THE POTENTIAL FOR INCREASED MECHANIZATION OF SHORTWOOD HARVESTING IN THE MAN-MADE FORESTS OF THE STATE OF SAO PAULO

by

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THE POTENTIAL FOR INCREASED MECHANIZATION OF SHORTWOOD HARVESTING IN THE MAN-MADE FORESTS OF THE STATE OF SAO PAULO

INTRODUCTION

The first man-made forests in the State of Sao Paulo, Brazil resulted from the efforts of Edmundo Navarro de Andrade, who worked for the State of Sao Paulo Company Railway. In the first decade of this century the company needed wood for fuel because the natural forest adjacent to the railroad had been depleted. Several species of trees were experimented with in order to produce fuelwood in areas close to the railroad. The best results were obtained with some species of the genus *Eucalyptus*, a native of Australia. Navarro de Andrade through patient work provided the company with a series of strategically located forest farms, which produced the majority of the fuel needed for the steam boilers of its locomotives.

The State Forest Service was also interested in the genus *Eucalyptus*, because the native species in that region of Brazil showed generally poor growth. In the period between the establishment of the first plantations and the development of the cellulose, paper, and fiber-board industries in the early 1950's, the planted area did not increase very much. However, the small plantations set out by farmers and local industries that needed firewood, like tile or brick manufacturers, proved that some species of the genus *Eucalyptus* could be very productive in the conditions of the State of Sao Paulo.

Some species of *Eucalyptus*, due to the fast growth and easy silviculture, became a potential source of raw material for forest products. These factors, coupled with the availability of land at reasonable prices within the industrial region of Sao Paulo, attracted some companies which began to utilize these species for pulp, paper, and fiberboard. These companies stimulated the growth of planted areas in several ways. They gave free seedlings or sold seedlings at low prices to other land owners and advised them on planting practices. In addition, they planted their own lands and provided a market for the wood. These efforts resulted in an increase in planted Eucalyptus near the industries. The species that have given the best results in the State of Sao Paulo are: Eucalyptus salignia, E. alba, E. grandis, E. tereticornis, and E. citridora.

In the decade of 1950 and the first half of 1960 some species of Pinus were introduced in Sao Paulo and in areas to the south. The first plantations of "Pinus" were of experimental size and were established by the State and Federal agencies and some forest products industries. Some species grew very well in the ecological conditions of the State of Sao Paulo. The species from the southern United States, Central America, and Caribbean region showed different rates of growth according to the regions that were planted. The species that gave best results were: slash pine (Pinus elliottii var elliottii), Caribbean pine (P. caribaea var hondurensis), spreading-leaved pine (Pinus patula) and loblolly pine (P. taeda). However, commercial plantations were not established until after the enactment of the Forest Incentive Law of 1967.

Several other species have been experimented with. There are some plantations of Parana Pine (Araucaria angustifolia): native in someplaces of the state, "Cryptomeria japonica" and Cuninghamia lanceolata.

The most important event concerning forest policy in Brazil and one that had great effect in increasing the forested area was the Forest Incentive Law of 1967. This law allowed individuals and companies to deduct the amount spent on reforestation from their income taxes. The incentive law stimulated the establishment of man-made forests by people that never had spent money in this undertaking before. In the seven years between 1967 and 1974 the reforested area in the State of Sao Paulo was doubled. Table 1 presents the magnitude of man-made forests in the State of Sao Paulo in 1975.

Silvicultural practices in the Eucalyptus plantations generally take advantage of the capacity of this genus to regenerate by stump sprouts. The main method of regeneration of Eucalyptus plantations in the State of Sao Paulo is by the coppice method. In fact, in most plantations, sprouts are the only method of regeneration after intermediate cuttings. The logical rotation length is that which produces the maximum mean annual increment in volume per unit of area, and generally disregards diameter and shape. As a general rule, the industrial plantations of Eucalyptus in the State of Sao Paulo are established from seedlings. These seedlings are usually grown in a "torrao paulista", a container made of clay and organic material which is compressed in a special device with hexagonal cross-section. This shape permits them to be easily arranged in the beds and allows them

Table 1. Man-Made Forests - State of Sao Paulo, 1975.[1/]

SPECIES	HECTARES	ACRES	PERCENT
Eucalyptus Spp.	499,560	1,212.199	76.48
Pinus Spp.	142,070	351.062	22.15
Others	8,790	21.721	1.37
TOTAL	641,420	1,584.982	100.00

[1/] Zoneamento Economico Florestal do Estado de Sao Paulo - Boletim Tecnico No. 17 - Instituto Florestal - Sao Paulo - Brasil to withstand the various handling operations during the time they are in the nursery and until they are planted in the field. Generally, care is needed only in the first months in order to control weeds and some species of ants. The density of planting is about 2,500 seedlings per hectare, or approximately 1,000 trees per acre. The first clearcut is generally made between six to eight years after planting. At this time the trees have a DBH of about 12 cm (about 5 inches). The volume of pulpwood obtained in this clearcutting varies from 140 to 360 steres (1 stere = 0.276 cords) per hectare, (15.6 to 40.2 cords/acre). All of the logging residue is left in the field, but the concentration is very small, since the majority of Eucalyptus trees have a very light crown, and all parts of the stem greater than two inches are utilized. Some months after sprouting occurs, it is necessary to reduce the number of sprouts per stump to two or three stems, which will form the new trees. This operation is accomplished with manual labor and machetes.

The second clearcutting usually occurs at the age of 11 or 13 years, and gives an output of 60 to 155 steres per hectare (6.75 to 17.4 cords/acre). Yields in the third clearcutting at the age of 16 to 18 years are about 50 to 120 steres per hectare (5.6 to 13.5 cords/acre). After the third cutting the vigor of sprouting diminishes dramatically, and the stand is usually replanted.

In Pine plantations silvicultural practices are very different from that of the Eucalyptus. In this case the main objective is to produce sawlogs or veneer logs. This management objective relies on silvicultural methods based on thinnings. Although no pine plantations have reached rotation age until recently, it is expected that in the ecological conditions of the State of Sao Paulo the plantation of Pines will reach sawlog and veneer dimensions between 20 and 30 years, depending on the species and locality. Thinnings are made at 7, 9, 12, and 16 years for a rotation age of 25 years. For a rotation of 35 years the thinnings are expected to be at 7, 9, 12, 16, and 23 years. Depending on species or locality, pruning may be necessary to produce logs free from knots in order to ensure their value.

There is not a generalized method of thinning, but today the most often used methods are "thinning from below", mechanical thinning, and some sort of crown thinning. The wood from the first thinnings is generally used for pulp and particle board, but there are some sawmills which use logs as small as 4 inches in diameter.

Present harvesting practices in both pine and Eucalyptus are primarily labor intensive. Originally wood was produced using only manual tools. Felling and bucking with axe or hand saw, limbing with axe, and prehauling with a carriage pulled by horse or oxen was common. Loading and unloading were usually manual operations and hauling was accomplished with medium-size trucks powered with gas engines.

Today, practices are still labor intensive, but certain improvements are beginning to occur. Industry has led the field in method improvements, with the introduction of certain labor-saving devices. Felling, limbing, and bucking are now usually carried out with one-man chain saws; piling of wood is by hand; manual loading still prevails; transport to the mill is by medium-sized trucks powered by diesel engines; and unloading at the mill is usually by manual means. Some industries are trying to utilize knuckleboom loaders mounted on farm tractors to load in the woods and others are utilizing tractor-trailers for transport to the mill.

The main constraints to the mechanization of harvesting operations are primarily lack of equipment and low labor rates. There is a lack of specialized equipment for harvesting operations because these machines are not produced in Brazil or, if produced, are in such small numbers that they are expensive. In addition, due to national economic problems, federal taxes on imported goods purchased by Brazilian companies result in almost prohibitive retail prices for foreign equipment.

In general, wages for woods labor in Sao Paulo are very low. Rates range from U.S. $0.40 per hour for unskilled workers to the U.S. $1.00 per hour for truck drivers and machine operators.

Some of the larger forest industries which had the necessary capital for equipment purchase have introduced a fair degree of mechanization. These operations may commonly employ skidders, mechanical loaders and large trucks. However, independent contractors generally prefer to utilize labor intensive operations which do not require large capital outlays.

Inflation of labor rates and prices of equipment will probably continue, but the major deterrent to increased mechanization of the harvesting process will most likely be the increasing price of equipment.

These economic problems and a general lack of knowledge and data about harvesting operations in the man-made forests of Sao Paulo point up the need for research in this area of forest management.

Therefore, the objectives of this study are: (1) To document present harvesting practices, (2) To analyze the economic differences in present systems with varying degrees of mechanization, and (3) To evaluate the potential of higher mechanization as used in other countries.

METHODS AND PROCEDURES

In order to meet the objectives of this study it was considered necessary to collect data from a variety of sources. The primary source of information was obtained through a questionnaire which was completed by the author's counterpart at the Institute of Technological Research. Another important source of data was obtained by correspondence with personnel from industry and the State of Sao Paulo. Additional information was obtained from the Industrial Forestry Operations faculty at Virginia Polytechnic Institute and State University, who were involved in field trips and seminars at the Institute of Technological Research in Sao Paulo.

A mathematical model was developed in order to compare and evaluate specific harvesting systems. Systems with varying degrees of mechanization, using equipment now available in the State of Sao Paulo, were analyzed. In addition, certain systems using a higher degree of mechanization were analyzed to assess their potential in this region.

Data Collection

Questionnaire

As mentioned above, the major mechanism to gather data concerning harvesting systems and stand characteristics was a questionnaire designed by the author and were administered by the author's counterpart at the Institute. The questionnaire and details concerning its completion may be found in Appendix A.

Twelve questionnaires were forwarded for analysis. Ten reported on operations in Eucalyptus and two were concerned with Pine operations. These questionnaires provided detailed information concerning crew organization, equipment spread, method of operation, productivity and harvesting conditions.

Correspondence

The next major source of information was a series of reports obtained through correspondence with the State of Sao Paulo Forest Service (Instituto Florest al do Estado de Sao Paulo). These reports presented specific data concerning stand characteristics and harvesting methods presently used in the state forests of Sao Paulo. The most important material obtained from the Forest Service, however, was their descriptions of the Eucalyptus and Pine plantations which were based on their forest inventory. From this material it was possible to develop very realistic models of Eucalyptus and Pine stands for the analyses.

Correspondence with equipment manufacturers and dealers provided up-to-date information regarding equipment specifications and prices. This information was used to develop machine capabilities used in the system design and their capitalization requirements.

Seminars and Field Trips

The determination of the kinds of data required for the study was made by the field trips of Dr. Walbridge and Mr. Stuart to Sao Paulo in June 1977.

Additional information and suggestions were obtained from a field trip to Vale do Rio Doce, State of Minas Gerais, Brazil, and a seminar conducted in September 1977 in Sao Paulo.

Other information was obtained through conversations with industry personnel. The source of this information is confidential and its use was allowed only by retaining its confidentiality.

Organization of the Data

Prior to analysis data obtained from all sources was organized to develop harvesting systems which represented typical operations with varying degrees of mechanization, as a basis for comparison to higher mechanization. Next , assumptions based on the best available data concerning costs and productivity were developed to allow evaluation and comparison of these operations. The organization of the data required analysis of the previously discussed questionnaire, industry reports, field trip data and seminar information.

For clarity and background, information pertaining to the terminology and description of harvesting functions, work areas, and equipment used in these operations is presented prior to the development of the systems used in the evaluation.

Description of the Harvesting Functions

Harvesting systems can be defined as a group of organized functions. In harvesting some functions are common to several systems and even to all systems. In order to better understand a specific system a clear presentation of the functions found in the system is required; therefore a detailed description of the common functions is presented below. Functions which are unique in any given system are so noted.

1. Felling and Bucking

Man-made forests in Brazil are generally very uniformly spaced and well aligned. This facilitates the planning and execution of field operations related to harvesting. For example, in thinnings in very uniform stands, the forester may decide to harvest every other row or every "n" rows. In clearcutting it is common practice to cut very low stumps every certain number of rows in order to allow trucks to go to the stump. In addition, the felling crew usually fells a certain number of rows each time they work through the stand.

The sawyer generally uses a chain saw of 3.4 to 8.0 hp, with a straight blade of 43 cm (17 inches). A commonly used practice is for the sawyer to be helped by another man. The helper's functions are to clean the area for the sawyer when necessary, to help in directing the fall of the trees, and carry fuel and lubricant. In some operations the helper is used to debark the region of the stump prior to felling in order to avoid excessive dulling of the chain. The helper measures the stem and the sawyer bucks the trees in lengths that vary from 1.0 m (3.3 feet) to 2.5 m (8.2 feet).

2. Delimbing and Topping

This operation is usually performed by a group of workers utilizing axes weighing 1.6 kg (3.5 lbs). Sometimes the chain saw is used for delimbing and topping but this practice is the exception rather than the rule. Generally, the group that performs this function also does manual debarking in operations with field debarking. They also do the manual prehauling required.

In this function the stems are delimbed and the top of the tree cut off. In Eucalyptus plantations this function includes windrowing of slash away from the stump. The removal of this slash avoids excessive moisture around the stump and avoids damage to the coppice.

3. Hand Debarking

Hand debarking is usually performed after the stem is bucked into bolts and is done by the same man that does the limbing, topping and manual prehauling. The tools utilized in debarking vary with the species and with the diameter of the bolts. Usually, bolts of diameters larger than 20 cm (8 inches) are debarked by axe or spud. In these cases the stick lays on the ground or on other sticks while it is being debarked by machete. Thin sticks, less than 20 cm (8 inches) in diameter are usually debarked in the vertical or near vertical position. The debarker uses one hand to hold the stick and the other to manipulate the machete.

4. Manual Prehauling

After the stick is processed in the stump area it is manually carried to the nearest strip road. The distance of manual prehauling depends on the distance between the strip roads. In Eucalyptus clearcuts the maximum distance of carrying is about 12 meters (39.37 feet). In the first and second Pine thinnings the manual prehauling distance may be 30 meters (100 feet) or even more. In later thinnings mechanized methods of prehauling such as farm tractors or horses are used to move the material to the strip road.

5. Mechanical Prehauling

When the weight of the sticks is such that they cannot be carried by hand, mechanical prehauling is employed. A variety of equipment such as trucks, farm tractors with trailers, and forwarders or prehaulers are utilized in Eucalyptus clearcutting and in Pine thinnings to accomplish this function.

6. Piling

In order to increase the efficiency of trucks used for prehauling or prehauling combined with hauling, and to make possible measurement, most of the wood is piled on the side of strip roads. Piling facilitates further movement of the bolts, expedites measurement and avoids the loss of bolts in the slash. Pile height usually is from 0.55 to 0.60 m (21.6 to 23.6 inches) and varies from 0.5 m to 1.0 m (20" to 3'4").

7. Storage

This function consists of leaving wood piled in the strip road or at the landing for certain intervals of time. This procedure is used for the purpose of decreasing weight and volume through drying, and also for inventory control. The time in storage depends on the requirements of the mill. Some industries such as particleboard and charcoal producers require dried wood, and in this case wood is stored up to 2 months in the strip road and 6 months on the landing. Some pulpmills limit the maximum storage period to two months.

8. Mensuration or Measurement

Wood in the piles is usually measured more than once during harvesting operations. This is necessary for two main reasons. First, it is usual to pay piece rates for a given volume. Second, because of the long period of time between some functions or phases, the wood needs to be measured for payment of labor or stumpage when the rate is based on the harvested volume.

Generally the piles of wood are of uniform length and height so the only variable measured is the width of the pile. Measurements are made on the strip road and at the landing.

