12	650	Excellent
Franklin 105 feller-buncher (rows)	30	3800	Excellent
Franklin 170 skidder	10	1250	Excellent
Clark 665D skidder	6	850	Excellent
Barko 160A	1	145	Excellent
CTR slasher	10	---	Very good

Table 36. System C Crew Characteristics

		Work Experience (Years)		
Employee Number	Age	With Crew	All Timber Harvesting	Other
1[1]	33	.83	15 various jobs[2]	
2	25	.83	8 clearcutting[2] .83 thinning[2]	
3	32	.83	8 clearcutting .83 thinning[2]	5 factory
4	32	.33	14.5 various jobs .33 thinning[2]	2 construction
5	45	.83	18 various jobs[2]	11 farming
6	42	.83	2.5 thinning[2]	
7	40	.83	20 logging and hauling[2]	
8	42	.83	20 logging and hauling[2]	

[1] Foreman

[2] At least a portion of experience on other operations run by owner

Table 37. System C Crew Responsibilities

Employee Number	Feller-Buncher	Skidder	Loader	Limb & top	Set-out	Haul Truck	Mechanic
1	1	X					
2	1		X				1
3	X	1	X		1		
4		1		X	X		
5	X	X	1		X		
6				1			
7						1	
8						1	

1 = Primary responsibility(s)
X = Other responsibilities

The crew worked 40 to 45 hours a week and usually reached their quota (25 to 30 loads per week) in 4 to 4.5 days. Average production over the previous 10 months had been 262.3 cords per week. Figure 24 illustrates System C's weekly production trends. Since production was reported on a monthly basis, an average for each week of the month was used. After an initial rise at the outset of the operation, production seems to have become relatively stable at the current level. The higher production rates observed in the fall and winter may be accounted for by fluctuations in quotas.

Both of System C's Franklin feller-bunchers were observed so that their productivity could be sampled. Only 10 cycles were timed for the feller-buncher which cut rows (Feller-buncher 1) because, as the crew mechanic, the operator spent a good deal of his time performing maintenance and repairs on the system's equipment. The felling and bunching cycles examined required from .99 to 1.98 minutes to complete and from four to seven trees were accumulated before being dropped. The distributions of times and trees per bunch are shown in Table 38.

Twenty four cycles were recorded for the selection feller-buncher (Feller-buncher 2). Much more variability was observed with this feller-buncher than with the row feller-buncher, both in cycle times and the number of trees per bunch. The felling cycles took from .83 to 4.94 minutes, much longer than with the row feller-buncher. While the maximum observed time for the row feller-buncher was 1.98 minutes, only 29.2 percent of the cycles for the selection machine took this amount of time or less. Most likely this was because selection cuttings require more maneuvering and more care to avoid damage than when removing rows. Also, much time was spent knocking down hardwoods while selecting the trees to leave. The number of trees per accumulated bunch ranged from two to 10, but three-quarters of the bunches contained four to six trees. The distribution of times and trees per bunch for the selection feller-buncher also appear in Table 38.

Turn times for System C's two skidders also were observed. The times of 22 turns for the Franklin skidder (Skidder 1) were recorded. They ranged from 1.86 to 17.10 minutes. Within this large range, 50 percent of the turns fell into the four to seven minute interval. The spread of turn times is shown in Table 39. Skidder 1 dragged from five to 21 trees per turn while watched. The number of trees per skidder load seemed to be distributed rather randomly, as seen in Table 39.

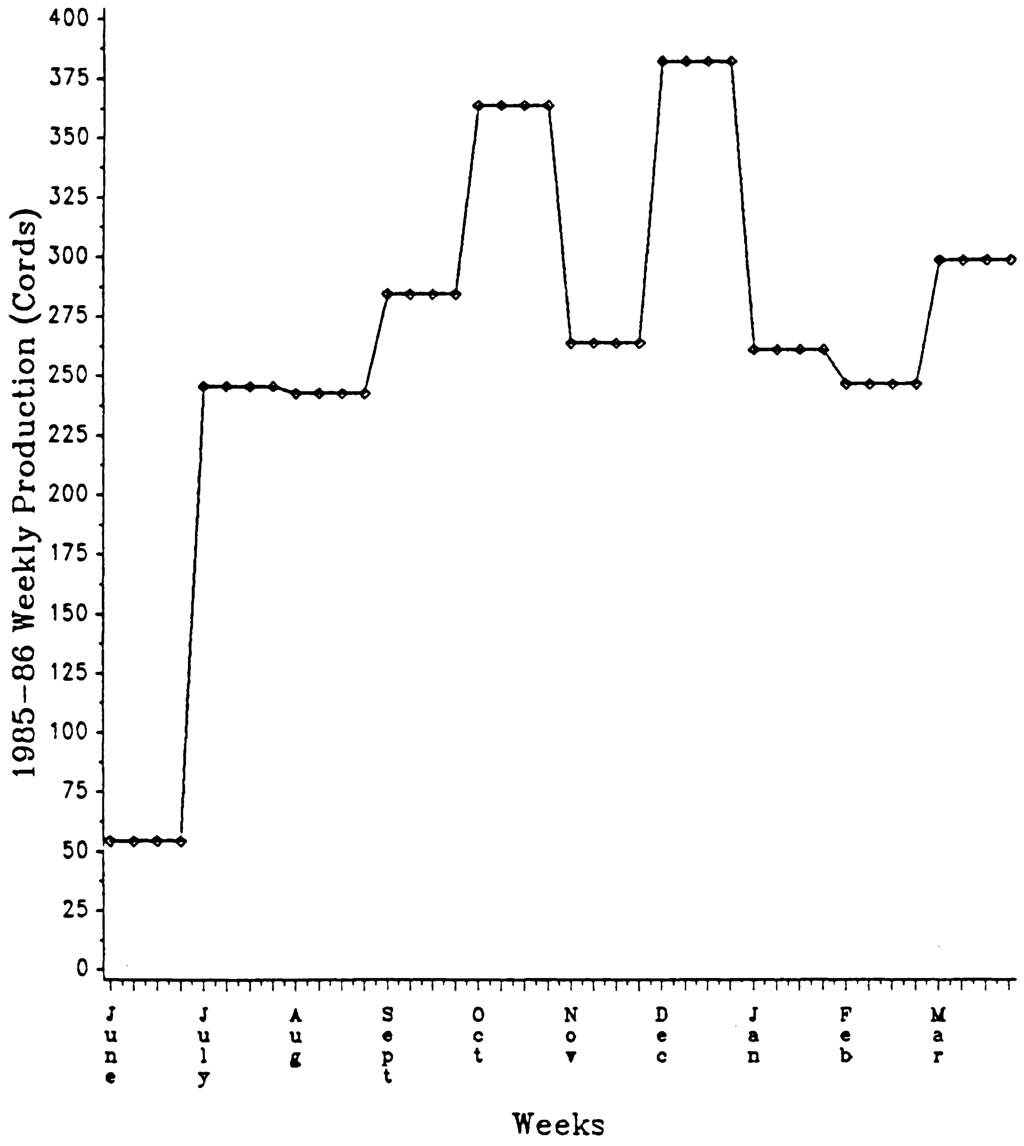

Figure 24. System C Weekly Production

Table 38. System C Observed Feller-buncher Productivity Data

Time per Bunch Interval Midpoint (Minutes)	Relative Frequency		Cumulative Relative Frequency		Trees per Bunch	Relative Frequency		Cumulative Relative Frequency	
Feller-buncher No. →	1	2	1	2		1	2	1	2
.75	---	.04	---	.04	2	---	.08	---	.08
1.00	.20	---	.20	.04	3	---	.04	---	.12
1.25	.40	.04	.60	.08	4	.20	.25	.20	.37
1.50	.10	.04	.70	.12	5	.30	.33	.50	.70
1.75	.20	.08	.90	.20	6	.10	.17	.60	.87
2.00	.10	.13	1.00	.33	7	.40	---	1.00	.87
2.25		.13		.46	8		.08		.95
2.50		.08		.54	9		---		.95
2.75		.08		.62	10		.04		.99
3.00		.08		.70					
3.25		.08		.78					
3.50		.08		.86					
3.75		---		.86					
4.00		---		.86					
4.25		.04		.90					
4.50		---		.90					
4.75		.04		.94					
5.00		.04		.98					

* Feller-buncher 1: 10 cycles recorded.
Feller-buncher 2: 24 cycles recorded.

