AN ABSTRACT OF THE PROJECT PAPER OF

Gregory A. Bassler for the degree of Master of Forestry in Forest Engineering presented on May 29, 1987.

Title: Producing Pulp Quality Chips in the Woods: A Short Term Study on Three Portable Delimber-Debarker Systems

Abstract approved: Eldon Olsen

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The Pulp and Paper Industry in the Pacific Northwest is obtaining an increasing share of its fiber supply by chipping small diameter trees from thinnings, insect damaged stands, and stand conversions. Since most of the mills require pulp grade fiber to contain less than 0.5% bark, the timber must be debarked prior to chipping. Traditional single-stem debarking operations have proven to be expensive compared with multiple-stem alternatives.

Thus, three portable chain-flail delimber-debarker systems have recently been developed in the Pacific Northwest. Two of the systems employ self-contained prototypes capable of simultaneously delimbing and debarking multiple whole-tree loads. The third is a two-machine system, with a mobile chain-flail delimber. Chip samples obtained during short-term productivity studies averaged 0.5%, 0.7%, and 1.5% in bark content, for the two self-contained units and the two-machine system, respectively.

The most productive of the three operations manufactured 170 Bone Dry Tons (BDT) of pulp grade chips per shift. Delimbing-debarking-chipping costs were $10.63 per BDT, with a 37% utilization rate. With minor machine modifications and better harvest system balancing, production is expected to double.

Producing Pulp Quality Chips in the Woods
A Short Term Study on
Three Portable Delimber-Debarker Systems

by

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INTRODUCTION

The Debarking Problem

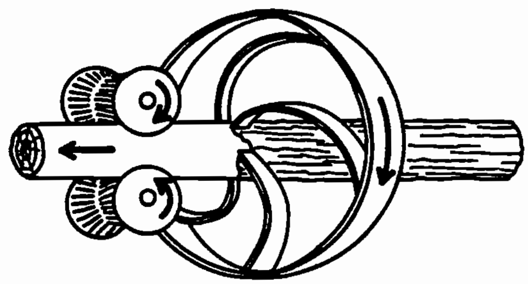
The pulp and paper industry in the Pacific Northwest has traditionally received the bulk of its raw materials from sawmill residues and old growth cull logs. As old growth timber stands are depleted, the availability of pulp quality chips, sawdust, and hog fuel from these two sources will diminish. Yet, by the year 2000, worldwide demand for paper is expected to expand to four to five times the consumption of the late 1970's (Bublitz, 1980). Competition for wood fiber from oriented strand board and structural composite beam manufacturers will also impact supply. The industry has begun to fill the widening gap between raw material demand and the traditional fiber supply by chipping small diameter materials from thinning removals, insect infested stands, and stand conversions.

Although the pulp industry's raw material sources are changing, the mills retain rather rigid quality requirements. Foremost among these is the need for a uniformly sized, bark free chip. Modern portable disk chippers are able to meet chip size standards in a wide range of stem sizes, providing knife sharpness is maintained. Bark removal poses a much more difficult problem in small timber.

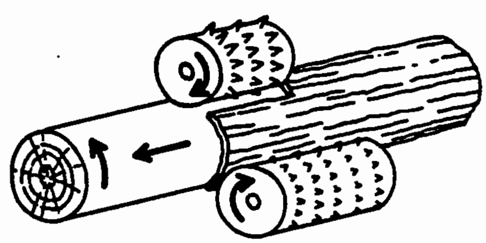
While whole tree barky chips are used to a limited extent, the industry prefers to obtain pulp grade fiber with less than 0.5% bark content by weight. Clean chips are worth between 65% and 100% more per Bone Dry Ton (BDT) than chips which contain bark, limbs, and needles. Depending on need, certain mills will relax pulp chip standards to allow as much as 4% bark content, but standards of 1% are more common for materials produced in the woods. Thus, there is a need for debarking equipment capable of meeting mill bark tolerances in small timber.