The unit of measure generally used is the stere. That is the volume of wood contained in a pile of 1.0 m X 1.0 m X 1.0 m (3.28' X 3.28' X 3.28'). This pile contains wood and air and is supposed to contain 0.7 cubic meters of solid wood. That is equivalent to 24.72 cubic feet and to 0.2759 cords.

Measurement is accomplished with a tape and is usually performed by the foreman, assisted by an interested party.

9. Hand Loading

This function refers to the loading of haul trucks in the strip road or at the landing. When trucks are used for prehauling, which is the most usual system, they enter the strip road between the piles and stop at each pile for loading. The loading is usually done by the truck driver and two helpers. Usually the truck driver stays on the truck platform to arrange the load. The helpers pick up the sticks from the pile and lift them onto the truck. When the pile is loaded the truck is moved to the next pile and the procedure is repeated until the truck is fully loaded.

10. Mechanical Loading.

Mechanical loading is usually accomplished using a knuckleboom loader mounted on a farm tractor or on a truck. The first alternative is more usual and will be considered in this work. Usually the tractor follows the truck and at each pile they stop and the sticks are mechanically loaded onto the truck platform. This operation is performed by a group of three people: the farm tractor-knuckleboom operator; the truck driver, who during the loading stays on the platform arranging the load; and a helper who arranges the pile on the ground when it is disarranged by the knuckleboom's grapple and also stacks wood into piles for the grapple as loading of the pile is completed.

11. Mechanical Debarking

Mechanical debarking is usually done by a portable ring debarker moved and powered by a farm tractor. This operation is done by a group of three or four people, depending on the size of the debarker and the infeed mechanism. A model, Valon Kone (VK 16) which uses three people, an operator and two helpers, is the machine modeled in this study. This debarker has the capacity to debark diameters from 6 to 36 cm (2.36 to 14.17 inches) with feed speeds varying from 18 to 63 meters per minute (59.06 to 206.69 fpm). It uses the tractor's power take off (PTO) which is about 48 hp. The most commonly used tractor is diesel powered with about 85 hp. The model considered has wheels which permits it to be towed down the strip road or moved about on the landing.

12. Truck Prehauling

The method most commonly used for prehauling in man-made forests in the State of Sao Paulo is truck prehauling. Most of the trucks are medium sized with capacities between 6 to 9 tons of payload with three axles, one of which is driven, equipped with a wooden platform and powered by a gasoline or diesel engine. Usually gasoline engines are utilized when the prehauling distances are small; maximum about 500 m (1640 feet). In more adverse conditions of soil and terrain trucks with two driven axles are used.

13. Hand Unloading and Piling

This operation refers to unloading of the truck at the landing. It is usually performed by three or four men; a truck driver and two or three helpers. It consists of transferring the load from the truck to a pile on the side of the road. Depending on the height of the load and the height of the pile, one stick is handled by one man on the truck and transferred to another that puts it on the pile, or a man on the ground or on the pile picks one stick from the truck's platform and transfers it to the pile.

14. Mechanical Unloading and Piling

This function refers to unloading at the landing from the truck which did the prehauling. It is usually done with a knuckleboom loader mounted on a farm tractor or on a truck. The operation normally is done by three people: one knuckleboom operator that operates the knuckleboom and the tractor; the truck driver that stays on the platform of the truck helping form the bunches; and a man on the pile helping to arrange the pile. However, the better knuckleboom operators with good equipment can perform the job without help.

15. Hauling

This function includes transport from the tract to the mill. In the State of Sao Paulo, it is performed mainly by trucks or tractor-semitrailers. The principal variation on hauling is at the point of loading. If the truck that does the prehauling also does the hauling, it is loaded in the strip road and goes from there to the mill. This system is used when the mill is not very far from the tract and the trucks have two rear axles, only one of which is powered, with load capacities of 6 to 9 tons. When the tract is far from the mill another basic system is used in which the trucks are loaded at the landing. In this case trucks are used with rear tandem axles and tractor-semitrailers. As a rule the hauling truck or tractor-trailers are powered by diesel engines because this fuel is less expensive than gasoline.

Definition of Work Areas

Timber harvesting may be defined as a convergent system in which wood is taken from the forest and concentrated at one or more mills. The various functions occur at several places between the stump and the mill. In order to facilitate this description five different locations are considered and are described as follows.

1. Stump Area

This location is essentially the place of the standing trees and the area which the tree occupies when it is felled. In this work the stump area also includes the space where the wood is piled on the side of the strip road.

2. Strip Road

The strip road is usually an opening resulting from clearcutting a row when thinning, or a road formed by cutting very low stumps when clearcutting in order to permit the entrance of trucks. In clear-cutting the distances between strip roads are less than in thinnings because the volume removed per unit of area is larger. In thinnings rows cut for strip roads are spaced as far apart as possible to reduce the removal of trees which would be better to maintain in the stand. Thus in clearcutting the distance between strip roads usually varies from 5 to 20 meters (16 to 66 feet), while in thinnings this distance varies from 6 to 40 meters (20 to 130 feet).

Strip roads have two main functions. They serve as the first point of concentration where the sticks are piled and measured for the first time. Usually the piles are made parallel to the strip road with the sticks perpendicular to it. They also permit the entrance of the equipment used for prehauling.

3. Landing

Landings are used to concentrate wood along main or branch haul roads. Generally these areas serve a relatively small radius of operation (usually less than 20 hectares). At present landings are usually used to unload prehaulers or forwarders onto larger haul trucks. They can also be used as areas for bucking and debarking when skidding is incorporated into the system.

4. Concentration Yard

This is usually an area which serves as a point of concentration for wood which is out of the stand but on the forest tract. Usually one yard serves as a point of concentration for the wood harvested on the entire tract. These areas are used to concentrate wood for drying before hauling; unload prehaul trucks; load hauling trucks or tractor-trailers; concentrate wood for measurement for payment of stumpage; and control of inventory.

The size and the layout of the landing may vary from a pile parallel to the main road to a well-designed woodyard with fixed places for strips and piles with one or more permanent resident employees that control the inventory, issue the bills that follow the truck, load the trucks, and protect against fire or other hazards.

5. Roads

Roads may be defined as the route followed by the hauling equipment from the tract to the mill. In the State of Sao Paulo the roads may be classified primarily as paved and unpaved. The state has a reasonable network of paved two-lane roads and some highways linking the main cities. However, between the tracts and the mills usually some portion of the route is unpaved. Such unpaved roads may be divided into all-weather roads, or those that can be traveled by any kind of trucks independent of weather, and roads that cannot be taveled during or after rainy periods. More information is needed concerning the distances of both paved and unpaved roads traveled during hauling, but this is beyond the scope of this work. However, it can be stated that the unpaved road distances are generally between zero to 50 km (30 miles), and the distance traveled on paved roads may vary from 1 to 500 km (300 miles) or even more in some special conditions. Shortwood hauling in the State of Sao Paulo is almost exclusively done by truck or tractor-trailers. Only a very small proportion is moved by rail.

Description of Brazilian Equipment Used in Shortwood Harvesting

Specifications of typical equipment used in shortwood operations in the State of Sao Paulo are presented in the following pages. The presentation of the specific model or manufacturer of any equipment is not intended as a recommendation or endorsement of that particular piece of quipment, but is given only for informative purposes.

The equipment described is arranged under the following headings: (1) Manual equipment; (2) Trucks; (3) Farm tractors; (4) Knuckleboom loaders; (5) Mechanical debarkers; and (6) Forwarders.

1. Manual Equipment

   A. Hand tools

      Axes - generally 1.60 kg (3.5 lbs) in weight with a straight wooden handle. They are used for delimbing, bucking small diameter stems, topping, debarking and in-truck loading to assist in lifting the bolts onto the truck.

Machete - usually with a blade of 50 cm (20 inches) long with slight curvature in the extremity of blade, wooden or plastic handles. They are sharpened on one edge and used for delimbing small limbs, topping, debarking and clearing of brush.

Brush hook - usually with a curved blade of 30 to 40 cm long (12 to 17 inches) with wooden handle of 60 to 90 cm (24 to 36 inches) long. They are sharpened on one edge and used for delimbing, bucking small diameter stems, topping, debarking and clearing of brush.

Push poles - made of wooden shafts about 4 cm (1.57 inches) to 6 cm (2.36 inches) in diameter and 2.0 m (6.5 ft) to 3.0 m long which are fitted with an iron spur. They are used for directing the fall of the trees.

B. Chain saws - the models of chain saws most used in shortwood harvesting in the State of Sao Paulo are described below:

1) STIHL - Model 08-S

Type of engine - 1 cylinder 2 cycle

Displacement - 56 cm^3 (3.42 cubic inches)

Horsepower - 3.4 HP (DIN)

Maximum rpm - 9,500

Drive - Direct

Weight - 8.30 kg (18.28 lbs)

Blade - 43 cm (17" straight bar)

Approximate price - U.S. \$602.50

2) STIHL - Model 41-AV

Type of engine - 1 cylinder 2 cycle

Displacement - 61 cm^3 (3.72 cubic inches)

Horsepower - 3.4 HP (DIN)

Maximum rpm - 11,000

Drive - Direct

Weight - 7.50 kg (16.50 lbs)

Blade - 43 cm (17" straight bar)

Approximate price - U.S. \$711.00

3) DOLMAR - Model 122-F

Type of engine - 1 cylinder 2 cycle

Displacement -70 cm^3 (4.27 cubic inches)

Horsepower -- 8 HP (SAE)

Drive - Direct

Weight - 8.10 kg (17.84 lbs)

Blade - 43 cm (17" straight bar)

Approximate price - U.S. \$659.00

4) DOLMAR - Model M-119

Type of engine - 1 cylinder 2 cycle

Displacement - 61 cm^3 (3.72 cubic inches)

Horsepower - 6.5 HP (SAE)

Drive - Direct

Weight - 7.10 kg (15.64 lbs)

Blade - 38 cm (15" straight bar)

Approximate price - U.S. $575.00

5) SOLO TROPICON - Model 620

Type of engine - 1 cylinder 2 cycle

Displacement - 56 cm^3 (3.42 cubic inches)

Horsepower - 7 HP (SAE) @7000

Drive - Direct

Weight - 7.8 kg (17.18 lbs)

Blade - 50 cm (20" straight bar)

Approximate price - U.S. $543.00

2. Trucks

Six truck manufacturers are presently producing more than 50 different models with load capacities varying from 6,200 to 20,000 kg, (13,600 to 44,000 lbs) and tractor trailers with load capacities up to 50,000 kg (110,000 lbs). The main characteristics of the most used models are as follows:

A. CHEVROLET - C 6503 P

Engine - GM Chevrolet Model 216, 151 HP @3.800 rpm, 6 cylinders in line, 4.28 liters, 259 cubic inches, maximum torque 32.1 mkgf (232 foot lbs) @2400 rpm

Transmission - synchromesh 4 speed

Drive - two wheel drive

Brakes - hydraulic, hydrovacuum

Tires - 6 tires 8.25 X 20

Overall dimensions - <u>width</u> 2.056 mm (80.94 inches)

<u>length</u> 6.060 mm (268 inches)

height 2.015 mm (79.33 inches)

weight 3.120 kg (6.872 lbs)

Carrying capacity - 7,450 kg (16,410 lbs)

Approximate price - U.S. $8,500.00

B. CHEVROLET - D-6503

Engine - Detroit, 4-53N, diesel, direction injection, 143 HP @2200 rpm (SEA), 4 cylinders in line, displacement 3.474 cm^3 (212 cubic inches), maximum torque 37.3 mkfg (269.60 foot lbs)

Transmission - 5 speed, 2nd, 3rd, 4th, and 5th synchronized

Drive - two wheel drive

Brakes - hydraulic, hydrovacuum

Tires - 6 tires 8.25 X 20

Overall dimensions - width 2.056 m

length 6.820 m

weight 3.150 kg

Carrying capacity - 6,180 kg

Approximate price - U.S. $13,500.00

C. MERCEDES BENZ - L-1113

Engine - Diesel Mercedez Benz, OM 351 130 HP @2800 rpm 6 cylinders in line 5,675 cm^3, 344 cubic inches maximum torque 37 mkgf, 267.4 foot lbs

Power train - Transmission, Mercedez Benz, mechanic, synchronized, 5 speed, differential Mercedez Benz

Drive - two wheel drive

Brakes - air actuated hydraulic

Tires - 6 tires 9.00 X 20

Overall dimensions - width 2,350 mm (92.52 inches)

length 7,500 mm (295.3 inches)

weight 3,685 kg (8,116 lbs)

Carrying capacity - 7,300 kg (16,080 lbs)

Approximate price - U.S. $15,500.00

D. MERCEDEZ BENZ - L-2213

Engine - Mercedez Benz OM 352 130 HP @2800 rpm

6 cylinders in line 5,675 cm^3, 344 cubic inches

maximum torque 37 mkgf, 267.4 foot lbs

Power train - Transmission, Mercedez Benz, 5 speed, synchronized, differential Mercedez Benz

Drive - four wheel drive, two rear axles in tandem

Brakes - air actuated hydraulic

Tires - 10 tires 10.00 X 20

Overall dimensions - width 2,490 mm (98 inches)

height 8,155 mm (321.06 inches)

weight 5,420 kg (11,938 lbs)

Carrying capacity - 16,600 kg (36,563 lbs) load plus platform

Approximate price - U.S. $24,400.00

D. FORD - F-700

Engine - Perkins 358, diesel, 154 HP (SAE) @3000 rpm

6 cylinders in line, maximum torque 43.0 mkgf 310.8 foot lbs @1500 rpm

Transmission - 5 speed, 4 speeds synchronized

Drive - two wheel drive

Brakes - air actuated hydraulic

Tires - 6 tires 7.0 X 20

Overall dimensions - width 2,286 mm (90.0 inches)

length 7,600 mm (299.2 inches)

weight 3,920 kg (8,634 lbs)

Carrying capacity - 8,080 kg (17,638 lbs)

Approximate price - U.S. $13,500.00

3. Farm tractors

Farm tractors have been manufactured in Brazil since the end of the 50's. Presently manufacturers produce about 20 different models of this equipment. The models that are more common in the operations visited are described.

A. MASSEY-FERGUSON - MF 265

Engine - Perkins AD4-203, diesel, direction injection, displacement 3,330 cm^3, cubic inches, 61 HP @2000 rpm, maximum torque 23 mkgf, foot lbs, @1300 rpm, 4 cylinders in line

Transmission - sliding gears with planetary reduction, 8 speeds forward and 2 rearward, clutch, dry discs

Brakes - front 7.50 X 16

rear 18.4/15 X 30

Overall dimensions - width 1,970 mm (77.56 inches)

length 3,270 mm (128.74 inches)

weight 2,370 kg (5,220 lbs) without ballast

3,820 kg (8,414 lbs) with ballast

P.T.O. - 48 HP @540 rpm

53 HP @2000 rpm

Approximate price - U.S. $7,600.00

B. VALMET 85 id.

Engine - MWM D225-4TVA, diesel direction injection, displacement 3,778 cm^3, 230 cubic inches, 4 cylinders in line, 78 HP @2300 rpm, maximum torque 28 mkgf, 202 foot lbs @1500 rpm

Transmission - mechanical, synchronized

clutch, monodisc

Brakes - disc, sealed, parking

Tires - front 7.50 X 18

rear 18.4/15 X 30

Overall dimensions - width 2,050 mm (80.7 inches)

length 3,320 mm (130.7 inches)

weight 3,700 kg (8,150 lbs) with ballast

2,520 kg (5,550 lbs) without

P.T.O. - 540 rpm @1720 engine rpm

722 rpm @2300 engine rpm

Approximate price - U.S. $8,045.00

4. Knuckleboom loaders

This equipment was introduced into harvesting operations only a few years ago. The author has information that only two models of knuckleboom loaders are in use in the State of Sao Paulo.