Table 39 also illustrates the distributions of the Clark skidder's (Skidder 2) times per turn and trees per turn. The 21 turn times seem to have had a distribution similar to the Franklin's, although shifted towards the longer times. The range was from 2.86 to 19.81 minutes. Trees per drag had a low of six and a high of 39. As with the other skidder, the number of trees per bunch did not congregate around any particular value.

Tallies were conducted on six sample trailer loads. The loads ranged from 188 to 270 trees and weighed from 22.20 to 25.33 tons. Loading took from 60.70 to 73.90 minutes, which was longer than in any other system studied. Undoubtedly, this was due to the added element of bucking the material to shortwood size before loading. Table 40 contains the tally data.

The foreman performing the selection cuttings and operating one of the Franklin 105 feller-bunchers had no complaints about the machine. In fact, he felt that the machine's balance of power and size made it one of the best available for the job he was faced with. The other feller-buncher operator preferred the one-bladed Morbark shear on his machine over the scissor type because of faster open and close times for the blade. He could use this type of shear since he cut rows only and travelled in a fairly straight line. However, the amount of maneuvering necessary to cut trees in a selection between rows would be increased with this anvil-type accumulating shear. The Morbark felling head had been modified in an effort to reduce breakage and subsequent down time. A cover had been put over the hydraulic fittings at the back of the head for protection. Also, the accumulator arm stops had been modified to reduce strain on welds. Employee 2 would rather have had his machine equipped with hydrostatic drive, as was the other feller-buncher, so that direction of travel could be controlled with a foot pedal instead of a hand lever.

The skidder drivers seemed generally content with the machines that they worked with. The transmission of the Franklin had been rebuilt once since the machine was purchased. However, the operator could not offer any improvements to the machine and seemed satisfied with all aspects of the skidder. The operator of the Clark skidder commented that he preferred his skidder over the other (Franklin 170) because of what he perceived as more power and a more comfortable ride.

Employee 5 had no problems or complaints with the Barko loader. He felt that it sufficed for the job he performed. It was observed, however, that when the machine was running but no one

Table 39. System C Observed Skidder Productivity Data

Time per Turn Interval Midpoint (Minutes)	Relative Frequency		Cumulative Relative Frequency		Trees per Turn	Relative Frequency		Cumulative Relative Frequency	
Skidder No. →	1	2	1	2		1	2	1	2
2	.05	---	.05	---	5	.05	---	.05	---
3	.09	.10	.14	.10	6	---	.05	.05	.05
4	.14	.05	.28	.15	7	.05	---	.10	.05
5	.18	.05	.46	.20	8	---	---	.10	.05
6	.18	.19	.64	.39	9	.05	---	.15	.05
7	.09	.19	.73	.58	10	.05	.05	.20	.10
8	.05	---	.78	.58	11	.09	.19	.29	.29
9	.09	.05	.87	.63	12	.09	.10	.38	.39
10	---	.05	.87	.68	13	.05	.10	.43	.49
11	.05	.05	.92	.73	14	.05	.05	.48	.54
12	.05	.14	.97	.87	15	.18	.10	.66	.64
13	---	.05	.97	.92	16	---	.05	.66	.69
14	---	---	.97	.92	17	.14	.14	.80	.83
15	---	---	.97	.92	18	.05	.05	.85	.88
16	---	.05	.97	.97	19	---	---	.85	.88
17	.05	---	1.02	.97	20	.14	---	.99	.88
18		---		.97	21	.05	.05	1.04	.93
19		---		.97	22		---		.93
20		.05		1.02	23		---		.93
					24		.05		.98
					> 24[1]		.05		1.03

* Skidder 1: 22 cycles recorded.
Skidder 2: 21 cycles recorded.

[1] One turn contained 39 trees.

Table 40. System C Load Tally Results

Load Number	Time to Load (Minutes)	Number of Trees	Load Weight (Tons)	Trees per Ton
1	62.73	232	25.04	9.27
2	70.90	270	25.16	10.73
3	72.62	222	24.17	9.18
4	60.70	218	24.58	8.87
5	73.90	188	22.20	8.47
6	66.45	215	25.33	8.49
Mean	67.88	224	24.41	9.17

was in it, the cab and boom swiveled slowly, which could be hazardous to personnel on the ground in the vicinity of the loader.

Once brought to the set-out point, the trailers were hauled about 70 miles to the mill. The haul began with a short (less than .1 mile) drive on a temporary road. The next 20 miles were on a Class 2 public road, followed by 48 miles on a Class 1 public highway. The loads then were hauled the final one mile on a village street.

Every operation run by the owner of System C had a Fiat-Allis 10-B dozer at the job site. The dozer in System C was used to construct decks and roads when necessary, but was not used in everyday operation. Though this may or may not affect the contract rate received for timber, crew construction allowed them to place and form the decks as desired by those who would use them. Also, decks and roads were kept clear and level with the dozer, although the company would provide rock for roads if needed. In addition to the dozer, the operation had access to the owner's shop and an extensive parts inventory that he kept on hand.

The mill purchasing the wood was not equipped to handle tree length material or chips. Thus, the job was required to produce shortwood which, if anything, was seen as a drawback by the owner. It did, however, allow the 10-cord capacity of the trailers to be more fully utilized than with conventional tree length loading techniques with small trees. The additional loading capacity could be especially advantageous on longer hauls such as the 70 miles to the mill during the study.

The owner's philosophy towards his thinning projects was to concentrate on a job that looked good first, then to work on increasing production. He felt that this led to good public relations. In fact, several industry personnel described stands following thinning by this crew as looking "like a park." An attempt was made to remove all trees without a chance to grow into a good sawlog. Fewer trees may have been left than with other operations, but those that remained were usually the best trees.

Very small pines were run over rather than harvested because deductions were made at the mill for trees less than 3.5 inches at the small end. An attempt was made to knock over all hardwoods, also. This practice was time consuming and could present problems in stands with a large hardwood component, but was consistent with the owner's thoughts concerning thinning.

In spite of these productivity-reducing activities, deliveries to the mill were consistently constrained by quotas. An incentive to keep production at the quota level was that the crew was paid by the load. Therefore, if the quota was met before the end of the work week, the crew could take the remainder of the week off while still receiving the same pay.

An unusual occurrence that occasionally befell this system was wood theft. At the end of a day, two loaded trailers were left at the set-out point for the next morning. Sometime during the night, the trailers were taken. An interesting point is that the trailers were returned, but empty. It should be noted that this was not a common occurrence, but it had happened more than once.

Appendix H. Detailed Description of System D

System D was a prelogging operation which had been working with small trees for four years. This system was under the same owner as System C, a sole proprietor. The major product was pine pulpwood, although some hardwood pulpwood was produced. The operation was located mainly in the Upper Coastal Plain of Virginia. Occasionally, the operation would move closer to the owner's headquarters and prelog in Virginia's Piedmont region.

System D operated in both plantations and natural stands. At the time of study, the crew was in a stand that was part natural and part aerial seeded (in 1958), with a fairly large hardwood component. Pine in the stand averaged 7.4 inches DBH and 17.9 cords per acre, while hardwoods averaged 8.8 inches DBH and 2.7 cords per acre prior to harvest. The prelogging removed 12.0 cords of pine and .85 cords of hardwood per acre on 404 acres.

Figure 25 depicts System D's material flow. Both feller-bunchers used in System D were Franklin 105's with 12-inch Tidewater heads. Both skidders were also Franklin 105's. The trees were manually limbed and topped after being skidded to an intermediate deck near the landing. The loader used was a Barko 160 which had had its fixed heel removed. It was equipped with a log grapple. As in System C, a Fiat-Allis 10-B dozer was used in the operation. Aside from the deck and road construction that the dozer in System C was used for, this machine was used with a dolly to set loaded trailers out at the pick-up point and bring empty trailers back to the deck.

Two International trucks, 1981 and 1979 models, with four 10-cord frame trailers were used to haul for the job. Three of the trailers had one-foot extensions inserted into their standards to increase possible loading height. The condition of System D's equipment when observed is tabulated in Table 41.