Traditionally, single-stem debarkers such as the ring (cambium shear) and the rosser head have been used in the Pacific Northwest (Figure 1). Contemporary ring machines are able to successfully debark stems down to a three inch top diameter. Processing speed is inversely related to diameter; the smallest stems can be debarked with infeed speeds as high as 320 feet per minute (Nicholson, 1987). However, increased throughput speed is insufficient to offset the decrease in volume production that occurs when processing smaller stems.

A rosser head debarker, the Morbark model 2250, was briefly studied by Gonsior (1986) in small lodgepole pine ranging from 3 to 12 inches in western Montana. Debarking quality was good, with the chip bark content well below the mill standard of two percent. Debarker throughput was only 47 cunits per 8 hour shift, or about 6.6 BDT per scheduled hour, however. Debarker utilization was only 39%. The major delay was attributed to "feed gaps"-- the time interval which occurs between the loading of successive stems into



Ring debarker



Rosser Head debarker

Figure 1. Common debarkers used in the Pacific Northwest.

the debarker infeed (Figure 2).

Feed gaps can be reduced, but not entirely eliminated, with the addition of a live deck at the infeed. While debarking quality is acceptable, single-stem debarker productivity is heavily influenced by stem diameter. Multi-stem or batch debarking machines are more able to maintain a given level of production regardless of stem size.

Drum debarkers have traditionally been used to handle small diameter materials in other regions of the United States. Large, fixed installation drums are able to delimb and debark multiple whole-tree or tree-segment loads, but have very high capital costs. And, because public highway load size restrictions make the highway hauling of limby tree segments unfeasible at present, delimbing and topping remain a part of such processing systems.

Two relatively inexpensive portable drum debarkers are currently on the market, but each can only process pulpwood length materials. One of these, the Price Industries debarker (Figure 3), can handle lengths up to 16 feet, with hourly throughput of 35 to 40 green tons (Duch, 1987). Though the fixed and operating costs of these portable drum debarkers have become more affordable, additional costs incurred in delimbing, slashing, and loading operations remain a problem.

A number of equipment fabricators have turned to chain flail technology in an effort to develop a portable, low cost, multi-stem whole-tree debarker. The chain flail