A. MUNK JONS - MF 3050

Mounting - on medium or heavyweight trucks or farm tractors

Lifting capacity - 3,000 kg @1.00 m (6,607 lbs @3.28 ft)

Swing - 380°

Maximum reach - 5.0 m (16.4 ft)

Hydraulic systems - Pump-Parker, Mod. M11AA1A, gear type, flow 62 liters per minute (16 gallons per minute) @1500 rpm, work pressure 160 kg/cm^2 (2,278 lbs/in^2)

Stabilizers - hydraulic action

Weight - approximately 600 kg (1,321 lbs)

Approximate price - U.S. $16,000.00

B. MARCOPLAN - farm tractor

Lifting capacity - 2,200 kg @2.0 m (4,846 lbs @6.56 ft)

1,600 kg @3.0 m (3,524 lbs @9.84 ft)

1,250 kg @4.0 m (2,753 lbs @13.12 ft)

Swing - 270°

Maximum reach - 4.4 m (14.44 ft)

Hydraulic system - gear pump, flow 87 liters/minute (22.5 gallons/minute) @1150 rpm, maximum pressure 210 kg/cm^2, psi

Stabilizers - laterals, hydraulic driven

Grapple - maximum opening 1,400 mm (55.12 inches)

Approximate price - U.S. $6,700.00

5. Mechanical debarkers

Because of the long period of time between felling and conversion at the mill, and also because of high hauling costs and large distances, mills that need debarked wood, such as pulpmills and particleboard mills, require field debarking. Field debarking may be done by hand with an axe or a machete or by mechanical debarkers. Mechanical debarkers have been used for a long time in other countries on a large number of species, but were only recently developed for Eucalyptus. A description of the more commonly used debarkers in the State of Sao Paulo follows:

A. VALMET - Valon Kone VK 10 portable

Range - 4 to 23 cm diameter (1.6 to 9.1 inches)

Minimum length of wood - 1.0 m (40 inches)

Rotor rotation - 434 rpm

Feed speed - 23 to 60 meters per minute (75 to 197 ft/min)

Power requirement - 20 HP delivered by tractor P.T.O.

Approximate price - unknown

B. VALMET - Valon Kone VK 16E portable

Range - 6 to 33 cm diameter (2.36 to 13 inches)

Minimum length - 1.30 m

Rotor rotation - 365 rpm

Feed speed - 23 to 42 meters per minute (75.46 to 137.8 fpm)

Power required - 30 HP driven by electric motor on tractor P.T.O.

Approximate price - U.S. $36,500.00

6. Forwarders or Prehaulers

This equipment is just being introduced into shortwood harvesting operations in the State of Sao Paulo. The type that is being introduced is basically a tractor coupled with a trailer and equipped with a knuckleboom loaders. The main function of this equipment is to selfload its platform from the pile in the strip road and then prehaul the wood to the landing where it is transferred to a pile or to a truck that performs the hauling.

A. VALMET - 110 T.A.

Engine - MWM D225-6 TVA, diesel, 6 cylinders in line, displacement 5,658 cm^3 (345 cubic inches), maximum power 116 HP @2300 rpm, maximum torque 42 mkgf (303 foot lbs) @1500 rpm

Transmission - syncromesh, 8 speeds forward 2 rear

Steering - hydrostatic, action over front wheels

Brakes - disc, hydraulic action on driven wheels

Drive - rear wheels, with a semicrawler device with a third axle

Platform trailer - two axles in tandem

Tires - driven wheels 15.00 X 34 - 12 ply

auxiliary axle wheels 7.5 X 16 - 10 ply

front wheels 9.00 X 16 - 10 ply

platform trailers 4 wheels 14.00 X 24 - 12 ply

Knuckleboom - mounted over cabin, maximum reach 4.7 m (15.4 ft) maximum gross lifting moment 4,100 mkgf (29,628 foot lbs), swing 380^{o}, area of maximum transversal section of the grapple 0.35m^2 (3.76 sq ft), lifting capacity at maximum reach 640 kg (1,410 lbs), hydraulic system, work pressure 160 kg/cm^2 (2,278 lbs/in^2), pump flow 16 cm^3 per revolution (1 cubic inch per revolution)

Overall dimensions - <u>total length</u> 9,830 mm (387 inches)

<u>maximum width</u> 2,450 mm (96 inches)

<u>platform length</u> 4,245 mm (167 inches)

<u>platform width</u> 2,405 mm (95 inches)

<u>total weight without load</u> 9,000 kg (19,823 lbs)

<u>maximum load</u> 9,000 kg (19,823 lbs)

Carrying capacity - 9,000 kg (19,823 lbs)

Approximate price - U.S. $39,000.00

B. ENGESA - 510

Engine - MWM - D225, diesel 6 cylinders in line, maximum power 130 HP (SAE) @3000 rpm

Power train - transmission - Allison automatic model AT-540, Transfer case EE with two speeds constant mesh helical gears

Axles - front and rear, with 10,000 kg (22,000 lbs) capacity each hypoid gear angular transmission, bevel differential gears and side reduction cases with helical gears

Brakes - service air brakes with double circuit, spring brake on rear wheels

Steering - by articulation of frame, through steering wheel for road and levers for off-road operation

Tires - front and rear 18.00 X 25 or 23.50 X 25 - 12 ply

Knuckleboom - mounted in the rear part of articulated frame, model MJ6166 Munck Jons, lifting moment 6 T x m (43.359 lbs X ft) maximum reach 6.6 m (21.6 ft) controls in operator cab, hydraulic system, flow 156 liters (40 gallons) per minute @2000 rpm work pressure 150 kg/cm^2 (2,136 lbs/in^2)

Speed ranges - up to 27 km/h (16.8 miles/hr)

Overall dimensions - <u>total length</u> 9,130 mm (359 inches)

<u>width</u> 2,820 mm (111 inches)

<u>length of platform</u> 4,760 mm (187 in)

<u>width of platform</u> 2,820 mm (111 in)

Approximate price U.S. $75,000.00

<u>Formulation of the Systems for Evaluation</u>

The survey of the shortwood harvesting operations in the State of Sao Paulo and the other sources of information indicated that it is possible to represent the most important harvesting systems in man-made forests with eight systems incorporating field debarking and five systems without field debarking. The systems with field debarking are very similar in Pines and Eucalyptus. However, shortwood harvesting without field debarking is not commonly used in Pines. In addition to the existing systems more highly mechanized systems were formulated. These systems utilize equipment presently in use in other more industrialized countries. Analysis was also made of three systems using the "Tine Power Grapple" and "Draw Shear" which are now being introduced in the State of Sao Paulo. Descriptions of the 22 systems analyzed follow:

1. Systems Using Field Debarking

A. System D-1, Manual Debarking and Loading at Strip Road

No. of Functions	Description of Functions
I.	Felling and bucking with chainsaw, one sawyer and one helper.
II.	Manual delimbing, topping, debarking, prehauling and piling at strip road, 12 workers with manual tools.

III Hand loading and at strip road, truck driver and two helpers.

IV Truck prehauling from strip road to the main road, one truck driver.

B. System D-2, Manual Debarking and Loading at Strip Road and Concentration Yard

I Felling and bucking with chain saw, one sawyer and one helper.

II Manual delimbing, topping, debarking and prehauling from stump area to strip road, piling, 12 workers with manual tools.

III Hand loading at the strip road, truck prehauling from strip road to concentration yard, one driver and two helpers.

IV Hand unloading at the concentration yard, truck driver and two helpers.

V Hand loading at the concentration yard, truck driver and two helpers.

C. System D-3, All Manual Except Mechanical Loading at the Concentration Yard

I Felling and bucking with chain saw, one sawyer and one helper.

II Manual delimbing, topping, debarking, prehauling from stump area to strip road and piling at strip road, 12 workers with manual tools.

III Hand loading and truck prehauling from strip road to concentration yard, one truck driver and two helpers.

IV Hand unloading of the truck at concentration yard, truck driver and two helpers.

V Mechanical loading of the truck at the concentration yard with knuckleboom loader mounted on a farm tractor, one operator and one helper.

VI Truck loading time during mechanical loading, truck driver.

D. System D-4, All Manual Except Mechanical Loading at Strip Road

I Felling and bucking with chain saw, one sawyer and one helper.

II Manual delimbing, topping, debarking and prehauling from stump area to strip road and piling at strip road, 12 workers with manual tools.

III Mechanical loading of the truck at the strip road, knuckleboom loader mounted on farm tractor, one operator and one helper.

IV Truck prehauling from strip road to the main road, one truck driver.

E. System D-5, All Manual Except Mechanical Debarking at the Strip Road

I	Felling and bucking with chain saw, one sawyer and one helper.
II	Manual delimbing, topping, prehauling from stump area to strip road and piling at strip road, four workers with manual tools.
III	Mechanical debarking at the strip road with ring debarker coupled on a farm tractor, one operator and two helpers.
IV	Hand loading of the truck and prehauling from strip road to main road, one truck driver and two helpers.

F. System D-6, Mechanical Debarking and Loading at Strip Road

I	Felling and bucking with chain saw, one sawyer and one helper.
II	Manual delimbing, topping, prehauling from stump area to strip road and piling at the strip road.
III	Mechanical debarking at the strip road with a ring debarker coupled with a farm tractor, one operator and two helpers.
IV	Mechanical loading at strip road with a knuckleboom loader mounted on a farm tractor, one operator and one helper.

V Truck prehauling from strip road to the main road, one truck driver.

G. System D-7, Mechanical Forwarding, Debarking and Loading at a Concentration Yard

I Felling and bucking with chain saw, one sawyer and one helper.

II Manual delimbing, topping, and piling at the stump area, 4 workers with manual tools.

III Mechanical forwarding from the stump area to the landing. Forwarder self loader, one operator and one helper.

IV Mechanical debarking at the landing, with a ring debarker coupled with a farm tractor. one operator and two helpers.

V Mechanical loading at the landing with a knuckleboom loader mounted on a farm tractor, one operator and one helper.

VI Truck prehauling from the landing to the main road, one truck driver.

H. System D-8, Manual Debarking Mechanical Forwarding and Off-loading Onto Haul Trucks at the Landing

I Felling and bucking with chain saw, one sawyer and one helper.

II Manual delimbing, topping, debarking and piling at the stump area, twelve workers with manual tools.

III Mechanical forwarding from the stump area to the landing, self-loader forwarder, one operator and one helper.

IV Mechanical transfer of the load from the forwarder onto the truck, one operator and one helper.

V Truck prehauling from the landing to the main road, one truck driver.

2. Systems Without Field Debarking

A. System U-1, All Manual with Loading Prehauler at the Strip Road

I Felling and bucking with chain saw, one sawyer and one helper.

II Manual delimbing, topping, prehauling and piling at the strip road, four workers with manual tools.

III Manual loading at strip road, truck driver and two helpers.

IV Truck prehauling from strip road to the main road, truck driver.

B. System U-2, All Manual with Concentration Yard

I Felling and bucking with chain saw, one sawyer and one helper.

II Manual delimbing, topping, prehauling and piling at strip road, four workers with manual tools.

III Hand loading at the strip road and truck prehauling from strip road to the concentration yard, truck driver and two helpers.

IV Hand unloading of the truck at the concentration yard, truck driver and two helpers.

V Hand loading at the concentration yard, truck driver and two helpers.

C. System U-3, All Manual Except Mechanical at the Concentration Yard

I Felling and bucking with chain saw, one sawyer and one helper.

II Manual topping, prehauling and piling at strip road, four workers with manual tools.

III Hand loading and truck prehauling from strip road to the concentration yard, truck driver and two helpers.

IV Hand unloading at the concentration yard, truck driver and two helpers.

V Mechanical loading at the concentration yard with knuckleboom loader mounted on a farm tractor, one operator and two helpers.

VI Truck mechanical load at the concentration yard, truck driver.

D. System U-4, All Manual Except Mechanical Loading at the Strip Road

I Felling and bucking with chain saw, one sawyer and one helper.

II Manual delimbing, topping, prehauling, piling at strip road, four workers with manual tools.

III Mechanical loading at the strip road, knuckleboom loader mounted on a farm tractor, one operator and one helper.

IV Truck prehauling from strip road to main road, truck driver.

E. System U-5, All Manual Except Mechanical Forwarding

I Felling and bucking with chain saw, one sawyer and one helper.

II Manual limbing, topping, prehauling and piling at the strip road, four workers with manual tools.

III Forwarding from strip road to landing, self loading forwarder, one operator and one helper.

IV Forwarder off-loading onto the truck at the landing, one operator and one helper.

V. Truck loading and prehauling from landing to the main road, truck driver.

3. Systems Using Higher Mechanization

A. System M-1, All Manual Except Cable Skidding and Mechanical Loading

I Felling, limbing and topping with chain saw, one sawyer.

II Cable skidding from strip road to landing, one operator.

III Bucking with chain saw at landing, one sawyer.

IV Manual debarking at the landing, worker with manual tools.

V Mechanical loading at the landing with knuckleboom loader mounted on a farm tractor, one operator and one helper.

VI Truck prehauling from landing to the main road, truck driver.

B. System M-2, All Manual Except Cable Skidding, Mechanical Debarking and Loading

I Felling, limbing and topping with chain saw, one sawyer.

II Cable skidding from stump area to the landing, one operator.

III Bucking with chain saw at the landing.

IV Mechanical debarking at the landing, ring debarker coupled with farm tractor, one operator and two helpers.

V Mechanical loading at the landing, knuckleboom loader mounted on farm tractor, one operator and one helper.

VI Truck prehauling from landing to main road, truck driver.

C. System M-3, Feller Bunching, Grapple Skidding, Mechanical Loading

I Felling and bunching with a feller buncher, one operator.

II Skidding with a grapple skidder from stump area to the landing, one operator.

III Bucking at the landing with chain saw, one operator.

IV Manual debarking at the landing, workers with manual tools.

V Mechanical loading at the landing, knuckleboom loader mounted on farm tractor, one operator and one helper.

VI Truck loading at the landing and prehauling from landing to main road, one truck driver.

D. System M-4, Feller Bunching, Grapple Skidding, Mechanical Debarking and Loading

I	Felling and bunching with a feller buncher, one operator.
II	Skidding with a grapple skidder from stump area to the landing, one operator.
III	Bucking with chain saw, one sawyer.
IV	Mechanical debarking at the landing, ring debarker coupled with farm tractor, one operator and two helpers.
V	Mechanical loading at the landing, knuckle-boom loader mounted on farm tractor, one operator and one helper.
VI	Truck prehauling from landing to the main road, truck driver.

E. System M-5, Draw Shear, Power-tine and Mechanical Loading

I	Felling and bunching with a draw shear mounted on a 65 HP farm tractor, one operator.
II	Manual limbing and topping, one worker using manual tools.
III	Skidding from stump area to landing with farm tractor with power-tine, one operator.
IV	Bucking at the landing with chain saw,

one sawyer.

V Manual debarking at the landing, workers with manual tools.

VI Mechanical loading at landing, knuckleboom loader mounted on farm tractor, one operator and one helper.

VII Truck prehauling from landing to main road, one truck driver.

F. System M-6, Draw Shear, Power-tine, Mechanical Debarking and Loading

I Felling and bunching with a draw shear, one operator

II Manual limbing and topping at the stump area, one worker with manual tools.

III Skidding from stump area to landing with a farm tractor with a power-tine, one operator.

IV Bucking at the landing with chain saw, one sawyer.