The crew, established with men who were drawn from throughout the owner's other crews, consisted of eight people. The foreman (Employee 1), who was also the crew mechanic, operated a feller-buncher. The other feller-buncher operator (Employee 2) also had operated a skidder for the crew. Employees 3 and 4 drove the skidders. The loader and dozer were operated by Employee 5. Being the only man constantly on the ground on this job and operating a chain saw, the limber-topper (Employee 6) was the only crew member required to wear any safety equipment (hard hat supplied by the owner, steel-toed boots). Another of his responsibilities was to assist the loader/dozer operator in setting out trailers. Two haul truck drivers (Employess 7 and 8) were employed with System D. Table 42 relates the system's crew characteristics. As with System C, nearly all crew members had spent a good deal of time working with the owner. Each member's responsibilities are shown in Table 43. As shown, several crew men can perform each job.

Prelogging operations were begun at the deck and moved radially outward to boundaries marked by the timberland owner. However, the stand which the system was in during study was surrounded by swampland and a farmer's field, so boundary marking was unnecessary. All pines less than nine inches DBH and any crooked nine to ten inch trees without a good 16-foot log were cut. Hardwoods which were smaller than would be harvested by the follow-up logging operation (less than five inches DBH) were run over. Each skidder followed one of the feller-bunchers and dragged the felled material through the stand. Since the remaining trees were to be removed in a second pass, moderate damage was acceptable. Therefore, to aid the limber-topper, clumps of trees were left in the stand and the skidders backed their loads through the clumps, breaking off many of the branches much like a gate delimber. The bunches then were skidded to an intermediate deck where the remainder of the limbs and the tops were removed. After dropping an unlimbed bunch at the intermediate deck, the skidders picked up a limbed bunch and dragged it to the main deck where it was loaded onto the trailer. While the landing was unoccupied during trailer set-out, the

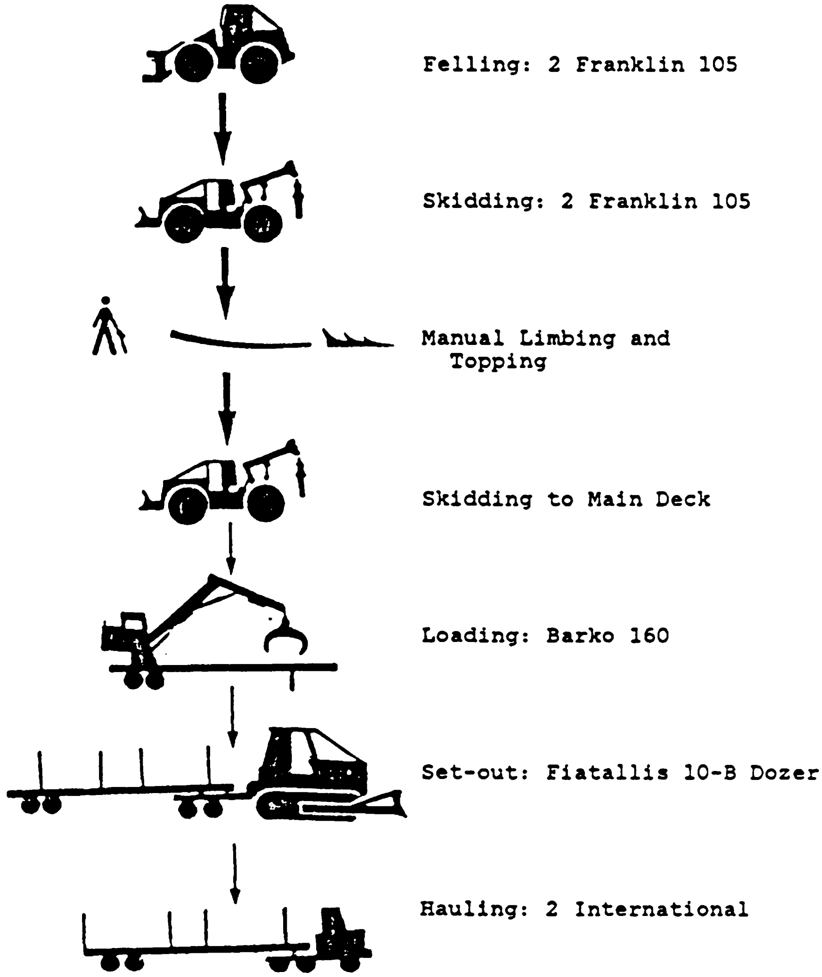

Figure 25. System D Material Flow

Table 41. System D Equipment Condition

Equipment	Age (Months)	Approximate Engine Hours	Condition
Franklin 105 feller-buncher-1	42	3200	Very good
Franklin 105 feller-buncher-2	24	1800	Excellent
Franklin 105 skidder-1	16	2070	Excellent
Franklin 105 skidder-2	18	1800	Excellent
Barko 160	24	4000	Excellent
Fiat-Allis 10-B	------Unknown[1]------		Good

[1] Bought used, operator could not give approximate figures.

Table 42. System D Crew Characteristics

		Work Experience (Years)		
Employee Number	Age	With Crew	All Timber Harvesting	Other
1[1]	32	4	4 hauling[2] 3 clearcutting[2] 4 prelogging[2]	3 construction
2	23	.67	.67 prelogging[2]	4 construction
3	35	1.5	17 various jobs[2]	4 military
4	22	1	4 clearcutting[2] 1 prelogging[2]	2 factory
5	26	.58	2 clearcutting 4 hauling[2]	
6	20	.58	1.4 shortwood .58 prelogging[2]	3 farming
7	25	.08	4 clearcutting 2 hauling[2]	
8	33	2.5	15 various jobs[2]	

[1] Foreman

[2] All experience with owner's crews

Table 43. System D Crew Responsibilities

Employee Number	Feller-buncher	Skidder	Loader	Set-out	Limb & top	Haul Truck	Mechanic
1	1	X	X	X		X	1
2	1	X					
3	X	1	X	X		X	X
4	X	1			X		
5			1	1		X	
6				1	1		
7						1	
8						1	

1 = Primary responsibility(s)
X = Other responsibilities

skidders would clear the accumulated slash off to the side so that the trailers had a level foundation to sit on.

The crew normally worked 45 hours a week in producing an average of 272.0 cords per week over the prior six months. The reported production for that time period is illustrated in Figure 26. Cords per month were broken down into weekly averages for each month. Production levels appear very consistent. This probably can be attributed to the fact that System D had been working with small trees for a fair amount of time (4 years). A quota of 30 to 40 loads per week sometimes limited production, but usually did not.

System D's two Franklin feller-bunchers were timed for 15 cycles each. Feller-buncher 1, operated by the foreman, took between .48 and 2.23 minutes to complete a cycle when observed. The times were relatively evenly spread throughout the range. This feller-buncher seemed to take slightly longer than the other to finish a cycle because more effort was made to knock down hardwoods. The number of trees per accumulator bunch ranged from one to seven. However, nearly 75 percent of the bunches contained either three or four trees. Table 44 shows the distribution of the observed times per bunch and the number of trees per bunch for both feller-bunchers.

Feller-buncher 2 had a tighter distribution of times per cycle than Feller-buncher 1. The times ranged from .67 to 1.90 minutes. All the bunches contained from three to five trees. The number of trees in the bunches were evenly spread throughout the range.

Turn times for both of the Franklin skidders were recorded as part of the study. Fourteen turns were documented on Skidder 1. The minimum time observed was 3.96 minutes. The maximum was 15.52 minutes. No time interval appeared to dominate in terms of frequency of occurrence, as shown in Table 45, which also contains a representation of the distribution of the number of trees in each grapple load of the 14 turns observed. They ranged from eight to 18 trees with over half containing 15 trees or more.