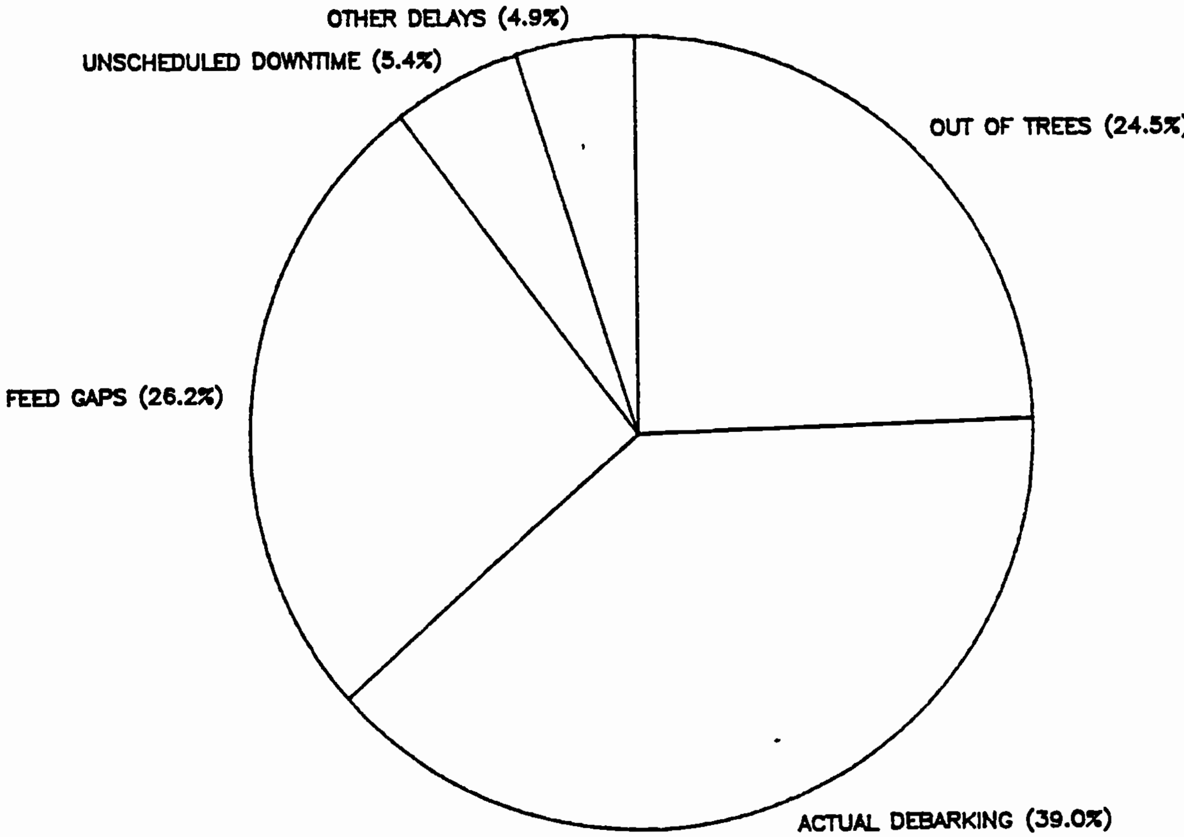


Figure 2. Morbark 2250 debarker activity time distribution.

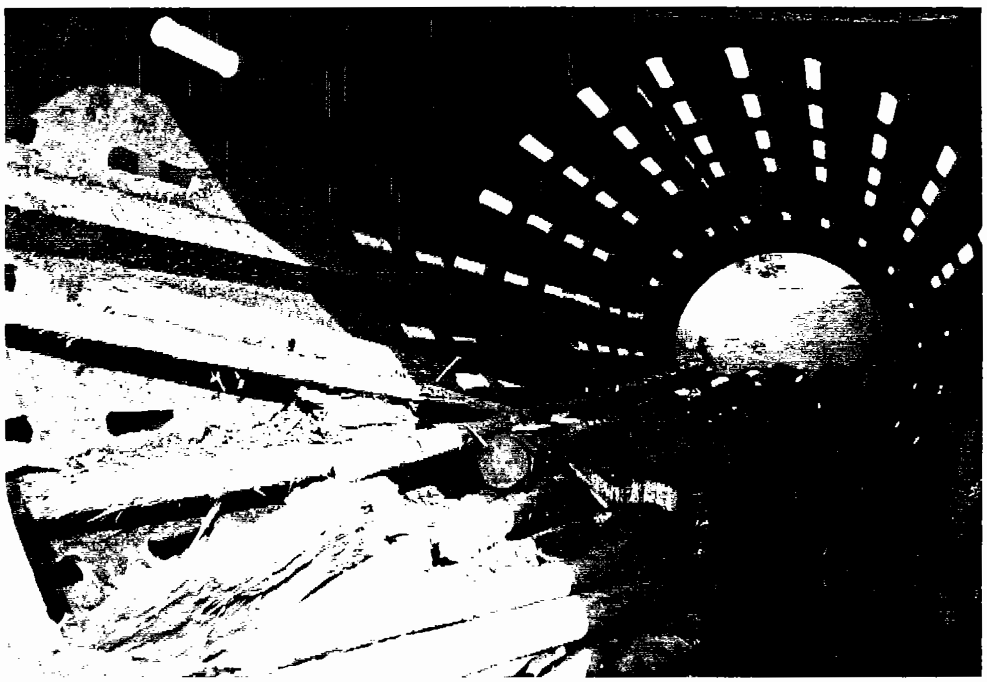


Figure 3. Price Industries portable drum debarker.

offers the advantage of combining delimbing and debarking functions into one unit. If operated at the logging site, tree tops and other material unsuitable for sawlog manufacture could be more fully utilized.