V Mechanical debarking at the landing, ring debarker mounted on a farm tractor, one operator and two helpers.

VI Mechanical loading at the landing with knuckleboom loader mounted on a farm tractor, one operator and one helper.

VII Truck prehauling from landing to the main road, one truck driver.

G. System M-7, Cable Skidding, Mechanical Loading, No Debarking

I Felling, limbing and topping with chain saw, one sawyer.

II Cable skidding from strip road to landing, one operator.

III Bucking with chain saw at the landing, one sawyer.

IV Mechanical loading at the landing with a knuckleboom loader mounted on a farm tractor, one operator and one helper.

V Truck prehauling from landing to the main road, one truck driver.

H. System M-8, Feller Bunching, Grapple Skidding, Mechanical Loading

I Felling and bunching with a feller buncher, one operator.

II Skidding with a grapple skidder from stump area to landing, one operator.

III Bucking at landing with chain saw, one operator.

IV Mechanical loading at the landing with knuckleboom loader on a farm tractor, one operator and one helper.

V Truck prehauling from landing to the main road, one truck driver.

I System M-9, Draw Shear and Power-tine, Mechanical Loading, No Debarking

I Felling and bunching with draw shear mounted on farm tractor, one operator.

II Manual limbing and topping on the bunch, one worker.

III Skidding from stump area to landing with farm tractor and power-tine, one operator.

IV Bucking with chain saw at the landing, one sawyer.

V Mechanical loading at the landing with a knuckleboom loader mounted on a farm tractor, one operator and one helper.

VI Truck prehauling from landing to the main road, one truck driver.

Description of Forest Stands Used in the Analysis

In order to provide a realistic situation regarding the impact of the size of the harvesting chance, the analyses of the systems are based on the time required to "harvest" the volume from a stand which is 20 hectares (50 acres) in area.

The "harvested" stand represents an average of stand parameters which were being cut at the time of Jara's field visits. In Eucalyptus stands the volume cut varied from 100 to 387 steres per hectare (11.2 to 43.2 cords per acre). The average was 190.25 steres per hectare (21.25 cords per acre). The number of trees per hectare varied from 1400 to 2500 (566 to 1,011 per acre). The average diameter varied from 11.7 cm (4.6 inches) to 16.6 cm (6.3 inches), and the average heiht varied from 12.0 m (40 feet) to 24.0 m (80 feet). The age of the stands varied from 6 to 16 years, but most of them were from 6 years to 10 years of age.

In the pine stands observed the volume harvested in thinnings varied from 33.0 steres per hectare (3.7 cords per acre) to 144.0 steres per hectare (16.1 cords per acre). The average was about 68.0 steres per hectare (7.6 cords per acre). Other stand parameters were so variable in regard to age, species, number of thinnings prior to the thinnings observed, that the numbers are of no particular value for this study.

For purposes of analysis the stand to be "harvested" in the system evaluations of Eucalyptus was assumed to be 20 hectares (50 acres) in size, and contain 190.25 steres per hectare of merchantable volume (21.25 cords per acre). Because of the lack of sufficient information no assumptions were made for operations on pine stands which were not analysed.

Data Analysis

There are several methods which have been developed for the analysis of the efficiency and effectiveness of harvesting systems. These methods fall into the three general classifications of: graphical analysis, mathematical modeling, and computer simulation. Generally speaking the objectives of the study dictate the choice of the analytical technique.

Graphical analysis is a method often used to rapidly assess the effect of production parameters on fixed and variable costs. In its most sophisticated form nomographs or alignment charts can be constructed which allow the user to easily predict the impact of machine availability, machine productivity, labor rates, capitalization and stand characteristics for a specific system. They are an effective means of production control which can be easily used by field supervisors. Since this work is concerned with more intensive comparisons of a variety of systems and machine a more comprehensive model was deemed suitable.

A second method of analysis, deterministic mathematical modeling, can be used to make more intensive studies. A model which is made up of the production functions can be developed to take into account a major portion of the important variables required for system evaluation. Essentially such a model would consist of a series of formulae which could be solved on a pocket or desk calculator which would lend themselves to analysis by administrative personnel and not require a large computer system. For these reasons such a model was developed for the analysis of the data obtained in this study.

The modeling of probabilistic or stochastic data is best accomplished with computer simulation. At the current level of harvesting technology in the State of Sao Paulo, which utilizes labor intensive systems and a piece rate method of payment which involves little or no interaction between functions, there is no particular advantage to the use of the method of analysis. However, in the future, computer simulation should be used for research and planning in order to assess the potential of highly mechanized systems which are capital intensive and have a high degree of interaction between functions.

Development of the Model

The model that was developed for cost analysis is the sum of production functions which consider the most important variables in the present harvesting systems in the State of Sao Paulo. These production functions are the Fixed Cost of Machines, the Variable Cost of Machines and the Cost of Labor. A formula which calculates the cost of each of these functions was developed in order to arrive at total cost per stere in U.S. dollars.

Because of the great variations among the operations observed and reported on, the model is limited to the calculation of direct cost of machine and labor and does not include the costs of supervision, overhead and support facilities such as the construction of roads and landings.

Each of the formulae developed for the production function mentioned above are set up below.

1. Fixed Cost of Machines

This component of cost was calculated using a method of financing rather than a machine rate approach. In this method the fixed cost of equipment is considered to be the amount that must be paid toward the principal plus the interest on the machine which was financed. This method has the advantage of requiring less assumptions than the process based on depreciation, such as the life of the equipment, salvage value, and the choice of one of the method of depreciation. In the financial method all the variables are known. These are initial cost of equipment, down payment, interest rate, period of financing, and the number of scheduled hours per year.

The financing cost per hour can be calculated by the formula:

$$\text{Machine fixed cost per hour} = \frac{(F \cdot i \cdot n) + F}{n \cdot h} \qquad (1)$$

where:

F = amount financed (cost of equipment in U.S. dollars minus down payment

i = add-on interest rate (decimal rate per year)

n = number of years of finance period

h = number of scheduled hours per year.

In order to calculate the total machine fixed cost for any specific function it is necessary to calculate the machine hours required to produce a given volume of wood. This calculation can be expressed by the following formula:

$$\text{Required machine hours} = \left(\frac{V}{P} + \frac{\frac{V}{L} \cdot 2D}{60\ t} \right) \frac{1}{U} \qquad (2)$$

where:

V = volume to be cut in the operation (steres)

P = productivity in volume per productive hour equipment (steres per hour)

= load capacity in volume for equipment that skids, hauls or transports material (steres)

D = average distance by which the material is moved (meters)

t = average travel rate from de point of loading to the point of unloading (meters per minute)

U = utilization or efficiency, that is the ratio between productive hours and scheduled hours.

Then the total equipment fixed cost for a specific harvesting function or activity is equal to:

Total equipment fixed cost for j^{th} function = $\frac{(F.i.n)+F}{n.h}\left(\frac{V}{P}+\frac{\frac{V}{L}.2D}{60\ t}\right)\frac{1}{U}$

which may be simplified to:

$$=\frac{(F.i.n)+F}{n.h}\left(\frac{V}{P}+\frac{VD}{30\ Lt}\right)\frac{1}{U}$$

The machine fixed cost per stere of j^{th} function is attaine by dividing the total fixed cost of the function by the volume produced.

Hence, the machine fixed cost per stere for a particular function of harvesting may be calculated by the formula:

$$=\frac{(F.i.n)+F}{n.h}\left(\frac{V}{P}+\frac{VD}{30\ Lt}\right)\frac{1}{U}\ /\ V = \text{ U.S. dollars per stere}$$

2. Variable Cost of Machine

Variable costs in harvesting equipment includes those costs that occur when the equipment is in operation. The more important components of variable costs are: fuel, lubricants, grease, and repair and maintenance. Generally this cost is attained from records, or through calculations based on engine size, and in some cases by rules of thumb. A rule of thumb generally accepted in the U.S. is to consider the repair and maintenance cost as a percentage of depreciation. A pessimistic view of maintenance and repair is considered equal to 125% of depreciation. An optimistic calculation of repair and maintenance uses 75% of depreciation while 100% of the depreciation per hour is considered a normal provision for repair and maintenance.

The total variable cost of the j^{th} function can be calculated by the formula:

$$\text{Total machine variable cost of } j^{th} \text{ function} = m\left(\frac{V}{P} + \frac{VD}{30\ Lt}\right)$$

where:

m = machine variable cost per hour.

Thus, machine variable cost per stere for a specific function is given by the equation:

$$\text{Machine variable cost per stere of } j^{th} \text{ function} = \frac{m\left(\frac{V}{P} + \frac{VD}{30\ Lt}\right)}{V}$$

3. Labor Cost

This component includes the wages and cost of fringe benefits that occur over the scheduled time of the operation. The basis for calculation is the sum of all wages allotted to a specific function multiplied by a factor that represents the cost of fringe benefits as a function of wages. So the formula for the total labor cost for the j^{th} function is:

$$\text{Total labor cost of } j^{th} \text{ function} = w \cdot f\left(\frac{V}{P} + \frac{VD}{30\ Lt} \cdot \frac{1}{U}\right)$$

where:

w = summation of the hourly wages of the function

f = fringe benefits that is equal to 1 + the decimal fraction of cost of fringe benefits as a function of wages.

The labor cost per stere is calculated by dividing the total labor cost by the total volume thus:

Labor cost per unit of volume (stere) for j^{th} function =

$$\frac{w \cdot f \left(\frac{V}{P} + \frac{VD}{30\ Lt}\right) \frac{1}{U}}{V}$$

4. Total Direct Cost of a Specific Function

The costs of each component for a specific function of the harvesting operation have been dealt with up to this point. The cost per unit of volume (stere) of a specific function of harvesting is thus equal to the summation of machine fixed cost, machine variable cost and labor cost. Thus the total cost of j^{th} function is:

$$C_j = \frac{\frac{(F \cdot i \cdot n)+F}{h \cdot n} \left(\frac{V}{P} + \frac{VD}{30\ Lt}\right) \frac{1}{U}}{V} + \frac{m \left(\frac{V}{P} + \frac{VD}{30\ Lt}\right)}{V} + \frac{w \cdot f \left(\frac{V}{P} + \frac{VD}{30\ Lt}\right) \frac{1}{U}}{V}$$

where C_j is the cost per unit of volume (stere) for the Function J.

5. Total Direct Cost of the Harvesting System

To estimate the total cost for a given system then, is only a matter of summing all function costs occurring in the system.

Total system cost per unit of volume = $\sum_{j=1}^{n} C_j$,

where:

n = number of functions.

This model was used to analyze all of the systems presented in this study. The format used for calculations and results obtained for each system are contained in Appendix B.

Assumptions Used in the Analyses

As inputs to the mathematical model the following labor costs, equipment costs, and function productivities were used.

1. Labor rates

U.S. dollar labor rates were obtained by converting piece rates in Brazilian cruzeiros at a rate of CR $20.00 per one U.S. dollar. This conversion rate is considered adequate at the present rate of exchange. The hourly wages per U.S. dollar by task are presented in Table 2. Fringe benefits were considered to be equal to 60% of these labor rates.

2. Equipment cost

Equipment costs used in the analyses were obtained from equipment dealers, trade journals and the various logging operations which were visited. The initial costs of equipment used in the analyses are set out in Table 3. With the exception of chain saws the amount financed was determined by assuming a 20% down payment for all equipment. In the case of chain saws the financed amount was assumed to be the initial cost.

3. Variable cost of machines

For this study the variable machine costs used in the calculations were made up to the cost of fuel and lubricants consumed and the cost of maintenance and repair. Fuel and lubricant costs were based on

Table 2. Hourly labor rates in U.S. dollars.

	TASK PERFORMED	WAGES (U.S. Dollars)
1.	Chain saw operator	$ 0.63
2.	Sawyer helper	.45
3.	Delimber and topper	.45
4.	Hand debarker	.45
5.	Manual prehauler	.45
6.	Piler	.45
7.	Truck driver	.75
8.	Truck driver helper	.45
9.	Tractor and knuckleboom operator	.75
10.	Tractor operator helper	.45
11.	Mechanical debarker operator	.60
12.	Mechanical debarker worker	.45
13.	Skidder operator	.80
14.	Feller buncher operator	.80
15.	Power tine grapple operator	.75
16.	Draw shear operator	.75

Table 3. Approximate initial cost of equipment in U.S. dollars.

EQUIPMENT	COST (U.S. Dollars)
Chain saw - 6 to 7 HP SAE	$ 600
Truck - diesel powered, 7.3 ton carrying capacity with wooden platform	13,500
Farm tractor - 60 to 70 HP	7,600
Knuckleboom loader - hydraulically operated 4100 kg (9.03 lbs) @1.00 m (3.28 feet)	16,000
Portable ring debarker - diameter capacity from 4 to 23 cm (1.6 to 9.0 inches)	36,500
Forwarders - 130 HP, carrying capacity 9,000 kg (19,820 lbs)	39,000
Cable skidder - 100 HP	75,000
Grapple skidder - 100 HP	100,000
Feller buncher - 80 HP carrier, with accumulating shear	100,000
Draw shear	5,000
Power tine grapple	2,000

consumption by engine size. Maintenance and repair costs were assumed to be equal to 100% of the straightline depreciation over a five year period, with a 20% salvage value. The variable machine costs assumed are set out in Table 4.

4. Productivity.

Productivity data used in the analyses was based on information gathered during the visits to harvesting operations, interviews with operators and research results. These data are not the result of statistical analyses but are estimations based on actual information from on-going operations. The productivity of some functions are grouped because they actually are combined in the field. The productivity rates are listed separately for Pinus and Eucalyptus are set out in Tables 5 and 6. Only Eucalyptus operations were analyzed.

5. Travel rates

All terrain and harvesting conditions were assumed equal for all systems. Since there were different points for loading and unloading during prehauling however, different travel rates were assumed according to the path followed by the machines. The assumed travel rates are as follows:

(1) Truck prehauling from strip road to concentration yard, 250 meters (820 feet) per minute.

(2) Truck prehauling from landing to concentration yard, 333 meters (1093 feet) per minute.

(3) Mechanical forwarding from strip road to landing, 166.7 meters (546.5 feet) per minute.

Table 4. Assumed variable hourly cost of machines in U.S. dollars.

EQUIPMENT	COST (U.S. Dollars)
Chain saw	$ 1.40
Prehauling trucks, 7.30 ton 130 HP diesel engine	4.17
Prehauling trucks, 7.30 tons being loaded at landing	2.08
Knuckleboom loader, mounted on a 65 HP farm tractor	3.20
Portable ring debarker coupled with 65 HP farm tractor	4.57
Forwarder, 130 HP	5.87
Cable skidder, 100 HP	5.00
Grapple skidder, 100 HP	5.00
Feller buncher, 80 HP	5.00
Farm tractor equipped with draw shear	3.20
Farm tractor equipped with power-tine grapple	3.20

Table 5. Productivity for harvesting functions in Pines.

FUNCTION	TOOLS AND CREW	PRODUCTIVITY
Felling & bucking	1 sawyer and helper, 1 chain saw, and manual tools	4.13 steres (1.14 cords) per hr.
Debarking, topping, delimbing, manual prehauling & piling	1 man with axe or machete	0.28 steres (0.08 cords) per hr.
Limbing, topping, manual prehauling & piling	1 man with axe or machete	0.63 steres (0.17 cords) per hr.
Hand loading	3 men	24.89 steres (6.9 cords) per hr.
Hand unloading	3 men	46.15 steres (12.7 cords) per hr.
Mechanical loading	Knuckleboom loader mounted on farm tractor, 2 men	52.5 steres (14.5 cords) per hr.
Mechanical debarking	Ring debarker coupled with farm tractor	7.14 steres (1.97 cords) per hr.