Skidder 2 was observed for 16 turns. The turns took from 3.03 to 13.29 minutes. Almost one-third of the cycles occurred in the seven minute interval. The remainder of the turns were distributed throughout the range with another 18.8 percent in the 11 minute interval. Skidder 2

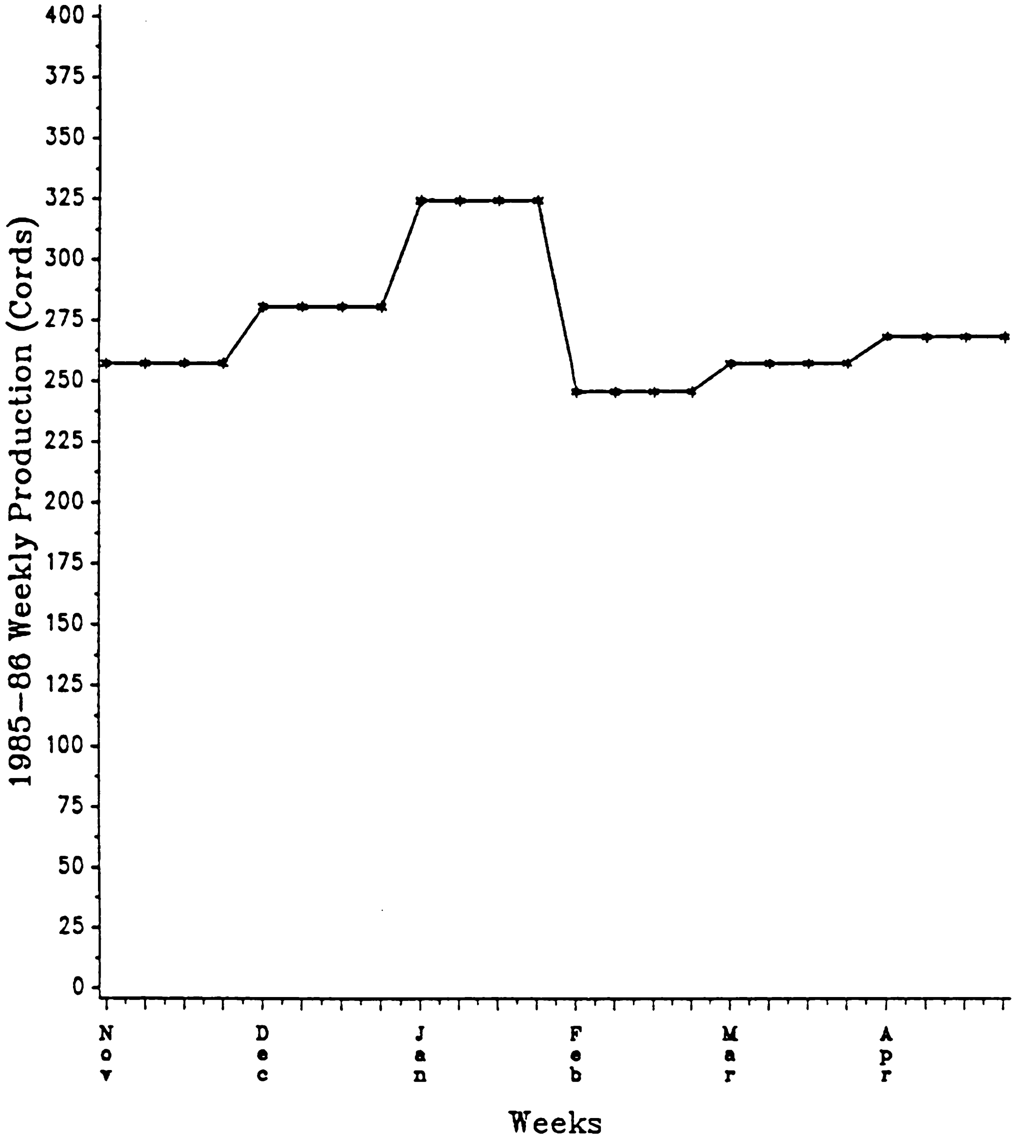

Figure 26. System D Weekly Production

Table 44. System D Observed Feller-buncher Productivity Data

Time per Bunch Interval Midpoint (Minutes)	Relative Frequency		Cumulative Relative Frequency		Trees per Bunch	Relative Frequency		Cumulative Relative Frequency	
Feller-buncher No. →	1	2	1	2		1	2	1	2
.50	.07	---	.07	---	1	.07	---	.07	---
.75	.07	.15	.14	.15	2	.07	---	.14	---
1.00	.20	.27	.34	.42	3	.33	.33	.47	.33
1.25	.15	.33	.49	.75	4	.40	.33	.87	.66
1.50	.33	.07	.82	.82	5	---	.33	.87	.99
1.75	.15	.15	.97	.97	6	.07	---	.94	
2.00	---	.07	.97	1.04	7	.07		1.01	
2.25	.07		1.04						

* Feller-buncher 1: 15 cycles recorded.
Feller-buncher 2: 15 cycles recorded.

consistently dragged more trees per turn than Skidder 1. The range extended from 11 to 21 trees. The distributions of times and number of trees per turn are illustrated in Table 45.

The data contained in Table 46 was obtained through tallies of five sample trailer loads. The number of trees placed on the trailers was fairly consistent. From 128 to 148 trees comprised the loads. The payloads ranged from net weights of 25.41 to 28.08 tons and they took from 35.44 to 43.84 minutes to be ready for setting out.

After set-out, the loads were hauled less than .1 mile on a temporary road to a county road. This Class 3 public road was travelled for 18 miles. The hauls continued for 28 miles on a Class 1 public road. From the interstate, one mile on a village street brought the loads to the mill.

The heads of both feller-bunchers had had two modifications. First, the hose connection point at the rear of the heads was moved to the side so that a clear line of sight from the cab to the blade was available. Also, an extra valve was added to the heads to allow the accumulator arm to open before the blades. In this way, the blades did not need to be opened completely, thus saving time when cutting smaller trees. Both operators commented that they would have preferred hydrostatic drive and its foot pedal direction control rather than the hand shift which the older models were equipped with. Additionally, one of the operators wanted more horsepower from the machine and a more comfortable seat. Aside from the modifications mentioned previously, he would have liked some type of cover over the hydraulic hoses connected to the shear to afford more protection from breakage. Also, he had cut the rear fenders off of his machine to reduce hangups. With these structures missing, more caution needed to be exercised when driving through the stand to avoid jamming trees in the rear spindle. The same operator believed that wet terrain imposed performance penalties on the feller-buncher.

The skidder drivers seemed content with their machines' operation. The only complaint that the two operators had was that they would have liked more power in their skidders. In fact, the younger man indicated that he would have preferred Franklin's 170 model over the 105.

The Barko loader operator felt that a larger engine or a turbocharger on the present engine was necessary on some jobs. Also, he thought visibility from the cab could be improved with a longer windshield (i.e. removal of the crosspiece through the middle of the windshield). His comfort was

Table 45. System D Observed Skidder Productivity Data

Time per Turn Interval Midpoint (Minutes)	Relative Frequency		Cumulative Relative Frequency		Trees per Turn	Relative Frequency		Cumulative Relative Frequency	
Skidder No. →	1	2	1	2		1	2	1	2
3	---	.06	---	.06	8	.07	---	.07	---
4	.07	---	.07	.06	9	---	---	.07	---
5	.14	.06	.21	.12	10	.07	---	.14	---
6	.14	.06	.35	.18	11	.07	---	.21	---
7	.14	.31	.49	.49	12	.14	.25	.35	.25
8	---	.06	.49	.55	13	---	.06	.35	.31
9	.14	---	.63	.55	14	.07	.06	.42	.37
10	.14	.06	.77	.61	15	.21	.25	.63	.62
11	.07	.19	.84	.80	16	.14	.06	.77	.68
12	.07	.06	.91	.86	17	.07	.13	.84	.81
13	---	.13	.91	.99	18	.14	.06	.98	.87
14	---		.91		19		.06		.93
15	---		.91		20		---		.93
16	.07		.98		21		.06		.99

* Skidder 1: 14 cycles recorded.
Skidder 2: 16 cycles recorded.

Table 46. System D Load Tally Results

Load Number	Time to Load (Minutes)	Number of Trees	Load Weight (Tons)	Trees per Ton
1	40.94	128	25.41	5.04
2	43.84	137	28.08	4.88
3	41.33	130	26.68	4.87
4	42.01	140	26.53	5.28
5	35.44	148	27.54	5.37
Mean	40.71	137	26.85	5.09

affected by the hardness of the seat and lack of arm and headrests. An irritation to the operator was the need to open one door on the engine compartment to check the oil level, but having to go to another door to add oil.

The loader/dozer operator thought that the Fiat-Allis was a good machine for setting out trailers. He did, however, believe that a larger dozer would be more useful for knocking over large trees during deck construction. Also, without hearing protection, which usually was not used on this operation, the noise produced by the dozer was extremely loud.

The mill was equipped to handle material loaded butt-to-top, but this technique was only utilized when the trees harvested were short. Often short trees were set aside until enough for a full load had been accumulated. The loads hauled to the mill by this crew were unusually clean because, besides trimming protruding limbs from the ground, the loader operator climbed on top of the load and cut branches, vines, and residues unreachable from below. This was probably done because part of the 47-mile haul to the mill was on interstate, but could be due to deductions at the mill for material less than 3.0 inches at the small end or to crew pride in the appearance of their work.