Chain Flail Technology

Chain flail debarking, as a concept, has been around for ten years. Benner (1976) reported on the development of a drum debarker-chain flail combination for treatment of logging slash. Yet, until recently, most of the developmental work on chain flail technology has been devoted strictly to the delimbing process (Johnson, 1976; Folkema and Giguere, 1979). Chain flail delimber manufacturers all use a similar design, based on a single, horizontally rotating drum to which rows of short chains are attached. The chains remove limbs on impact and by a scraping action which occurs when they wrap around and slide along the stem bole.

Kammenga (1983) was one of the first to explore the debarking capabilities of flail delimbers. In a conifer thinning operation in Western Washington he recorded a 7% bark content after one pass over a turn of whole trees with a Hydro-Ax chain flail delimber. After repositioning the turn and flailing it once more, bark content was reduced to 4%.

Recognizing the debarking capabilities of the chain flail delimber, several fabricators have developed machines which utilize two or more counter-rotating chain flail drums to simultaneously delimb and debark multiple whole tree loads (Figure 4). The Weyerhaeuser Company was one of the first to build such a machine. In 1981, they began developing a portable double-flail prototype for producing clean chips from southern pine thinnings (Selby and Iff, 1986). During in-woods testing, the prototype had a productivity of 73 green tons per productive hour. Throughput was so high that the harvest system had difficulty supplying enough wood to the machine.

In order to increase utilization, Weyerhaeuser moved the prototype to a satellite yard. At the yard, productivity averaged 485 green tons per scheduled 8 hour shift when working in Loblolly pine [Pinus taeda]. Chip bark content was consistently under 1%, even during winter conditions. Flail speed and chain configuration were adjusted to maintain productivity in tight bark conditions.

Currently, a larger, stationary system is operating at one of Weyerhaeuser's pulp mills in North Carolina. In addition, they have sold their design and patents for a smaller, portable delimber-debarker to Manitowoc Engineering Company. Manitowoc plans to develop their first prototype by the end of 1987.

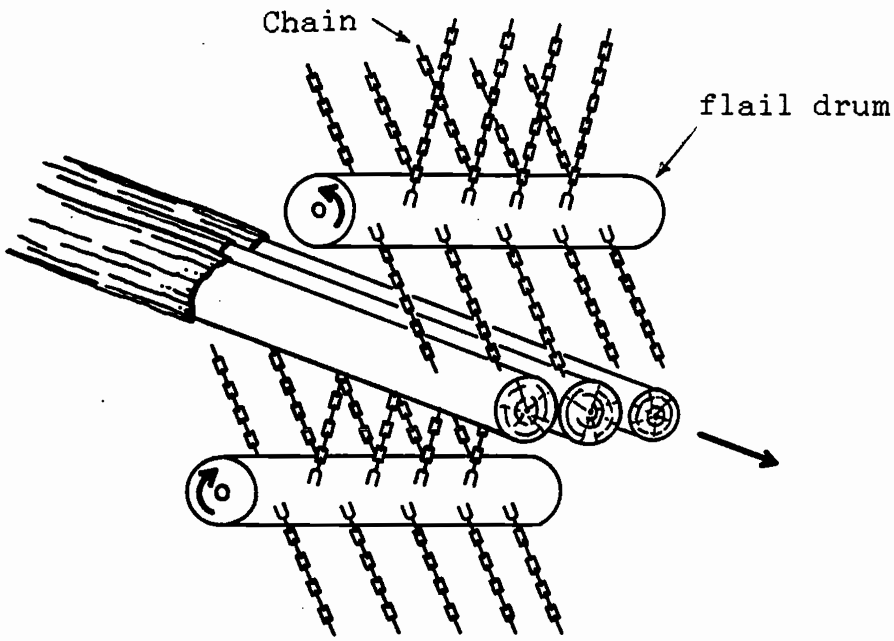


Figure 4. Chain flail debarker.