Table 6. Productivity for harvesting functions in Eucalyptus.

FUNCTION	TOOLS AND CREW	PRODUCTIVITY
Felling & bucking	1 sawyer and helper, 1 chain saw, and manual tools	4.44 steres (1.23 cords) per hr.
Debarking, topping, delimbing, manual prehauling & piling	1 man with axe or machete	0.33 steres (0.09 cords) per hr.
Limbing, topping, manual prehauling & piling	1 man with axe or machete	1.11 steres (0.31 cords) per hr.
Hand loading	3 men	24.89 steres (6.9 cords) per hr.
Hand unloading	3 men	46.15 steres (12.7 cords) per hr.
Mechanical loading	Knuckleboom loader mounted on farm tractor, 2 men	52.5 steres (14.5 cords) per hr.
Mechanical debarking	Ring debarker coupled with farm tractor	7.14 steres (1.97 cords) per hr.

Travel rates for other prehauling equipment were not needed, since their productivity includes travel time.

6. Other assumptions

Assumptions not related to labor and equipment were made as follows:

A. Distance from the strip road to the concentration yard or main haul road was calculated to be 1501.5 meters (4926 feet); from the strip road to the landing was calculated to be 228.5 meters (750 feet); from the landing to the concentration yard or main road was calculated to be 1500 meters (4921 feet).

B. Number of scheduled hours per year was estimated as 2,400.

C. Rate of interest was assumed to be 17.61% add-on per year which is equal to 2.5% per month on a declining balance.

D. Finance period for chain saws was assumed to be two years; all other equipment was assumed to be for a period of three years.

RESULTS AND DISCUSSION

The results of the analyses of the systems presented in the previous chapter are presented in two major categories. The first, includes eight domestic systems with varying degrees of mechanization and six systems of higher mechanization not yet in use in the State of Sao Paulo which utilize field debarking. The second, includes five domestic systems with varying degrees of mechanization and three systems of higher mechanization not yet in use in the State of Sao Paulo which do not utilize field debarking. Each category is presented separately. The systems of higher mechanization represent non-existent systems and are essentially projections of the potential of introducing equipment and systems being used in other countries.

Comparison of Systems with Field Debarking - Eucalyptus

The results of the analyses of both domestic and exotic systems using field debarking are grouped into comparisons of total direct cost, labor input, and capitalization requirements. If comparisons of these systems are made on the basis of total direct cost per stere as shown in Figure 1, the following conclusions can be drawn:

1. The range in total direct costs in dollars per stere is from \$3.08 to \$6.06.
2. Systems D-1 and D-4 show the lowest direct cost per stere. Both systems load the truck in the strip road. Since one uses manual loading and the other a hydraulic loader, it appears that mechanical loading is economically feasible.

Systems	Stump Fell	Strip Road		Method of Forwarding	Landing			Woodyard		Main Road	Direct Cost US $/Stere	Direct Cost Index *
		Deb.	Ldg.		Unldg.	Deb.	Ldg.	Unldg.	Ldg.			
D-1	CS	H	H	TRUCK							3.12	1.00 (1.70)
D-2	CS	H	H	TRUCK				H	H		3.57	1.14 (1.95)
D-3	CS	H	H	TRUCK				H	M		3.57	1.14 (1.95)
D-4	CS	H	M	TRUCK							3.08	0.99 (1.68)
D-5	CS	M	H	TRUCK							3.87	1.24 (2.11)
D-6	CS	M	M	TRUCK							3.81	1.22 (2.08)
D-7	CS		M	FORWARDER	M	M	M				4.40	1.41 (2.40
D-8	CS	H	M	FORWARDER			M				3.45	1.11 (1.89)
M-1	CS			CABLE SK.		H	M				3.86	1.24 (2.11)
M-2	CS			CABLE SK.		M	M				4.58	1.47 (2.50)
M-3	FB			GRAPPLE SK.		H	M				5.17	1.66 (2.83)
M-4	FB			GRAPPLE SK.		M	M				5.89	1.89 (3.22)
M-5	DS			TINE GRAPP.		H	M				5.35	1.71 (2.92)
M-6	DS			TINE GRAPP.		M	M				6.07	1.94 (3.32)

* Indices in parenthesis have U-1 as a basis.

CS - chain saw
FB - feller buncher
DS - draw shear
H - hand work
M - mechanical work

load up from ground
unload down to ground
unload to other equipment
load from other equipment

Figure 1. Total Direct Costs of Systems with Field Debarking in Eucalyptus.

3. When the wood is concentrated at a woodyard, as in systems D-2 and D-3, it appears that mechanical loading of haul trucks is economically feasible.
4. Comparing system D-5 with D-1 and D-6 with D-4 indicates that the addition of mechanical debarking results in about a 25% increase in total direct cost per stere.
5. Comparing system D-8 and D-4 indicates that the use of a forwarder instead of taking the haul truck to the stump results in an increase in cost of 12%.
6. Comparing D-7 with D-6 indicates that shifting the mechanical debarking from the strip road to a landing results in an increase in cost of approximately 19%.
7. The simplest system incorporating tree length skidding, which is system M-1, would probably result in a cost per stere equivalent to the more mechanized domestic systems.
8. The addition of mechanical felling and bunching, and mechanical debarking at the landing would result in incremental cost increases up to about twice that for system D-1.

Comparisons of these systems based upon labor input expressed in terms of man hours per stere as shown in Figure 2 lead to the following conclusions:

1. The addition of mechanical loading to the domestic systems appears to have little impact on labor requirements.
2. When mechanical debarking is used in the domestic systems

Systems	Stump Fell	Strip Road Deb.	Strip Road Ldg.	Method of Forwarding	Landing Unldg.	Landing Deb.	Landing Ldg.	Woodyard Unldg.	Woodyard Ldg.	Main Road	Man Hours Per Stere	Manpower Index *
D-1	CS	H	H	TRUCK							3.28	1.00 (2.22)
D-2	CS	H	H	TRUCK				H	H		3.49	1.06 (2.36)
D-3	CS	H	H	TRUCK				H	M		3.42	1.04 (2.31)
D-4	CS	H	M	TRUCK							3.22	0.98 (2.18)
D-5	CS	M	H	TRUCK							1.92	0.59 (1.30)
D-6	CS	M	M	TRUCK							1.84	0.56 (1.24)
D-7	CS	–	M	FORWARDER	M	M	M				1.92	0.59 (1.30)
D-8	CS	H	M	FORWARDER			M				3.26	0.99 (2.20)
M-1	CS			CABLE SK.		H	M				2.22	0.68 (1.50)
M-2	CS			CABLE SK.		M	M				0.82	0.25 (0.55)
M-3	FB			GRAPPLE SK.		H	M				2.14	0.65 (1.45)
M-4	FB			GRAPPLE SK.		M	M				0.74	0.23 (0.50)
M-5	DS			TINE GRAPP.		H	M				2.86	0.87 (1.93)
M-6	DS			TINE GRAPP.		M	M				1.46	0.45 (0.99

*Indices in parenthesis have U-1 as a basis.

CS - chain saw
FB - feller buncher
DS - draw shear
H - hand work
M - mechanical work

load up from ground
unload down to ground
unload to other equipment
load from other equipment

Figure 2. Man Hours Per Stere in Systems with Field Debarking in Eucalyptus.

a decrease of approximately 40% of the manpower required is indicated.

3. System M-4, which incorporates a feller buncher and mechanical debarking and loading, suggests the highest labor productivity or the lowest labor requirements of all systems analyzed.

4. The labor requirements for system M-2, which uses chain saw felling, appear to be nearly equal to that of system M-4, which suggests that with the current level of feller buncher technology and the tree sizes encountered in these studies no appreciable labor advantage is to be gained from the additional investment.

5. Manual debarking in systems M-1, M-3 and M-5 result in approximately the same labor productivity as mechanical debarking in systems D-5, D-6 and D-7, which suggests that if a shortage of woods labor develops alternative strategies are available.

Comparisons of these systems based on capitalization per stere of annual production as shown in Figure 3 lead to the following conclusions:

1. Capital investment per stere of annual production ranges from $0.33 for system D-1 to $9.14 for system M-4.

2. The addition of mechanical debarking in domestic system D-5 increases the capital required by 782% over system D-1.

3. Comparing systems D-1 and D-4 and systems D-2 and D-3

Systems	Stump Fell	Strip Road Deb.	Strip Road Ldg.	Method of Forwarding	Landing Unldg.	Landing Deb.	Landing Ldg.	Woodyard Unldg.	Woodyard Ldg.	Main Road	Investment Per Stere Per Year	Investment Index *
D-1	CS	H	H	TRUCK							0.33	1.00
D-2	CS	H	H	TRUCK				H	H		0.68	2.06
D-3	CS	H	H	TRUCK				H	M		0.71	2.15
D-4	CS	H	M	TRUCK							0.40	1.21
D-5	CS	M	H	TRUCK							2.91	8.82
D-6	CS	M	M	TRUCK							2.98	9.03
D-7	CS		M	FORWARDER	M	M	M				3.64	11.03
D-8	CS	H	M	FORWARDER			M				0.88	2.67
M-1	CS			CABLE SK.		H	M				2.89	8.76
M-2	CS			CABLE SK.		M	M				5.46	16.65
M-3	FB			GRAPPLE SK.		H	M				6.57	19.91
M-4	FB			GRAPPLE SK.		M	M				9.14	27.70
M-5	CS			TINE GRAPP.		H	M				3.16	9.58
M-6	CS			TINE GRAPP.		M	M				5.74	17.39

* Indices refer to system U-1.

CS - chain saw
FB - feller buncher
DS - draw shear
H - hand work
M - mechanical work

load up from ground
unload down to ground
unload to other equipment
load from other equipment

Figure 3. Investment Per Stere Per Year in Systems with Field Debarking in Eucalyptus.

illustrates that the additional capital invested in mechanical loading is nearly offset by the decrease in the number of trucks required, due to faster turn around.

4. System M-4 which is the most highly mechanized system increases the capitalization requirement to $9.14 per stere of annual production.

5. Capitalization levels comparable to domestic systems which utilize mechanical debarking can be achieved by more highly mechanized systems depending on their level of sophistication or if manual debarking is used.

Figure 4 presents the projected manpower and capital requirements to produce 750,000 steres per year to a 500 ton per day pulp and paper mill. Inspection of the data illustrates the trade-offs between labor and capital requirements. The impact of systems which utilize manual debarking on manpower requirements and the impact of capital requirements for mechanized tree-length systems is clear.

Comparison of Systems Without Field Debarking - Eucalyptus

The results of the analyses of the systems without field debarking are grouped into comparisons of total direct cost, labor input and capital requirements.

Comparisons of the systems are made on the basis of direct cost per stere as shown in Figure 5 and lead to the following conclusions:

1. Total direct costs range from U.S. $1.78 to $4.08 per stere.

2. System U-1 and U-4 present the lowest direct cost per stere.

Systems	Stump Fell	Strip Road Deb.	Strip Road Ldg.	Method of Forwarding	Landing Unldg.	Landing Deb.	Landing Ldg.	Woodyard Unldg.	Woodyard Ldg.	Main Road	Number of People	Investment in $1,000
D-1	CS	H	H	TRUCK							1,026	251
D-2	CS	H	H	TRUCK				H	H		1,089	512
D-3	CS	H	H	TRUCK				H	M		1,070	530
D-4	CS	H	M	TRUCK							1,006	302
D-5	CS	M	H	TRUCK							600	2,181
D-6	CS	M	M	TRUCK							574	2,232
D-7	CS		M	FORWARDER	M	M	M				600	2,733
D-8	CS	H	M	FORWARDER			M				1,020	662
M-1	CS			CABLE SK.		H	M				693	2,167
M-2	CS			CABLE SK.		M	M				255	4,097
M-3	FB			GRAPPLE SK.		H	M				669	4,924
M-4	FB			GRAPPLE SK.		M	M				232	6,854
M-5	DS			TINE GRAPP.		H	M				894	2,371
M-6	DS			TINE GRAPP.		M	M				457	4,301

CS - chain saw
FB - feller buncher
DS - draw shear
H - hand work
M - mechanical work

load up from ground
unload down to ground
unload to other equipment
load from other equipment

Figure 4. Total Labor Requirements and Capital Investment Required to Harvest 750,000 Steres of Pulpwood per Year with Field Debarking.

Systems	Stump Fell	Strip Road Loading	Method of Forwarding	Landing Unldg.	Landing Ldg.	Woodyard Unldg.	Woodyard Ldg.	Main Road	Direct Cost U.S.$/stere	Indices
U-1	CS	H	TRUCK						1.82	1.00
U-2	CS	H	TRUCK			H	H		2.27	1.24
U-3	CS	H	TRUCK			H	M		2.27	1.24
U-4	CS	M	TRUCK						1.78	0.97
U-5	CS	M	FORWARDER		M				2.15	1.17
M-7	CS		CABLE SKDR.		M				2.55	1.40
M-8	FB		GRAPPLE SK.		M				3.86	2.11
M-9	DS		TINE GRAPP.		M				4.03	2.20

CS - Chain Saw
FB - Feller Buncher
DS - Draw Shear
H - Hand Work
M - Mechanical Work

Loading from ground
Unloading down ground
Transfering load onto other equipment
Receiving load from other equipment

Figure 5. Direct Cost for Systems Without Field Debarking in Eucalyptus.

Both systems load the truck in the strip road. System U-1 uses hand loading and system U-4 uses a hydraulic loader. Since both present very similar direct costs it appears that mechanical loading is economically feasible.

3. When wood is concentrated at the woodyard, as in systems U-2 and U-3, it appears that mechanical loading of haul trucks is economically feasible.
4. The use of forwarders for moving the wood from the strip road to a landing and then transferring the load onto the haul truck increases the cost 23% in comparison with system U-4 which mechanically loads haul trucks in the strip road.
5. The introduction of tree-length skidding with a cable skidder as in system M-7 increases the direct cost 40% when compared to loading of the haul truck in the strip road.
6. System M-8 which uses a feller buncher and grapple skidder increases the cost over the base system U-1 40%.
7. Because of lower production in system M-9 costs exceed system M-8 by 4% but capital requirements are reduced by 50%.

Comparison of the systems without field debarking based upon labor input expressed in terms of man hours per stere is shown in Figure 6 and leads to the following conclusions:

1. Addition of mechanical loading to the domestic systems appears to have little impact on labor requirements. This can be seen by comparing labor inputs for system U-3 with

Systems	Stump Fell	Strip Road Loading	Method of Forwarding	Landing Unldg.	Landing Ldg.	Woodyard Unldg.	Woodyard Ldg.	Main Road	Man Hours Per Stere	Man Hours Per Stere Index
U-1	CS	H	TRUCK						1.48	1.00
U-2	CS	H	TRUCK			H	H		1.59	1.07
U-3	CS	H	TRUCK			H	M		1.62	1.09
U-4	CS	M	TRUCK						1.42	0.96
U-5	CS	M	FORWARDER		M				1.46	0.99
M-7	CS		CABLE SK.		M				0.40	0.27
M-8	FB		GRAPP. SK.		M				0.32	0.22
M-9	DS		TINE GRAPP.		M				1.04	0.70

CS - chain saw
FB - feller buncher
DS - draw shear
H - hand work
M - mechanical work

loading from ground
unloading down ground
transferring load onto other equipment
receiving load from other equipment

Figure 6. Man Hours Requirements Per Stere in Systems Without Field Debarking in Eucalyptus.

U-2, and U-4 with U-1.