In order to keep production consistently high, the crew was paid on a per-load basis, as was the case with System C. This pay method may have acted as an incentive to the crew. Also, several crew members were trained for each job in the operation, as noted previously, in order to reduce the impact of a person who missed work at any time.

Appendix I. Detailed Description of System E

System E had performed thinnings for 16 months at the time of study and was the only operation directly owned by a wood dealer who dealt with five crews. The other four crews were run by private contractors who leased their equipment from the dealer. He felt that in this way he retained an element of control over all the operations. The operation produced tree length pine pulpwood in the Lower Coastal Plain of South Carolina.

System E mainly thinned industry plantations, but occasionally worked on private lands. The previous four sales averaged 7.8 inches DBH and 19.5 years old when thinned. The stands contained 23.7 cords per acre before treatment and had 12.1 cords per acre removed. The tract being thinned during the study, bordering on a power line right-of-way, was similar to these last four stands.

Figure 27 shows the wood flow of System E. The feller-buncher used was a Franklin 105 with a 17-inch Morbark shear. A Franklin 105 grapple skidder dragged the material out of the woods. The trees were gate delimbed as they were skidded to the landing. The loader used was a trailer-mounted Husky XL-185 with a fixed heel and log grapple. It was bought used from the company to which wood was delivered. The wood was loaded onto trailers owned by the contract trucker. The observed condition of the operation's equipment is detailed in Table 47.

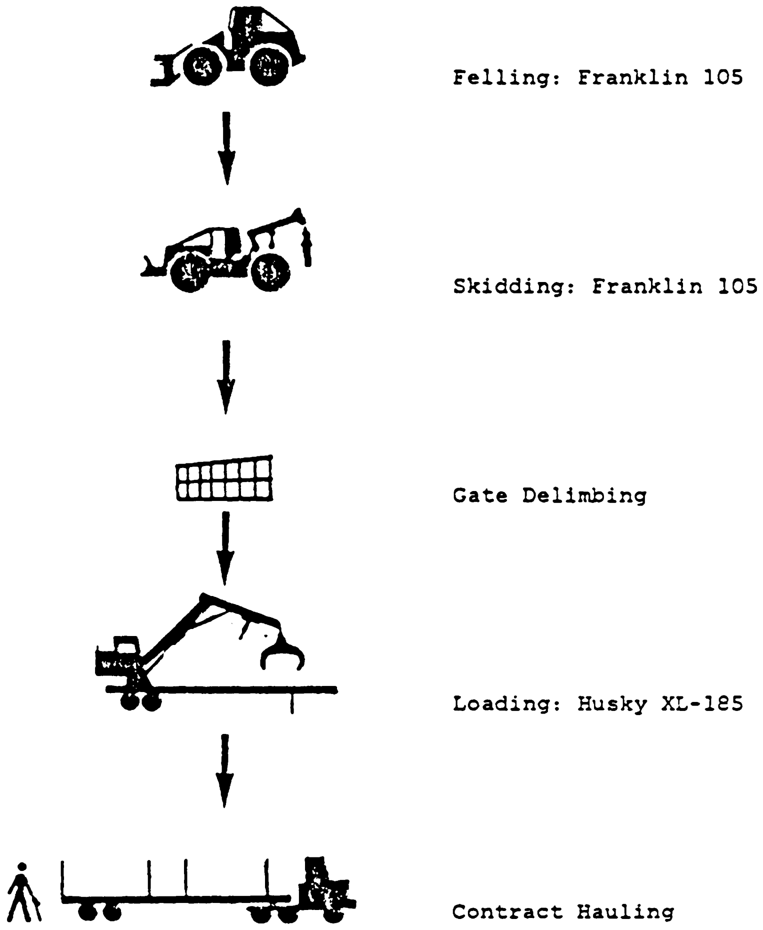

Figure 27. System E Material Flow

Table 47. System E Equipment Condition

Equipment	Age (Months)	Approximate Engine Hours	Condition
Franklin 105 feller-buncher	16	880	Very good
Franklin 105 skidder	16	780	Good
Husky XL-185	60	Unknown[1]	Very good

[1] Bought used, crew members could not give approximate figure.

The owner divided his time between supervising the crews and dealing with the company that bought his timber. System E's crew consisted of three men plus a contract trucker. An attempt was being made to work the foreman (Employee 1) into a purely supervisory position, as when the crew was established, rather than a working foreman. During the study, the crew was short one member, so the foreman had to operate the feller-buncher. System E's skidder operator (Employee 2) could also operate feller-bunchers so that, when the foreman moved to a more supervisory position, the skidder driver could take over the felling tasks. Employee 3 had many years of woods experience. Except for the one year he had spent with this crew, his experience was mainly as a choker setter on a swamp logging operation. He was able to operate the skidder and loader for System E, but after all the years in the swamps he had contracted arthritis, so he may not have been as proficient as necessary on the equipment for efficient long-term operation. When using the loader, his primary purpose was to straighten up the inventory piles around the deck to keep it clean and maintain good traffic flow around the landing. Occasionally, he would begin loading empty trailers. Loading of trailers was normally undertaken by the contract trucker when he returned from a haul, although since two frame trailers were used on the job, one of them may have been partially loaded by the deck man, as noted. The crew members' characteristics and responsibilities are listed in Table 48 and Table 49, respectively.

To initiate a plantation thinning, the main skid trail was cut perpendicular to the rows. Next, two or three corridors were cleared at an angle to the skid trail and the rows. Operator selection was conducted between the corridors. This process was continued until the stand had been thinned. The bunches were skidded to the edge of the deck, where they were gate delimbed, then dropped near the loader. When large amounts of slash had accumulated around the gate, the skidder would pick up a grapple load of the residues and slowly release them as it travelled back through the stand. The owner believed that this practice lessened the site impact of the harvesting activities. Since the stand thinned during the study was bordered on one side by a power line right-of-way, no landing preparation was necessary. Boundaries and skid trails usually were not marked for this operation. The timberland owner, however, would build and maintain roads when necessary.

Table 48. System E Crew Characteristics

Employee Number	Age	Work Experience (Years): With Crew	All Timber Harvesting	Other
1[1]	34	1.25	1.25 thinning[2]	12 trucking-driver, shop man, mechanic[2]
2	22	1	1 clearcutting 1 thinning[2]	
3	59	1	37 swamp logging and various jobs 1 thinning[2]	

[1] Foreman

[2] All experience with owner.

Table 49. System E Crew Responsibilities

Employee Number	Feller-buncher	Skidder	Loader[1]	Deck Man	Mechanic
1	1	X	X		1
2	X	1			
3		X	X	1	

1 = Primary responsibility(s)
X = Other responsibilities

[1] Normally operated by contract trucker.

The crew worked 40 to 45 hours per week producing an average of 133.6 cords per week over the six months preceding the study. Figure 28 illustrates System E's weekly production during that period. Missing data points represent weeks not spent thinning. Production seems to have increased through the summer before declining during the fall. The low point in the fall may not have been a complete week of thinning since the preceding and succeeding weeks were not spent thinning.

System E's Franklin feller-buncher was observed for 49 cycles. Less than two minutes were needed to complete 91.8 percent of them. One minute or less was required in 69.4 percent of the felling and bunching cycles. The short duration of time taken for the bunches was probably due to their usually small size. About 97 percent of the accumulator loads consisted of three or fewer trees. Over 63 percent consisted of only one or two. The distributions of times per bunch and trees per bunch are portrayed in Table 50.

Times per turn were examined with the Franklin skidder. Fourteen turns, ranging in time from 5.10 to 12.73 minutes, were observed. Although the range extended for over seven minutes, 78.6 percent of the turns were within 2.65 minutes of the minimum observed value. From nine to 21 trees were brought to the landing per turn. However, 71.4 percent of the grapple loads contained 11, 12, 13, or 15 trees. Table 51 depicts the distribution of turn times and the number of trees per turn.

Four trailer loads of tree lengths were sampled. The data collected is displayed in Table 52. Load size ranged from 123 to 174 trees with net weights of 20.83 to 23.82 tons. The times taken to load the trailers were not recorded in this study.

Once trimmed and bound, the loads were hauled 27 miles from the study site to the mill. The hauls began with .5 miles on a Class 3 permanent woods road. A Class 3 public road was travelled for .8 miles, followed by 20.5 miles over a Class 2 public road. From that point, the mill entrance was 5.2 miles down a Class 1 public road.