Concurrent with the Weyerhaeuser development, three Pacific Northwest equipment fabricators introduced prototype chain-flail delimber-debarkers designed for in-woods application (Table 1). Each unit is portable, but remains stationary at the landing during operation. Infeed speeds for all three machines are synchronized to that of the chipper, into which the debarked materials are automatically fed.

Mischel Brothers Logging of Port Orchard, Washington, developed a portable delimber-debarker which was briefly marketed as the Bigfoot D/D 20 Delimber/Debarker (Figure 5). The machine has four chain flail drums and an infeed deck. A tree stand, a tee-shaped metal stand with a top roller, is used near its infeed deck to help support and spread the payload for improved debarking. The drumsets are mechanically driven by a 150 horsepower diesel engine and are run at approximately 600 rpm. Speeds can be somewhat varied by changing engine speed. Bark and limb debris are removed from the bottom of the machine by a series of drag chain conveyors.

In early 1986, Gibson Chip Company of LaGrande, Oregon re-designed and built a second prototype based on the first Bigfoot design (Figure 6). This model, which has a much larger throughput capacity than the first machine, is powered by a 375 horsepower diesel engine. All four chain flail drums are hydraulically driven. Drum speeds and infeed speeds can be varied hydraulically to accomodate the

Table 1. Summary of design features for the three Pacific Northwest prototypes.

Feature	Mischel	Gibson	Peterson (Edman)
Horsepower	150	375	--
Number of flail drums	4	4	2
Flail speeds (rpm)	600	325-375	350
Rows of chain per drum	4	4	4
No. of chains per row	7-8	10	7-8
No. of links per chain	5	10-15	5

Figure 5. Mischel Brothers Bigfoot delimber-debarker.

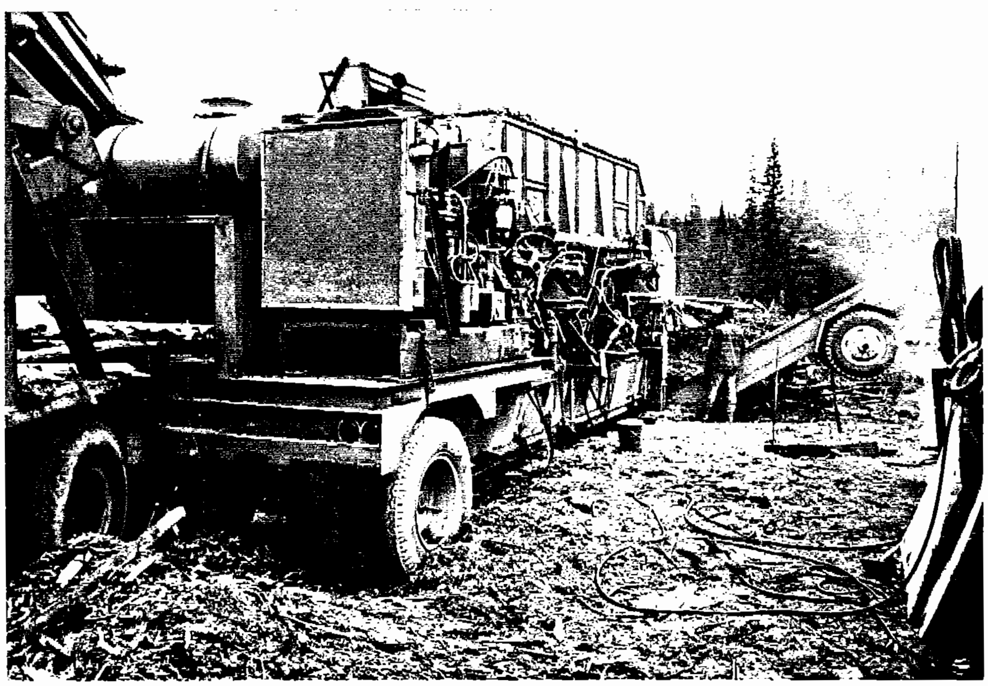


Figure 6. Gibson Bigfoot delimber-debarker.

level of bark adhesion experienced in a particular species or operating season. A single conveyor is used to remove bark and branch materials from the machine. Like the Mischel Brothers' machine, the Gibson prototype uses a tree stand to help support and spread its payload.