2. The use of forwarding appears to have little impact in man hours per stere when compared with systems that utilize trucks as prehaulers.
3. System M-7 reduces manpower requirements 70% when compared with systems U-1 and U-4.
4. System M-8 which utilizes a feller buncher and grapple skidder reduces labor input by 80% over the base systems.
5. System M-9 reduces labor input by 30%.

When systems without field debarking are compared on the basis of capital requirements per stere of annual production as shown in Figure 7 the following conclusions can be drawn:

1. Capital investment per stere of annual production ranges from $0.33 for system U-1 to $6.57 for system M-8.
2. Introduction of mechanical loading in domestic systems has a relatively small impact on capital required. This can be seen by comparing capital requirement of system U-4 with U-1 and U-3 with U-2.
3. The introduction of forwarders for prehauling has a severe impact on capital requirements. In comparison with the systems that do not use concentration yards, it increases capital requirements about 150%.
4. System M-7 increases the investment requirement 750% over the investment required by system U-4.
5. System M-8 increases capital requirements almost 20 times

Systems	Stump Fell	Strip Road Loading	Method of Forwarding	Landing		Woodyard		Main Road	Investment Per Stere Per Year	Index
				Unldg.	Ldg.	Unldg.	Ldg.			
U-1	CS	H	TRUCK						0.33	1.00 (1.00)
U-2	CS	H	TRUCK			H	H		0.68	2.06 (2.06)
U-3	CS	H	TRUCK			H	M		0.75	2.27 (2.27)
U-4	CS	M	TRUCK						0.40	1.21 (1.21)
U-5	CS	M	FORWARDER		M				0.88	2.67 (2.67)
M-7	CS		CABLE SK.		M				2.88	8.73 (8.73)
M-8	FB		GRAPPLE SK.		M				6.57	19.91 (19.91)
M-9	DS		TINE GRAPP.		M				3.16	9.58 (9.58)

CS - chain saw
FB - feller buncher
DS - draw shear
H - hand work
M - mechanical work

loading from ground
unloading down ground
transferring load onto other equipment
receiving load from other equipment

Figure 7. Capital Requirements Per Stere in Systems Without Field Debarking in Eucalyptus.

compared to system U-1.

6. And finally, M-9 increases capital requirements almost 1800%.

Figure 8 presents the projected manpower and capital requirements to produce 750,000 steres per year to a 500 ton per day pulp and paper mill unit with systems which do not field debark. The data illustrates the trade-offs between labor and capital requirements. As in the previous comparison of these factors, the relationship is inverse.

Comparison of Systems With and Without Field Debarking

When all systems with and without field debarking are compared the following general conclusions can be made regarding the potential of mechanizing shortwood harvesting systems in the State of Sao Paulo:

1. That the requirement of field debarking for comparable systems almost doubles direct costs, increases labor requirements dramatically (100% to 800%), and requires significant increases in capital when portable mechanical debarkers are used.
2. That mechanical loading appears to be both cost effective and an efficient use of capital across all systems.
3. That additional mechanization results in increased costs. However, this situation is due largely to the prevailing low labor rates and could change rapidly in the future.

Figure 9, which is a graph of the data contained in Figure 4 and Figure 8, presents the relationship between labor and capital

Systems	Stump Fell	Strip Road Loading	Method of Forwarding	Landing		Woodyard		Main Road	Number of Workers	Capital Requirements 1000 Dollars
				Unldg.	Ldg.	Unldg.	Ldg.			
U-1	CS	H	TRUCK						462	251
U-2	CS	H	TRUCK			H	H		497	512
U-3	CS	H	TRUCK			H	M		506	563
U-4	CS	M	TRUCK						444	302
U-5	CS	M	FORWARDER		M				456	663
M-7	CS		CABLE SK.		M				124	2,167
M-8	FB		GRAPPLE SK.		M				101	4,924
M-9	DS		TINE GRAPP.		M				325	2,371

CS - chain saw
FB - feller buncher
DS - draw shear
H - hand work
M - mechanical work

loading from ground
unloading down ground
transferring load onto other equipment
receiving load from other equipment

Figure 8. Total Labor and Capital Requirements to Produce 750,000 Steres Per Year of Pulpwood Without Field Debarking.

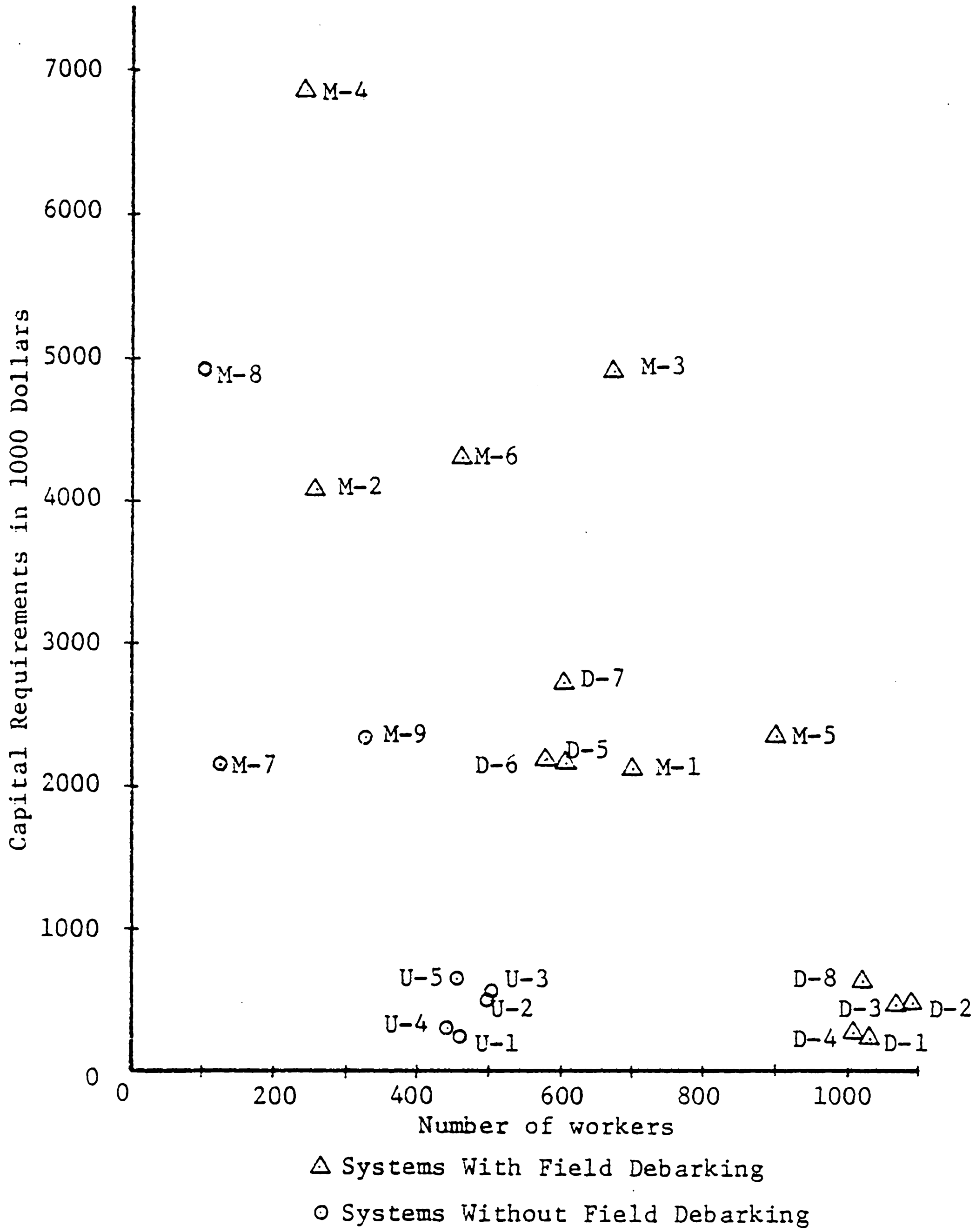

Figure 9. Number of Workers and Capital Requirements to Harvest 750,000 Steres of Pulpwood in Several Systems With and Without Field Debarking.

requirements for all systems. A major conclusion from inspection of this graph is that if shortages of woods labor develop the transition from domestic systems to mechanical systems without field debarking could be made without a major infusion of capital.

SUMMARY AND CONCLUSIONS

The objectives of this study were to document present harvesting practices in the State of Sao Paulo, analyze the economic differences in domestic systems with varying degrees of mechanization, and evaluate the potential of increased mechanization.

Data was obtained through field questionnaires, correspondence, field trips and seminars. From this information it was possible to understand present practices and procedures, and formulate eight systems with field debarking and five systems without field debarking. Nine systems using machines from more industrialized countries were designed to test their potential in the State of Sao Paulo.

Analysis of these systems was made by a mathematical model. This model uses production functions of Machine Fixed Cost, Machine Variable Cost, and Labor to predict the total direct cost per stere in U.S. dollars to harvest 20 hectares of Eucalyptus. It was also used to predict man hours per stere, capital investment per stere, and finally the total manpower and capital required to harvest 750,000 steres of pulpwood which would be required to furnish a 500 ton per day pulpmill.

Comparisons were made within systems with field debarking, within systems without field debarking, and between all systems without and with field debarking.

These comparisons led to the following general conclusions:

1. That the requirements of field debarking for comparable

systems almost doubles direct costs, increases labor requirements dramatically, and requires significant increases in capital when portable mechanical debarkers are used.

2. That mechanical loading appears to be both cost effective and an efficient use of capital across all systems.
3. That additional mechanization results in increased costs. However, this situation is due largely to the prevailing low labor rates and could change rapidly in the future.
4. That if shortages of woods labor develop the transition from domestic systems to mechanical systems without field debarking could be made without a major infusion of capital.

Additional research in the field of harvesting is badly needed. This study has shown that there is a great need for the standardization of terminology, and improved methods of data collection and analysis. The use of computer simulation for systems analysis should be implemented as soon as feasible to provide a sound basis for research and planning.

APPENDIX A

HARVESTING FIELD QUESTIONNAIRE

VISIT REPORT DATE

Firm______________________ City______________________

Name of Property______________________ Place______________________

Personnel Contacted, Name and Function______________________

____

Total Forested Area in the Property__________ Stand Area__________

Soil: Clay Sandy Moisture Stony

Slope: 0-5% 6-10% 11-20% 21-33% 34-50% +50%

Type of Slope: Uphill Downhill Length of Slope__________

Species__________ Age__________ Cutting__________

Spacing__________ No. Trees/Ha__________ Basal Area__________

Average D.B.H.__________ Max D.B.H.__________ Avg. Height__________

Form Factor__________ No. Stems/Stump__________

Output: Pulpwood Fiberboard Charcoal Poles

Sawlogs Fuelwood Others

Length of the Pieces__________ Minimum Diameter Admitted__________

Max. Dia. Admitted__________ Debarked Unbarked

Volume/Ha__________ No. Pieces/Estere__________

No. of Worked Hours/Day__________ No. of Worked Days/Month__________

Volume Output/Day__________ Weekly or Monthly Output__________

Distance to the Mill__________ Paved Road__________ Ground Road__________

Processor Mill__________ Local__________

Is it a hot system?______________________

Influence of weather______________________

HARVESTING FIELD QUESTIONNAIRE

FIELD CREW DESCRIPTION

EQUIPMENT DESCRIPTION

FLOW CHART

INSTRUCTIONS

Instructions for filling up the report visit.

1. Firm name. Refers to the company that owns the operations; i.e., who employs the people. The company may be the landowner, the owner of stumpage, a timber utilizing mill or also a dealer.
2. Contacted personnel. May be the forest engineer of a company, or the owner of a companv, a producer or a dealer.
3. Slope. Refers to the terrain slope where the work is being done during the visit. Type of slope, uphill when timber is withdrawn from the forest from lower parts to upper sites. Downhill, when timber is withdrawn downhill.
4. Length of slope. Refers to the length of slope in the stand being harvested.
5. Species, age, spacing, etc. Refers to the stand that is being harvested. Cutting refers, in the case of Eucalyptus, if the present harvesting is the first, second, or third clearcutting. In the case of Pinus, it will be the original thinning.
6. Number of trees per hectare. Refers to the actual number of trees per hectare, deducted, deaths, falls, or previous thinnings.
7. Basal area. Refers to the mean basal area of the stand at the time of harvesting. In the case of thinning if possible mention the basal area before and after the operation.
8. Average and maximum DBH and average height. If possible get a sample which will provide reasonable information about the stocking of the stand.

9. Number of stems per stump. In the stands of Eucalyptus after the first cutting, mention the number of stems that is permitted to develop. Mention the median of the number.

10. Outputs. When there is not more than one product, mark the product with an X. When there is more than one product determine the main product with number one in the box, the second in importance with the number two and so on.

11. Length of the pieces. Refers to the length of the sticks as prepared in the field. If there is more than one length, note all lengths.

12. Volume. Because of the large variation of units presently utilized in timber harvesting, it is recommended that they be defined as completely as possible. For example 1 estere measured as the volume on a pile of 1m X 1m X 1m or the variations that might be found.

13. Volume output/day per week or per month. Refers to median volumes and should be relative to the system and the stand being described. This information may be obtained from company records.

14. Distance to the mill. Refers to the distance from the stand to the mill or any other unloading point, as for example, a rail woodyard in this case. The considered distance is up to this point, then an observation is made about the distance by rail up to the processing mill.

15. Hot system. An operation in which the timber is felled, processed, prehauled, hauled without interruptions in the same day. In the

case in which the system is not hot specify the storage and delay time.

16. Influence of weather. Refers mainly to the influence of rain on production. This influence may be defined as the number of weekdays lost because of rain in a month. If possible, report other influences of weather in safety, productivity, etc.

17. Yield crew description. This section includes the enumeration of all people working in the harvesting operation, their function and productivity.

18. Equipment description. This section characterizes all the equipment utilized in the operation. It should contain a brief description of each equipment, their number and functions. The equipment with some modification should be noted; e.g., L Truck Ford F600 with a third dead axle.

19. Flow chart. In this section the system of timber harvesting is represented through the symbols utilized by Industrial Engineers. The symbols have the following meanings:

○ OPERATION - e.g. felling, delimbing, topping, bucking,

⇨ TRANSPORTATION - e.g. manual prehauling, truck prehauling, hauling.

△ STORAGE - e.g. the storage of shortwood in piles in the strip road or in the landing.

□ INSPECTION - e.g. measurement, inspection, weighing.

D DELAY - e.g. time in lines.

APPENDIX B

System D-1, Manual Debarking and Loading at Strip Road

Description

I. Felling and bucking with chainsaw, one sawyer and one helper.

II. Manual delimbing, topping, debarking, prehauling and piling at strip road, 12 workers with manual tools.

III. Hand loading and at strip road truck driver and two helpers.

IV. Truck prehauling from strip road to the main road, one truck driver.

Data and Results

	I	II	III	IV	
F	600	0	0	10,800	
i	0.1761	-	-	0.1761	
n	2	-	-	3	
h	2400	-	-	2400	
V	3,805	3,805	3,805	3,805	
P	4.44	4.44	24.89	24.89	
D	0	0	0	1501.5	
U	1	1	1	1	
L	-	-	-	21.43	
t	-	-	-	250	
w	1.08	5.40	0.90	.75	
m	1.40	0	-	4.17	
TIME	856.98	856.98	152.87	188.42	
Mach Fix	0.04			0.11	0.15
Mach Var	0.31			0.20	0.51
Labor	0.39	1.95	0.06	0.06	2.46
TOTAL/ STERE	0.74	1.95	0.06	0.37	3.12

System D-2, Manual Debarking and Loading at Strip Road and Concentration Yard

Description

I. Felling and bucking with chain saw, one sawyer and one helper.

II. Manual delimbing, topping, debarking and prehauling from stump area to strip road, piling, 12 workers with manual tools.