The feller-buncher operator felt that, when working on the wetter sites which were fairly prevalent in the area, flotation sometimes was inadequate for efficient operation. When observed, however, the system was in a plantation located on a sandy ridge, so flotation presented no diffi-

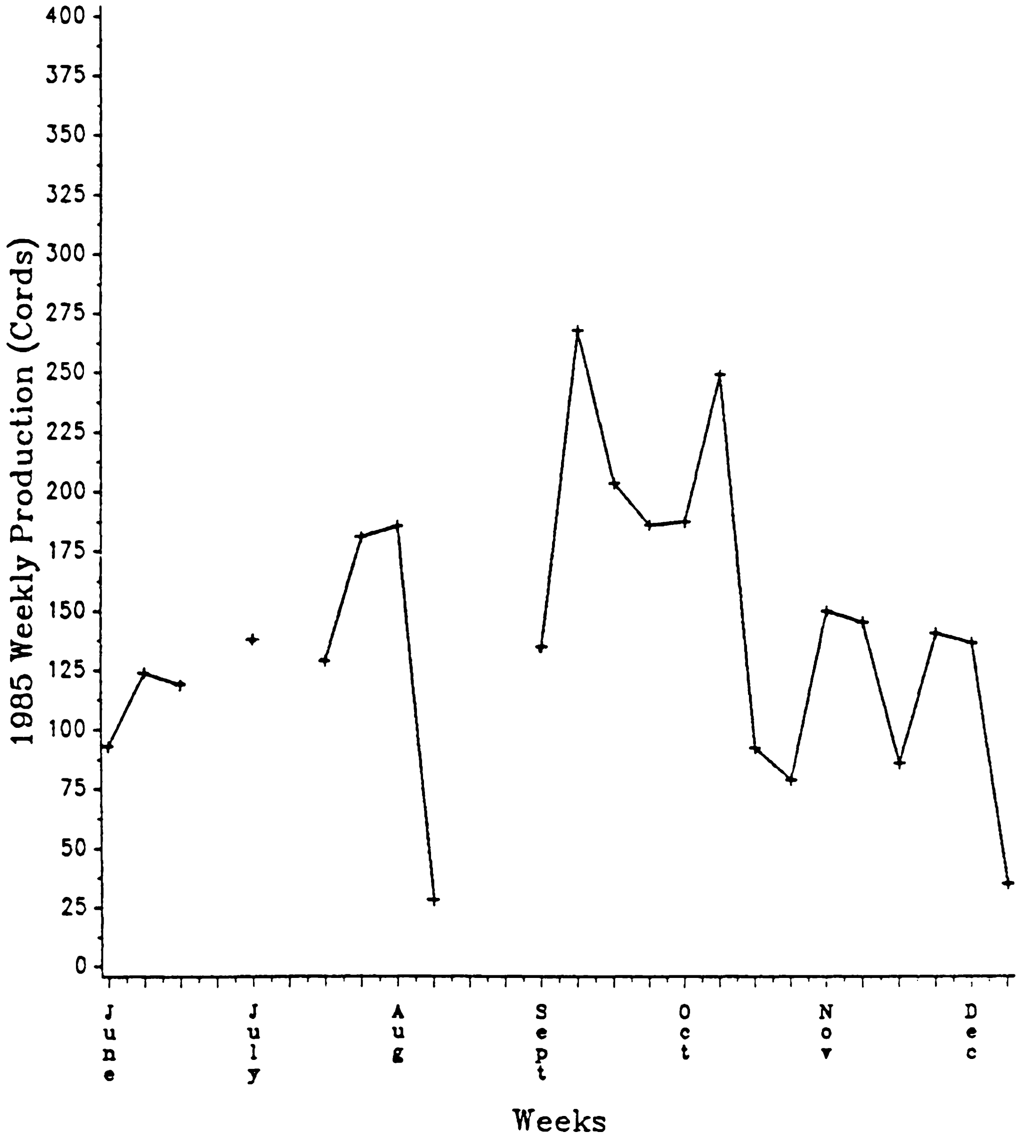

Figure 28. System E Weekly Production

Table 50. System E Observed Feller-buncher Productivity Data

Time per Bunch Interval Midpoint (Minutes)	Relative Frequency	Cumulative Relative Frequency	Trees per Bunch	Relative Frequency	Cumulative Relative Frequency
.25	.06	.06	1	.27	.27
.50	.16	.22	2	.37	.64
.75	.33	.55	3	.33	.97
1.00	.24	.79	4	.04	1.01
1.25	.06	.85			
1.50	.04	.89			
1.75	.02	.91			
2.00	.02	.93			
2.25	.04	.97			
2.50	.02	.99			

* 49 cycles recorded.

Table 51. System E Observed Skidder Productivity Data

Time per Turn Interval Midpoint (Minutes)	Relative Frequency	Cumulative Relative Frequency	Trees per Turn	Relative Frequency	Cumulative Relative Frequency
5	.21	.21	9	.07	.07
6	.21	.42	10	.07	.14
7	.21	.63	11	.21	.35
8	.21	.84	12	.21	.56
9	---	.84	13	.14	.70
10	---	.84	14	---	.70
11	.07	.91	15	.14	.84
12	---	.91	16	.07	.91
13	.07	.98	17	---	.91
			18	---	.91
			19	---	.91
			20	---	.91
			21	.07	.98

* 14 cycles recorded.

Table 52. System E Load Tally Results

Load Number	Number of Trees	Load Weight (Tons)	Trees per Ton
1	123	20.83	5.90
2	153	23.33	6.56
3	149	23.72	6.28
4	174	23.82	7.30
Mean	150	22.93	6.51

culties. Also, problems had been experienced with hose and wiring damage from down trees due to what the operator perceived as insufficient protection at some points. From a mechanic's perspective, the hydraulic oil reservoir was not thought to be of ample capacity for cooling and reconditioning the oil before recirculation. This could increase the repair and replacement requirements of hydraulic components from inordinate levels of contamination by foreign materials. The operator felt that the maneuverability of the feller-buncher in closely spaced stands was a positive aspect in minimizing damage to the residual stand.

As with the feller-buncher, flotation of the skidder with conventional width tires was felt to be insufficient on some of the wetter sites. Other complaints dealt with operator comfort when skidding and performing maintenance. The cab was not climate controlled, which could increase operator fatigue during operation and decrease productivity. The operator believed that, when cleaning and servicing his equipment, he was sometimes forced into hazardous locations and, to check his transmission (every other day), he had to assume an unusually awkward position.

A good relationship with the company seemed to aid the dealer's operations. Before establishing his wood dealership, he owned a contract trucking company which worked closely with the mill. In fact, this corporation persuaded the owner to begin his dealership firm and accommodated him where possible to enable him to succeed in his small tree harvesting endeavors. For example, whatever amount of wood was delivered by the dealer was accepted by the mill. That is, no form of quota was imposed on his weekly production. He also was offered about 5000 acres per year by the company for thinning.

When hiring crew members or contractors, the owner looked for honesty and integrity in the person. Because of this, he had low turnover and very few other problems with his crews. A notable approach is that, when hiring equipment operators and especially foremen, he preferred a person with little or no harvesting experience over someone who had worked extensively in a high production-oriented operation. An inexperienced crew member could be trained from the start to thin stands the way that the owner felt was appropriate, whereas a person experienced with a high production clearcutting system may have had to unlearn habits which were inapplicable to acceptable thinning operations.

Appendix J. Detailed Description of System F

System F had been prelogging for six years when studied, although some of the jobs on company lands may have been more appropriately classified as precommercial thinnings. The operation was one of a number of company wood energy crews for a large southern forest products corporation. Whole tree chips (mostly hardwood, some pine) had been produced for use as fuel. The system was located in the Coastal Plain of Alabama.

The system operated in both natural stands and plantations with time divided fairly evenly between company fee lands and private lands. During the study, System F was working in a 20-year-old natural stand of mixed pine and hardwood owned by a large non-industrial private forestland owner in the area. The amount of volume harvested during prelogging by this crew was quite variable. On private lands, owner desires dictated the quantity of fuelwood removed. On fee lands, the volume removed was dependent on the need of the land and time until final harvest. In stands that were closer to final harvest, more borderline merchantable trees may have been taken for fuel.

System F's material flow is represented in Figure 29. All three of the feller-bunchers used were Hydro-Ax 411B's with 16-inch heads. Only one of the machines was operating during the study. The older feller-buncher was in the shop for a clutch replacement. Another of the machines was down for a portion of the time. For the remainder, the operator was scouting other stands with the unit manager for potential energy harvests. Both skidders were Timberjack 450 grapple skidders with parallelogram arch configuration. The chipper was a Morbark Model 22 Total Chiparvestor. The equipment's condition when studied is shown in Table 53. One company driver and two contract truckers were used to haul the nine 25-ton chip vans to the mill during observation. The company driver was thought to be a more reliable means of keeping in contact with the mill. In the past, contract truckers, who sometimes wanted to quit earlier in the day, had relayed the message that the mill was not accepting any more fuel chips that day when it actually would have.

The prelogging jobs were overseen by the company unit manager. The crew itself consisted of seven men plus one company truck driver and two contract truckers. The drivers were shifted between jobs as necessary. Three of the crew members (Employees 1, 2, and 3) operated feller-bunchers. One of the skidder operators (Employee 4) was the working foreman of the crew. Employee 5 was the other skidder driver. Two men (Employees 6 and 7) operated the system's chipper. When a van was filled, the operator on the chipper set it out while the other man began loading the next van. As they got a break after each van load, the men were refreshed and the chipper could be in operation almost constantly, barring down time. All crew members performed their own mechanic work unless the problem was serious enough that the machine had to go to the company shop nearby. Table 54 relates the crew's ages and work histories. As shown, every crew member had been with the company in some capacity for at least eight years. The responsibilities of each member are shown in Table 55. Unlike the other systems studied, the workers in System F generally were trained for only one job in the operation (besides their mechanic work).

Areas to be prelogged had their boundaries flagged (private land) or painted (fee lands) by company personnel. When necessary, roads were built in the tracts by a separate company crew. All pine and hardwoods eight inches DBH or less down to about one inch were felled to be chipped. Most brushy material was removed during felling and much of it was sent through the chipper, also. Large skid bunches were assembled and dragged to the chipper. The bulkiness of the brushy bunches sometimes forced the skidders to be held up at the chipper until enough room was cleared for them to drop their loads within reach of the boom. An attempt was made to keep the feller-bunchers about a week's work ahead of the skidders. This was impossible during the

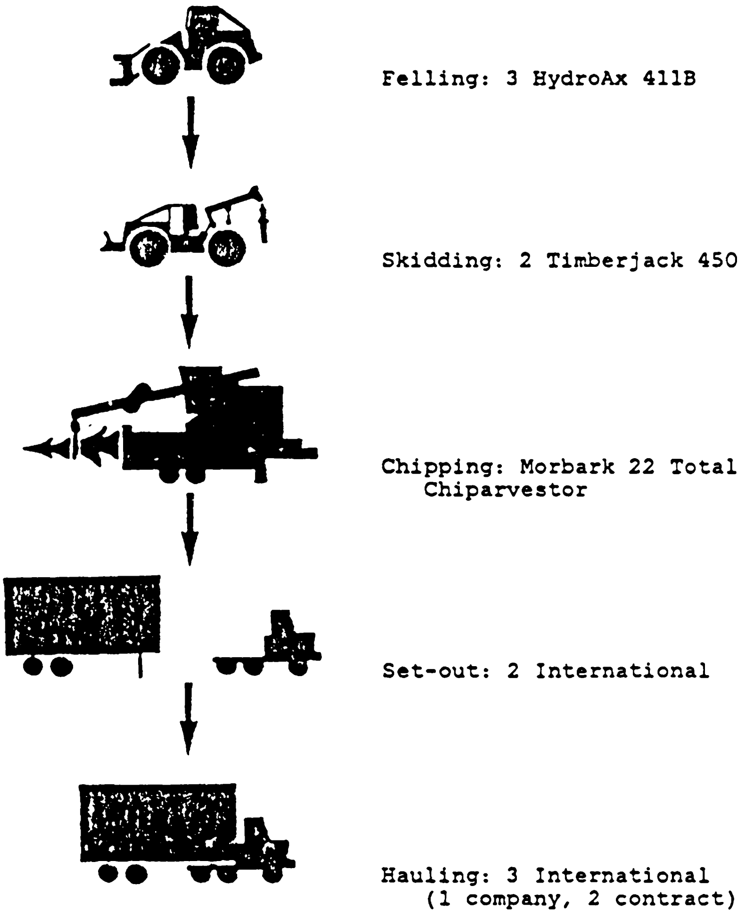

Figure 29. System F Material Flow

Table 53. System F Equipment Condition

Equipment	Age (Months)	Approximate Engine Hours	Condition
Hydro-Ax 411B-1	8	840	Excellent
Hydro-Ax 411B-2	8	790	Excellent
Hydro-Ax 411B-3	60	250[1]	Unknown[2]
Timberjack 450-1	48	3000	Excellent
Timberjack 450-2	48	3200	Excellent
Morbark 22 Total Chiparvestor	36	5400	Excellent

[1] New engine in machine.

[2] Machine was in the company shop for clutch replacement during the study.

Table 54. System F Crew Characteristics

Employee Number	Age	Work Experience (Years): With Crew	All Timber Harvesting	Other
1	32	6	4 woodyard[2] 3 piling yard 6 prelogging[2]	
2	28	6	2 woodyard[2] 6 prelogging[2]	
3	27	2	6 chip mill[2] 2 prelogging[2]	2 factory
4[1]	50	6	15 clearcutting 8 woodyard[2] 6 pulpwood crew[2] 6 prelogging[2]	
5	49	6	18 pole mill and clearcutting 8 various jobs[2] 6 prelogging[2]	
6	45	2.5	7 woodyard[2] 16 various yard and logging jobs 2.5 prelogging[2]	
7	30	6	2 hauling[2] 6 prelogging[2]	

[1] Foreman

[2] All experience with company.

Table 55. System F Crew Responsibilities

Employee Number	Feller-buncher	Skidder	Chipper	Set-out	Mechanic
1	1				1
2	1				1
3	1				1
4		1			1
5		1			1
6		X	1	1	1
7		X	1	1	1

1 = Primary responsibility(s)
X = Other responsibilities

study, however, since two of the three feller-bunchers were not operating. The chipper was moved fairly frequently to maintain relatively short skidding distances.

The unit manager was not comfortable disclosing exact production figures. He did, however, report that System F had produced an average of 1000 tons per week (333.3 cord equivalents assuming 6000 pounds per cord of mixed pine and hardwood) for the prior six months. The crew worked 45 to 50 hours a week in attaining this productivity.

Because two of the three feller-bunchers were not operating during the study, only one could be timed. Twenty two felling and bunching cycles were observed. The times ranged from .18 to 2.20 minutes with 50 percent occurring between 1.0 and 1.5 minutes. The number of trees accumulated before being dropped was from two to eighteen. Between six and nine trees were contained in 54.5 percent of the bunches. The high number of trees often accumulated was due to the small size of trees used for fuel chips. The distribution of times per bunch and the number of trees per bunch are depicted in Table 56.

Because of the brushiness of the skidder bunches and the small tree size, it was difficult to accurately count the number of trees per bunch. Therefore, 25 bunches were tallied while still on the ground. The numbers derived from these tallies are illustrated in Table 57. The bunches ranged in size from 18 to 47 trees with a mean of 27, more than the maximum number of trees dragged by almost every other skidder studied.

Although trees per turn were not recorded directly, times per turn were examined for both of System F's Timberjack skidders. The foreman's skidder (Skidder 1) was observed for 28 turns. The times ranged from 1.83 to 13.65 minutes per turn. Over 50 percent of the turns were completed in between four and six minutes.

Twenty two turns were recorded for Skidder 2. They ranged in time from 2.00 to 13.17 minutes. Skidder 2 seemed to take longer per turn than Skidder 1 the majority of the time. Nearly 60 percent of Skidder 2's turns took between six and nine minutes. The turn times of both skidders, also shown in Table 57, were increased by having to wait to drop their loads at the chipper when excess inventory would sometimes build up.

Table 56. System F Observed Feller-buncher Productivity Data

Time per Bunch Interval Midpoint (Minutes)	Relative Frequency	Cumulative Relative Frequency	Trees per bunch	Relative Frequency	Cumulative Relative Frequency
.25	.05	.05	2	.09	.09
.50	.05	.10	3	---	.09
.75	---	.10	4	.05	.14
1.00	.27	.37	5	.05	.19
1.25	.14	.51	6	.09	.28
1.50	.23	.74	7	.14	.42
1.75	.18	.92	8	.14	.56
2.00	.05	.97	9	.18	.74
2.25	.05	1.02	10	.05	.79
			11	.05	.84
			12	.05	.89
			13	.09	.98
			14	---	.98
			15	---	.98
			16	---	.98
			17	---	.98
			18	.05	1.03

* 22 cycles recorded.