III. Hand loading at the strip road, truck prehauling from strip road to concentration yard, one driver and two helpers.

IV. Hand unloading at the concentration yard, truck driver and two helpers.

V. Hand loading at the concentration yard, truck driver and two helpers.

Data and Results

	I	II	III	IV	V	VI
F	600	0	10,800	10,800	10,800	
i	0.1761	0	0.1761	0.1761	0.1761	
n	2	0	3	3	3	
h	2400	2400	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	
P	4.44	4.44	24.89	46.15	24.89	
D	0	0	1501.5	0	0	
U	1	-	1	1	1	
L	-	-	21.43	-	-	
t	-	-	250	-	-	
w	1.08	5.40	165	1.65	1.65	
m	1.40	0	4.17	2.08*	2.08*	
TIME	856.98	856.98	188.42	82.45	152.87	
Mach Fix	0.04		0.11	0.05	0.09	0.29
Mach Var	0.31		0.21	0.04	0.08	0.64
Labor	0.39	1.95	0.13	0.06	0.11	2.63
TOTAL/ STERE	0.74	1.95	0.45	0.15	0.28	3.57

*var. cost of truck waiting in landing considered ½ normal var. cost.

System D-3, All Manual Except Mechanical Loading at the Concentration Yard

Description

I. Felling and bucking with chain saw, one sawyer and one helper.

II. Manual delimbing, topping, debarking, prehauling from stump area to strip road and piling at strip road, 12 workers with manual tools.

III. Hand loading and truck prehauling from strip road to concentration yard, one truck driver and two helpers.

IV. Hand unloading of the truck at concentration yard, truck driver and two helpers.

V. Mechanical loading of the truck at the concentration yard with knuckleboom loader mounted on a farm tractor, one operator and one helper.

VI. Truck loading time during mechanical loading, truck driver.

Data and Results

	I	II	III	IV	V	VI	
F	600	0	10,800	10,800	18,880	10,800	
i	0.1761	-	0.1761	0.1761	0.1761	0.1761	
n	2	-	3	3	3	3	
h	2400		2400	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	3,805	
P	4.44	4.44	24.89	46.15	52.50	52.50	
D	0	0	1501.5	0	0	0	
U	1	1	1	1	1	1	
L	-	-	21.43	-	-	-	
t			250	-	-	-	
w	1.08	5.40	1.65	1.65	1.20	0.75	
m	1.40	0	4.17	2.08*	3.20	2.08*	*½ of the cost
TIME	856.98	856.98	188.4	82.45	72.48	72.48	
Mach Fix	0.04		0.11	0.05	0.07	0.05	0.32
Mach Var	0.31		0.21	0.04	0.06	0.04	0.66
Labor	0.39	1.95	0.13	0.06	0.04	0.02	2.59
TOTAL	0.74	1.95	0.45	0.15	0.17	0.11	3.57

System D-4, All Manual Except Mechanical LOading at Strip Road

Description

I. Felling and bucking with chain saw, one sawyer and one helper.

II. Manual delimbing, topping, debarking and prehauling from stump area to strip road and piling at strip road, 12 workers with manual tools.

III. Mechanical loading of the truck at the strip road, knuckleboom loader mounted on farm tractor, one operator and one helper.

IV. Truck prehauling from strip road to the main road, one truck driver.

Data and Results

	I	II	III	IV	
F	600	0	18,880	10,800	
i	0.1761	-	0.1761	0.1761	
n	2	-	3	3	
h	2400	2400	2400	2400	
V	3,805	3,805	3,805	3,805	
P	4.44	4.44	52.50	52.50	
D	0	0	0	1501.50	
U	1	1	1	1	
L	-	-	-	21.43	
t	-	-	-	250	
w	1.08	5.40	1.20	0.75	
m	1.40	0	3.20	4.17	
TIME	256.98	856.98	72.48	108.02	TOTALS
Mach Fix	0.04		0.07	0.07	0.18
Mach Var	0.31		0.06	0.12	0.49
Labor	0.39	1.95	0.04	0.03	2.41
TOTAL/ STERE	0.74	1.95	0.17	0.22	3.08

System D-5, All Manual Except Mechanical Debarking at the Strip Road

Description

I. Felling and bucking with chain saw, one sawyer and one helper.

II. Manual delimbing, topping, prehauling from stump area to strip road and piling at strip road, four workers with manual tools.

III. Mechanical debarking at the strip road with ring debarker coupled on a farm tractor, one operator and two helpers.

IV. Hand loading of the truck and prehauling from strip road to main road, one truck driver and two helpers.

Data and Results

	I	II	III	IV	
F	600	0	35,280	10,800	
i	0.1761	0.1761	0.1761	0.1761	
n	2	-	3	3	
h	2400	-	2400	2400	
V	3,805	3,805	3,805	3,805	
P	4.44	4.44	7.14	24.89	
D	0	0	0	1501.50	
U	1	1	1	1	
L	-	-	-	21.43	
t	-	-	-	250	
w	1.08	1.80	1.50	1.65	
m	1.40	0	4.57	4.17	
TIME	856.98	856.98	532.91	188.42	
Mach Fix	0.04		1.05	0.11	1.20
Mach Var	0.36		0.64	0.21	1.16
Labor	0.39	0.65	0.34	0.13	1.51
TOTAL/ STERE	0.74	0.65	2.03	0.45	3.87

System D-6, Mechanical Debarking and Loading at Strip Road

Description

I. Felling and bucking with chain saw, one sawyer and one helper.

II. Manual delimbing, topping, prehauling from stump area to strip road and piling at the strip road.

III. Mechanical debarking at the strip road with a ring debarker coupled with a farm tractor, one operator and two helpers.

IV. Mechanical loading at strip road with a knuckleboom loader mounted on a farm tractor, one operator and one helper.

V. Truck prehauling from strip road to the main road, one truck driver.

Data and Results

	I	II	III	IV	V	
F	600	0	35,280	18,880	10,800	
i	0.1761	-	0.1761	0.1761	0.1761	
n	2	-	3	3	3	
h	2400	2400	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	
P	4.44	4.44	7.14	52.50	52.50	
D	0	0	0	0	1501.50	
U	1	1	1	1	1	
L	-	-	-	-	21.43	
t	-	-	-	-	250	
w	1.08	1.80	1.50	1.20	0.15	
m	1.40	0	4.57	3.20	4.17	
TIME	856.98	856.98	532.91	72.48	108.02	
Mach Fix	0.04		1.05	0.07	0.07	1.23
Mach Var	0.31		0.64	0.06	0.12	1.13
Labor	0.39	0.65	0.34	0.04	0.03	1.45
TOTAL/ STERE	0.74	0.65	2.03	0.17	0.22	3.81

System D-7, Mechanical Forwarding, Debarking and Loading at a Concentration Yard

Description

I. Felling and bucking with chain saw, one sawyer and one helper.

II. Manual delimbing, topping, and piling at the stump area, 4 workers with manual tools.

III. Mechanical forwarding from the stump area to the landing. Forwarder self loader, one operator and one helper.

IV. Mechanical debarking at the landing, with a ring debarker coupled with a farm tractor, one operator, two helpers.

V. Mechanical loading at landing with knuckleboom loader mounted on a farm tractor, one operator and one helper.

VI. Truck prehauling from the landing to the main road, one truck driver.

Data and Results

	I	II	III	IV	V	VI	
F	600	0	31,200	35,280	18,880	10,800	
i	0.1761	-	0.1761	0.1761	0.1761	0.1761	
n	2	-	3	3	3	3	
h	2400	2400	2400	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	3,805	
P	4.44	4.44	26.25	7.14	52.50	52.50	
D	0	0	228.5	0	0	1500	
U	1	1	1	1	1	1	
L	-	-	12	-	-	21.43	
t	-	-	166.67	-	-	333.33*	
w	1.08	1.80	1.35	1.50	1.20	0.75	
m	1.40	-	5.87	4.57	3.20	4.17	
TIME	856.98	856.98	159.44	532.91	72.48	99.11	
Mach Fix	0.04		0.28	1.05	0.07	0.06	1.50
Mach Var	0.31		0.24	0.64	0.06	0.11	1.36
Labor	0.39	0.65	0.09	0.34	0.04	0.03	1.54
TOTAL/ STERE	0.74	0.65	0.61	2.03	0.17	0.20	4.40

*Travel rate of the truck is changed because it is supposed that it will travel only in roads and out of stands.

System D-8, Manual Debarking Mechanical Forwarding and Off-loading Onto Haul Trucks at the Landing

Description

I. Felling and bucking with chain saw, one sawyer and one helper.

II. Manual delimbing, topping, debarking and piling at the stump area, 12 workers with manual tools.

III. Mechanical forwarding from the stump area to the landing, self-loader forwarder, one operator and one helper.

IV. Mechanical transfer of the load from the forwarder onto the truck, one operator and one helper.

V. Truck prehauling from the landing to the main road, one truck driver.

Data and Results

	I	II	III	IV	V	
F	600	0	31,200	31,200	10,800	
i	0.1761	-	0.1761	0.1761	0.1761	
n	2	-	3	3	3	
h	2400	-	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	
P	4.44	4.44	52.50	52.50	52.50	
D	0	0	228.46	0	1.500	
U	1	1	1	1	1	
L	-	-	12	-	21.43	
t	-	-	166.67	-	333.33	
w	1.08	5.40	1.25	1.25	0.75	
m	1.40	-	4.57	4.57	4.17	
TIME	856.98	856.98	86.96	72.48	99.11	
Mach Fix	0.04		0.15	0.12	0.06	0.37
Mach Var	0.31		0.10	0.09	0.11	0.61
Labor	0.39	0.65	0.05	0.04	0.03	1.16
TOTAL/ STERE	0.74	0.65	0.30	0.25	0.20	3.44

System U-1, All Manual With Loading Prehauler at the Strip Road

Description

I. Felling and bucking with chain saw, one sawyer and one helper.

II. Manual delimbing, topping, prehauling and piling at the strip road, four workers with manual tools.

III. Manual loading at strip road, truck driver and two helpers.

IV. Truck prehauling from strip road to the main road, truck driver.

Data and Results

	I	II	III	IV	
F	600	0	0	10,800	
i	0.1761	-	-	0.1761	
n	2	-	-	3	
h	2400	-	-	2400	
V	3,805	3,805	3,805	3,805	
P	4.44	4.44	24.89	24.89	
D	0	0	0	1501.50	
U	1	1	1	1	
L	-	-	-	21.43	
t	-	-	-	250	
w	1.08	1.80	0.90	.75	
m	1.40	0	0	4.17	
TIME	856.98	856.98	152.87	188.42	
Mach Fix	0.04			0.11	0.15
Mach Var	0.31			0.21	0.52
Labor	0.39	0.65	0.06	0.06	1.16
TOTAL/ STERE	0.74	0.65	0.06	0.38	1.83

System U-2, All Manual with Concentration Yard

Description

I. Felling and bucking with chain saw, one sawyer and one helper.

II. Manual delimbing, topping, prehauling and piling at strip road, four workers with manual tools.

III. Hand loading at the strip road and truck prehauling from strip road to the concentration yard, truck driver and two helpers.

IV. Hand unloading of the truck at the concentration yard, truck driver and two helpers.

V. Hand loading at the concentrationyard, truck driver and two helpers.

Data and Results

	I	II	III	IV	V	
F	600	0	10,800	10,800	10,800	
i	0.1761	-	0.1761	0.1761	0.1761	
n	2	-	3	3	3	
h	2400	-	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	
P	4.44	4.44	24.89	46.15	24.89	
D	0	0	1501.50	0	0	
U	1	1	1	1	1	
L	-		21.43	-	-	
t	-		250	-	-	
w	1.08	1.80	0.75	1.65	1.65	
m	1.40	0	4.17	2.08	2.08	
TIME	856.98	856.98	188.42	82.45	152.87	
Mach Fix	0.04		0.11	0.05	0.09	0.29
Mach Var	0.31		0.21	0.04	0.08	0.64
Labor	0.39	0.65	0.13	0.06	0.11	1.34
TOTAL/ STERE	0.74	0.65	0.45	0.15	0.28	2.27

System U-3, All Manual Except Mechanical at the Concentration Yard

Description

I. Felling and bucking with chain saw, one sawyer and one helper.

II. Manual topping. prehauling and piling at strip road, four workers with manual tools.

III. Hand loading and truck prehauling from strip road to the concentration yard, truck driver and two helpers.

IV. Hand unloading at the concentration yard, truck driver and two helpers.

V. Mechanical loading at the concentration yard with knuckleboom loader mounted on a farm tractor, one operator and two helpers.

VI. Truck mechanical load at the concentration yard, truck driver.

Data and Results

	I	II	III	IV	V	VI	
F	600	0	10,800	10,800	18,880	10,800	
i	0.1761	-	0.1761	0.1761	0.1761	0.1761	
n	2	-	3	3	3	3	
h	2400	2400	2400	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	3,805	
P	4.44	4.44	24.89	46.15	52.50	52.50	
D	0	0	1501.50	0	0	0	
U	1	1	1	1	1	1	
L	-	-	21.43	-	-	-	
t	-	-	250	-	-	-	
w	1.08	1.80	1.65	1.65	1.20	0.75	
m	1.40	0	4.17	2.08	3.20	2.08	
TIME	856.98	856.98	188.42	82.45	72.48	72.48	
Mach Fix	0.04		0.11	0.05	0.07	0.05	0.32
Mach Var	0.31		0.21	0.04	0.06	0.04	0.66
Labor	0.39	0.65	0.13	0.06	0.04	0.02	1.29
TOTAL/ STERE	0.74	0.65	0.45	0.15	0.17	0.11	2.27

System U-4, All Manual Except Mechanical Loading at the Strip Road

Description

I. Felling and bucking with chain saw, one sawyer and one helper.

II. Manual delimbing, topping, prehauling, piling at strip road, four workers with manual tools.

III. Mechanical loading at the strip road, knuckleboom loader mounted on a farm tractor, one operator and one helper.

IV. Truck prehauling from strip road to main road, truck driver.

Data and Results

	I	II	III	IV	
F	600	0	18,880	10,800	
i	0.1761	-	0.1761	0.1761	
n	2	-	3	3	
h	2400	-	2400	2400	
V	3,805	3,805	3,805	3,805	
P	4.44	4.44	52.50	52.50	
D	0	0	0	1501.50	
U	1	1	1	1	
L	-	-	-	21.43	
t	-	-	-	250	
w	1.08	1.80	1.20	0.75	
m	1.40	0	320	4.17	
TIME	856.98	856.98	72.48	108.02	
Mach Fix	0.04		0.07	0.07	0.18
Mach Var	0.31		0.06	0.12	0.49
Labor	0.39	0.65	0.04	0.03	1.11
TOTAL/ STERE	0.74	0.65	0.17	0.22	1.78

System U-5, All Manual Except Mechanical Forwarding

Description

I. Felling and bucking with chain saw, one sawyer and one helper.

II. Manual limbing, topping, prehauling and piling at the strip road, four workers with manual tools.

III. Forwarding from strip road to landing, self-loading forwarder, one operator and one helper.

IV. Forwarder off-loading onto the truck at the landing, one operator and one helper.

V. Truck loading and prehauling from landing to the main road, truck driver.

Data and Results

	I	II	III	IV	V	
F	600	0	31,200	31,200	10,800	
i	0.1761	-	0.1761	0.1761	0.1761	
n	2	-	3	3	3	
h	2400	-	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	
P	4.44	4.44	52.50	52.50	52.50	
D	0	0	228.46	0	1.500	
U	1	1	1	1	1	
L	-	-	12	-	21.43	
t	-	-	166.67	-	333.33	
w	1.08	1.80	1.25	1.25	.75	
m	1.40	0	4.57	4.57	4.17	
TIME	856.98	856.98	86.96	72.48	99.11	
Mach Fix	0.04		0.15	0.13	0.06	0.38
Mach Var	0.31		0.10	0.09	0.11	0.61
Labor	0.39	0.65	0.05	0.04	0.03	1.16
TOTAL/ STERE	0.74	0.65	0.30	0.26	0.20	2.15