Table 57. System F Observed Skidder Productivity Data

Time per Turn Interval Midpoint (Minutes)	Relative Frequency		Cumulative Relative Frequency		Trees per Bunch Class Minimum	Relative Frequency	Cumulative Relative Frequency
Skidder No. →	1	2	1	2			
2	.04	.05	.04	.05	18	.12	.12
3	.07	---	.11	.05	20	.12	.24
4	.07	.18	.18	.23	22	.08	.32
5	.43	---	.61	.23	24	.20	.52
6	.14	.27	.75	.50	26	.12	.64
7	.04	.18	.79	.68	28	.08	.72
8	.11	.09	.90	.77	30	---	.72
9	.04	.14	.94	.91	32	.04	.76
10	---	.05	.94	.96	34	.12	.88
11	.04	---	.98	.96	36	.08	.96
12	---	---	.98	.96	> 36[1]	.04	1.00
13	---	.05	.98	1.01			
14	.04		1.02				

* Skidder 1: 28 cycles recorded.
Skidder 2: 22 cycles recorded.
25 skidder bunches tallied.

[1] One bunch contained 47 trees.

It was necessary to modify the load tally for this study due to the extremely small trees harvested and the speed with which they were fed into the chipper. Rather than tallying each grapple load as it went into the chipper, the number of skidder loads needed to fill the vans was counted. This tally was conducted on six sample vans and indicated that from 10 to 13 skidder bunches were sufficient to load the vans, which contained from 21.04 to 23.15 tons per load. The vans required between 23.25 and 39.25 minutes to fill. The data from the load tally is contained in Table 58. The unit manager noted that van loads from the operation normally weigh more (26 to 28 tons) than from this tract.

After leaving the set-out point, the filled vans were hauled about 40 miles to the mill. The hauls began with .2 miles on a temporary road built on the private land. A Class 3 public road was travelled for eight miles before 32 miles on a Class 2 public road which led to the mill.

None of the feller-buncher operators had many comments, either positive or negative, concerning their equipment. They did comment that they liked the foot pedal control of the hydrostatic drive as opposed to the hand control that they had either experienced before or had seen. The unit manager, however, noted that maintenance of the Hydro-Ax 411's was expensive, especially with regard to hydraulic components.

One of the skidder operators remarked that he preferred the present models over the Caterpillar 518's which used to be utilized in System F. He felt that the Timberjacks were easier to handle and that there was less vibration during operation. Also, since the front axle shifted, the ride was smoother. He also noted that the parallelogram arch design allowed additional rearward extension in comparison to single arch skidders and could be used to advantage to push the machines out of the mud in the river swamps where the crew sometimes worked.

The chipper operators commented that they would like the feed mechanism to be faster. They also noted that they preferred the slide boom with which the chipper was equipped over a knuckleboom because they felt that it allowed smoother operation. Both men believed that the Morbark 22 was more than adequate for the size of material that the system usually worked with.

A situation which would be expected to decrease trucking costs per ton-mile relative to the other systems studied was that haul trucks were allowed 88,000 pounds GVW in Alabama. Most

Table 58. System F Load Tally Results

Load Number	Time to Load (Minutes)	Load Weight (Tons)	Number of Skidder Bunches	Trees per Ton[1]
1	28.75	22.08	11	13.45
2	39.25	22.20	10	12.16
3	35.00	22.14	12	14.63
4	23.25	23.15	13	15.16
5	29.32	21.04	10	12.83
6	26.25	21.38	10	12.63
Mean	30.30	22.00	11	13.48

[1] Assuming 27 trees per skidder bunch.

other southern states permitted only 80,000 pounds, which was the average GVW of System F's haul trucks in the stand during the study. Normally, however, the average GVW was 4000 to 6000 pounds more. To be allowed this increased tonnage, trucks must have been loaded in-woods and could not haul on interstates.

A harvestable volume of 22 to 23 tons per acre (8.7 to 9.3 cord equivalents) was thought to be a minimum for System F to operate efficiently. Below this limit, the feasibility of harvesting a stand was at the discretion of the unit manager, the feller-buncher operators, and/or the foreman. When the pulpwood was bought from a private timberland owner, a separate bond was written to obtain the energy wood at no additional cost, if the owner was agreeable. The owners were usually willing to allow removal of small and malformed trees and brush since it cleaned up the stand and could decrease site preparation costs.

System F was the only operation studied in which safety awareness was an integral part of the job. All crew members were required to wear hard hats and ear protection provided by the company, and hard-toed boots. Also, they all had Red Cross first aid training through the company. Probably the most important factors in accounting for the absence of injuries was that there were no chainsaws on the job and that every crew member was inside the cab of a piece of equipment rather than on the ground.

The use of company crews was common practice with this corporation. It was felt that they provided greater dependability and allowed a greater degree of control than private contractors. In fact, most of the wood delivered to the mill was harvested by company crews. For example, just in the area that System F worked in, 26 three-man pulpwood crews and nine five-man crews operated, accounting for 170 to 200 thousand cords per year. Because of the high wage rate paid to the crew members, job turnover within the energy crews was virtually non-existent.

Appendix K. Equipment Condition Classes

Excellent Like-new condition, 90 percent of paint in place. All shields, covers, and glasses in place. No major dents, tires with nearly full tread, all functional items, such as lights, working. No significant signs of wear on shear anvils, etc. No signs of oil leakage, little trash accumulation.

Very Good Seventy five percent of the paint in place. All shields, covers, and glass in place. Limited dents. Tire wear beginning to show. All lights and reflectors in place, wear beginning on major points, cover layer cut or cracked on hydraulic lines, minor oil leakage around hydraulic cylinders, trash accumulation in frame cavities.

Good Paint scarred, manufacturer's insignia and decals still in place and legible. Major dents showing, especially in sheet metal. No cracked welds on major frame members. Tire tread one-half or more of original depth. Shields, covers, and glasses in place, but bent or cracked. Wear showing clearly on working parts. Engine burning some oil, cover layers of hydraulic lines worn and cut but no visible signs of imminent failure. Moderate trash accumulation in unexposed areas.

From Sobhany (1985)

Note: Lower condition classes (Fair and Poor) exist, but were not needed in this research project.

Appendix L. Road Classes

Temporary

- No ditches
- Vertical cut banks
- 4 meter width or less
- Turnouts .5 km or more apart
- 16 percent favorable grade
- 12 percent adverse grade
- Curve radius 15 meters or less
- May be temporary or reserved for occasional use

Permanent Class 3

- Ditched with water bars and culverts
- Cut banks and fills appropriately sloped for local soils
- 4 meter width with 7 meter width at turnouts
- 10 percent sustained favorable grade-short distances of up to 16 percent
- 8 percent sustained adverse grade-short distances of up to 12 percent
- Curve radius 15 meters or more
- Surfacing only in weak spots

- Occasional maintenance

Permanent Class 2

- Ditched with culverts
- Cut banks and fills graded and seeded
- 5 meter width at turnouts
- Maximum sustained favorable and adverse grade of 10 percent
- 12 percent favorable for distances of 150 meters
- Maximum curve 55 degrees, 30 meter radius
- Switchbacks 15 meter radius
- Regular maintenance (grading, cleaning ditches)
- Surfacing where needed

Permanent Class 1

- Same as Class 2 except:
- 9 to 10 meter width to support two-way traffic over entire length
- Surfacing material applied over entire length
- Routine maintenance allows speeds in excess of 75 km per hour

Public Class 5

- Same as Permanent Class 3 except:
- Regular maintenance and culverting more common
- Single lane bridges

Public Class 4

- Same as Permanent Class 3 except for regular maintenance
- Surfacing in areas of heavy use and weak spots

Public Class 3

- Same as Permanent Class 1
- Surfacing may be bituminous or gravel
- May have center line and indicated passing zones

Public Class 2

- Bituminous or concrete surface width in excess of 10 meters
- Shoulders well maintained
- Centerline and edge lines present
- Warning signs where needed
- Supports two-way traffic at posted speeds

Public Class 1

- Divided highway, 2 or more lanes moving each direction
- May be limited access

Urban, Village, or City Streets

- Speed controlled by posted limits and affected by traffic

From Sobhany (1985)

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