System M-1, All Manual Except Cable Skidding and Mechanical Loading

Description

I. Felling, limbing and topping with chain saw, one sawyer.

II. Cable skidding from strip road to landing, one operator.

III. Bucking with chain saw at landing, one sawyer.

IV. Manual debarking at the landing, worker with manual tools.

V. Mechanical loading at the landing with knuckleboom loader mounted on a farm tractor, one operator and one helper.

VI. Truck prehauling from landing to the main road, truck driver.

Data and Results

	I	II	III	IV	V	VI	
F	600	60,000	600	0	18,880	10,800	
i	0.1761	0.1761	0.1761	-	0.1761	0.1761	
n	2	3	2	-	3	3	
h	2400	2400	2400	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	3,805	
P	4.80	12.5	21.72	0.55	52.50	52.50	
D	0	0	0	0	0	1500	
U	1	1	1	-	1	1	
L	-	-	-	-	-	21.43	
t	-	-	-	-	-	333.33	
w	0.63	0.80	0.63	0.45	1.20	0.75	
m	1.40	5.00	1.40	0	3.20	4.17	
TIME	792.71	304.40	175.18	6918.18	72.48	99.11	
Mach Fix	0.04	1.02	0.01		0.07	0.06	1.20
Mach Var	0.29	0.40	0.06		0.06	0.11	0.92
Labor	0.21	0.10	0.05	1.31	0.04	0.03	1.74
TOTAL/ STERE	0.54	1.52	0.12	1.31	0.17	0.20	3.86

System M-2, All Manual Except Cable Skidding, Mechanical Debarking and Loading

Description

I. Felling, limbing and topping with chain saw, one sawyer.

II. Cable skidding from stump area to the landing, one operator.

III. Bucking with chain saw at the landing.

IV. Mechanical debarking at the landing, ring debarker coupled with farm tractor, one operator and two helpers.

V. Mechanical loading at the landing, knuckleboom loader mounted on farm tractor, one operator and one helper.

VI. Truck prehauling from landing to main road, truck driver.

Data and Results

	I	II	III	IV	V	VI	
F	600	60,000	600	35,280	18,880	10,800	
i	0.1761	0.1761	0.1761	0.1761	0.1761	0.1761	
n	2	3	2	3	3	3	
h	2400	2400	2400	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	3,805	
P	4.80	12.50	21.72	7.14	52.50	52.50	
D	0	0	0	0	0	1500	
U	1	1	1	1	1	1	
L	-	-	-	-	-	21.43	
t	-	-	-	-	-	333.33	
w	0.63	0.80	0.63	1.50	1.20	0.75	
m	1.40	5.00	1.40	4.57	3.20	4.17	
TIME	792.71	304.40	175.18	532.91	72.48	99.11	
Mach Fix	0.04	1.02	0.01	1.05	0.07	0.06	2.25
Mach Var	0.29	0.40	0.06	0.64	0.06	0.11	1.56
Labor	0.21	0.10	0.05	0.34	0.04	0.03	0.77
TOTAL/ STERE	0.54	1.52	0.12	2.03	0.17	0.20	4.58

System M-3, Feller Bunching, Grapple Skidding, Mechanical Loading

Description

I. Felling and bunching with a feller buncher, one operator.

II. Skidding with a grapple skidder from stump area to the landing, one operator.

III. Bucking at the landing with chain saw, one operator.

IV. Manual debarking at the landing, workers with manual tools.

V. Mechanical loading at the landing, knuckleboom loader mounted on farm tractor, one operator and one helper.

VI. Truck loading at the landing and prehauling from landing to main road, one truck driver.

Data and Results

	I	II	III	IV	V	VI	
F	80,000	80,000	600	0	18,880	10,800	
i	0.1761	0.1761	.1261	-	0.1761	0.1761	
n	3	3	2	-	3	3	
h	2400	2400	2400	-	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	3,805	
P	15.22	21.75	18.10	0.55	52.50	52.50	
D	0	0	0	0	0	1500	
U	0.75	0.75	0.5	1	1	1	
L	-	3.62	-	-	-	21.43	
t	-	85	-	-	-	333.33	
w	0.80	0.80	0.63	0.45	1.20	0.75	
m	5.00	5.00	1.40	0	3.20	4.17	
TIME	333.33	233.26	420.44	6918.20	72.48	99.11	
Mach Fix	1.49	1.04	0.02		0.07	0.06	2.68
Mach Var	0.33	0.23	0.08		0.06	0.11	0.81
Labor	0.11	0.08	0.11	1.31	0.04	0.03	1.68
TOTAL/ STERE	1.93	1.35	0.21	1.31	0.17	0.20	5.17

System M-4, Feller Bunching, Grapple Skidding, Mechanical Debarking and Loading

Description

I. Felling and bunching with a feller buncher, one operator.

II. Skidding with a grapple skidder from stump area to the landing, one operator.

III. Bucking with chain saw, one sawyer.

IV. Mechanical debarking at the landing, ring debarker coupled with farm tractor, one operator and two helpers.

V. Mechanical loading at the landing, knuckleboom loader mounted on farm tractor, one operator and one helper.

VI. Truck prehauling from landing to the main road, truck driver.

Data and Results

	I	II	III	IV	V	VI	
F	80,000	80,000	600	35,280	18,880	10,800	
i	0.1761	0.1761	0.1761	0.1761	0.1761	0.1761	
n	3	3	2	3	3	3	
h	2400	2400	2400	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	3,805	
P	15.22	21.75	18.10	7.14	52.50	52.50	
D	0	0	0	0	0	1500	
U	0.75	0.75	0.5	1	1	1	
L	-	3.62	-	-	-	21.43	
t	-	85	-	-	-	333.33	
w	0.80	0.80	0.63	1.50	1.25	0.75	
m	5.00	5.00	1.40	4.57	3.20	4.17	
TIME	333.33	233.26	420.44	532.91	72.48	99.11	
Mach Fix	1.49	1.04	0.02	1.05	0.07	0.06	3.73
Mach Var	0.33	0.23	0.08	0.64	0.06	0.11	1.45
Labor	0.11	0.08	0.11	0.34	0.04	0.03	0.71
TOTAL/ STERE	1.93	1.35	0.21	2.03	0.17	0.20	5.89

System M-5, Draw Shear, Power-tine and Mechanical Loading

Description

I. Felling and bunching with a draw shear mounted on a 65 HP farm tractor, one operator.

II. Manual limbing and topping, one worker using manual tools.

III. Skidding from stump area to landing with farm tractor with power-tine, one operator.

IV. Bucking at the landing with chain saw, one sawyer.

V. Manual debarking at the landing.

VI. Mechanical loading at landing, knuckleboom loader mounted on farm tractor, one operator and one helper.

VII. Truck prehauling from landing to main road, one truck driver.

Data and Results

	I	II	III	IV	V	VI	VII	
F	10,080	0	7,680	600	0	18,880	10,800	
i	0.1761	-	0.1761	0.1761	-	0.1761	0.1761	
n	3	-	3	2	-	3	3	
h	2400		2400	2400	-	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	3,805	3,805	
P	4.00	4.00	5.00	21.72	.55	52.50	52.50	
D	0	0	0	0	0	0	1500	
U	.75	.75	.75	1.00	1.00	1.00	1	
L	-	-	-	-	-	-	21.43	
t	-	-	-	-	-	-	333.33	
w	.75	.45	.75	.63	.45	1.20	.75	
m	3.20	0	3.20	1.40	0	3.20	4.17	
TIME	1268.33	1268.33	1014.67	175.18	6918.18	72.48	99.11	
Mach Fix	0.17		0.44	0.01		0.07	0.06	1.29
Mach Var	0.80		0.64	0.06		0.06	0.11	1.67
Labor	0.40	0.24	0.32	0.05	1.31	0.04	0.03	2.39
TOTAL/ STERE	1.91	0.24	1.40	0.12	1.31	0.17	0.20	5.35

System M-6, Draw Shear, Power-tine, Mechanical Debarking and Loading

Description

I. Felling and bunching with a draw shear, one operator.

II. Manual limbing and topping at the stump are, one worker with manual tools.

III. Skidding from stump area to landing with a farm tractor with a power-tine, one operator.

IV. Bucking at the landing with chain saw, one sawyer.

V. Mechanical debarking at the landing, ring debarker mounted on a farm tractor, one operator and two helpers.

VI. Mechanical loading at the landing with knuckleboom loader mounted on a farm tractor, one operator and one helper.

VII. Truck prehauling from landing to the main road, one truck driver.

Data and Results

	I	II	III	IV	V	VI	VII	
F	10,080		7,680	600	35,280	18,880	10,800	
i	0.1761		0.1761	0.1761	0.1761	0.1761	0.1761	
n	3		3	2	3	3	3	
h	2400		2400	2400	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	3,805	3,805	
P	4.00	4.00	5.00	21.72	7.14	52.50	52.50	
D	0	0	0	0	0	0	1.500	
U	.75	.75	.75	1.00	1	1.00	1.00	
L	-	-	-	-	-	-	21.43	
t	-	-	-	-	-	-	333.33	
w	.75	.45	.75	.63	1.50	1.20	.75	
m	3.20	0	3.20	1.40	4.57	3.20	4.17	
TIME	1268.33	1268.33	1014.67	175.18	532.91	72.48	99.11	
Mach Fix	0.71		0.44	0.01	1.05	0.07	0.06	2.34
Mach Var	0.80		0.64	0.06	0.64	0.06	0.11	2.31
Labor	0.40	0.24	0.32	0.05	0.34	0.04	0.03	1.42
TOTAL	1.91	0.24	1.40	0.12	2.03	0.17	0.20	6.07

System M-7, Cable Skidding, Mechanical Loading, No Field Debarking

Description

I. Felling, limbing and topping with chain saw, one sawyer.

II. Cable skidding from strip road to landing, one operator.

III. Bucking with chain saw at the landing, one sawyer.

IV. Mechanical loading at the landing with a knuckleboom loader mounted on a farm tractor, one operator and one helper.

V. Truck prehauling from landing to the main road, one truck driver.

Data and Results

	I	II	III	IV	V	
F	600	600	600	18,880	10,800	
i	0.1761	0.1761	0.1761	0.1761	0.1761	
n	2	3	2	3	3	
h	2400	2400	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	
P	4.80	12.50	21.72	52.50	52.50	
D	0	0	0	0	1500	
U	1	1	1	1	1	
L	-	-	-	-	21.43	
t	-	-	-	-	333.33	
w	.63	.80	.63	1.20	.75	
m	1.40	5.00	1.40	3.20	4.17	
TIME	492.71	304.40	175.18	72.48	99.11	
Mach Fix	0.04	1.02	0.01	0.07	0.06	1.20
Mach Var	0.29	0.40	0.06	0.06	0.11	0.92
Labor	0.21	0.10	0.05	0.04	0.03	0.43
TOTAL/ STERE	0.54	1.52	0.12	0.17	0.20	2.55

System M-8, Feller Bunching, Grapple Skidding, Mechanical Loading

Description

I. Felling and bunching with a feller buncher, one operator.

II. Skidding with a grapple skidder from stump area to the landing, one operator.

III. Bucking at the landing with chain saw, one operator.

IV. Mechanical loading at the landing, knuckleboom loader on a farm tractor, one operator and one helper.

V. Truck prehauling from landing to the main road, one truck driver.

Data and Results

	I	II	III	IV	V	
F	80000	80000	600	18,880	10,800	
i	0.1761	0.1761	0.1761	0.1761	0.1761	
n	3	3	2	3	3	
h	2400	2400	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	
P	15.22	21.75	18.10	52.50	52.50	
D	0	0	0	0	1500	
U	.75	.75	0.5	1	1	
L	-	3.62	-	-	21.43	
t	-	85	-	-	333.33	
w	0.80	0.80	.63	1.20	.75	
m	5.00	5.00	1.40	3.20	4.17	
TIME	333.33	233.26	420.44	72.48	99.11	
Mach Fix	1.49	1.04	0.02	0.07	0.06	2.68
Mach Var	0.33	0.23	0.08	0.06	0.11	0.81
Labor	0.11	0.08	0.11	0.04	0.03	0.37
TOTAL/ STERE	1.93	1.35	0.21	0.17	0.20	3.86

System M-9, Draw Shear and Power-tine, Mechanical Loading, No Debarking

Description

I. Felling and bunching with draw shear mounted on farm tractor, one operator.

II. Manual limbing and topping on the bunch, one worker.

III. Skidding from stump area to landing with farm tractor and power-tine, one operator.

IV. Bucking with chain saw at the landing, one sawyer.

V. Mechanical loading at the landing with a knuckleboom loader mounted on a farm tractor, one operator and one helper.

VI. Truck prehauling from landing to the main road, one truck driver.

Data and Results

	I	II	III	IV	V	VI	
F	10,080	0	7,680	600	18,880	10,800	
i	0.1761	-	0.1761	0.1761	0.1761	0.1761	
n	3	-	3	2	3	3	
h	2400	-	2400	2400	2400	2400	
V	3,805	3,805	3,805	3,805	3,805	3,805	
P	4.00	4.00	5.00	21.72	52.50	52.50	
D	0	0	0	0	0	1500	
U	.75	.75	.75	1.00	1.00	1.00	
L	-	-	-	-	-	21.43	
t	-	-	-	-	-	333.33	
w	.75	.45	.75	.63	1.20	.75	
m	3.20	0	3.20	1.40	3.20	4.17	
TIME	1268.33	1268.33	1014.67	175.18	72.48	99.11	
Mach Fix	.71		.44	.01	.07	.06	1.29
Mach Var	.80		.64	.06	.06	.11	1.67
Labor	.40	.24	.32	.05	.04	.03	1.08
TOTAL/ STERE	1.91	.24	1.40	.12	.17	.20	4.04

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THE POTENTIAL FOR INCREASED MECHANIZATION OF SHORTWOOD HARVESTING IN THE MAN-MADE FORESTS OF THE STATE OF SAO PAULO

by

Reinaldo Herrero Ponce

(ABSTRACT)

In order to assess the potential of increased mechanization of shortwood harvesting in the man-made forests of Sao Paulo, Brazil, surveys and field studies of present systems were made to provide a basis for evaluation. From this information typical domestic systems with field debarking and without field debarking were compared to mechanized systems used in other countries. The analysis of twenty-two systems were made using a deterministic mathematical model to predict total direct cost per stere, man hour per stere, and capital requirements per stere of annual production. In addition, labor and capital requirements to supply a 500 ton per day pulpmill were calculated. The analysis indicated that:
(1) field debarking almost doubles direct cost, dramatically increases labor requirements, and significantly increases capital requirements when portable debarkers are used: (2) mechanical loading appears to be both cost effective and an efficient use of capital;
(3) additional mechanization results in increases cost, however, this situation is due largely to the prevailing low labor rates which could change in the future; and (4) if shortages of wood labor develops, the transition from domestic systems with field debarking

to mechanical systems without field debarking could be made without a major infusion of capital. This study has shown that there is a great need for the standardization of terminology and improved methods of data collection and analysis. The use of computer simulation for systems analysis should be implemented as soon as feasible to provide a sound basis for research and planning.