Peterson Pacific Corporation of Pleasant Hill, Oregon has manufactured a series of flail debarker prototypes. The first models were freestanding, self-contained two drum units which utilized carbide-tipped tire cord flails. A third prototype mounts directly on the chipper infeed and runs off hydraulic power provided by the chipper (Figure 7). The tire cord flails were replaced with a chain flail design on this model. Flail rotational speed is 350 rpm. Bark and limb debris are pushed out from under the debarker by a hydraulic ram.

Edman Company of Tacoma, Washington employs the third prototype in their chipping operation, and have found it to be unable to simultaneously delimb and debark whole-trees satisfactorily. Therefore, they use a Hydro-Ax chain flail delimber prior to debarking (Figure 8).

Presently, Peterson Pacific Corporation is testing another prototype which incorporates the original freestanding, self-contained design. Testing is being done in southern species at various locations around the South. Information on throughput capability and chip quality is unavailable at this time.

Figure 7. Peterson Pacific Corporation debarker.

Figure 8. Hydro-Ax chain flail delimber.

Except for shift level production and the average bark content per van load, little was known about the productivity and product quality manufacturing capabilities of the prototype chain flail delimber/debarkers operating in the Pacific Northwest. This study was undertaken to examine each prototype in more detail.

STUDY OBJECTIVES

The specific objectives of this research project were to:

1) Determine productivity and costs for the following three chain flail delimber-debarker systems:

    A. Mischel Brothers prototype Bigfoot delimber-debarker

    B. Gibson Chip Co. prototype Bigfoot delimber-debarker

    C. Peterson Pacific Debarker w/ Hydro-Ax chain flail delimber

2) Determine the bark removal capabilities of each prototype in Pacific Northwest conifers in summer conditions. Included in this an exploration of:

    A. Effect of piece size on debarking capabilities

    B. Effect of piece count (stems per debarker payload) on the debarking capabilities

STUDY SITE DESCRIPTIONS

Mischel Brothers Prototype Delimber-Debarker

At the time of the study, Mischel Brothers were working in a conifer thinning operation on the City of Bremerton Watershed near Bremerton, Washington. The stand was predominantly Douglas-fir [*Pseudotsuga menziesii* (Mirb.)Franco], age 30-35 years, and had a stocking of 280 trees/acre. Volume per acre was 20.8 MBF (63 cunits) with an average diameter of 9.7 inches DBH. Slopes ranged from 5 to 25 percent.

Using a three-person crew, Mischel Brothers ran a fully mechanised sawlog and pulp chipping operation. One person operated a track mounted feller-buncher, a second ran a grapple skidder, and the third fed the delimber-debarker and merchandised stud logs from the cab of a hydraulic loader.

The silvicultural prescription called for the removal of all trees below 9 inches DBH and one-half of the 10 inch DBH trees. Residual stocking was targeted at 175-200 trees per acre. Leave-tree selection was up to the discretion of the feller-buncher operator. Harvest volume was estimated to be 14.3 cunits (35 tons) per acre.

Whole tree bunches were skidded to the landing and deposited near the loader (Figure 9). Trees that contained a stud log were merchandised by a loader-activated hydraulic shear. Tree tops and whole-trees unsuitable for stud log manufacture were loaded into the delimber-debarker, from which they were automatically fed into a Sumner two knife sawmill chipper. Chips were hauled to the Simpson Paper Mill in Tacoma, a distance of 35 miles one way.

Gibson Chip Co. Prototype Delimber-Debarker

This machine, designed and built by Mr. Harvey Gibson, was studied while working in a beetle-killed Lodgepole pine [Pinus contorta (Dougl.)] stand located on the Umatilla National Forest, near Heppner, Oregon. The stand, which was being clearcut, had a stocking level of 528 trees per acre, with approximately 44% of the stems being dead. Average tree diameter was 7.1 inches DBH. Volume per acre averaged

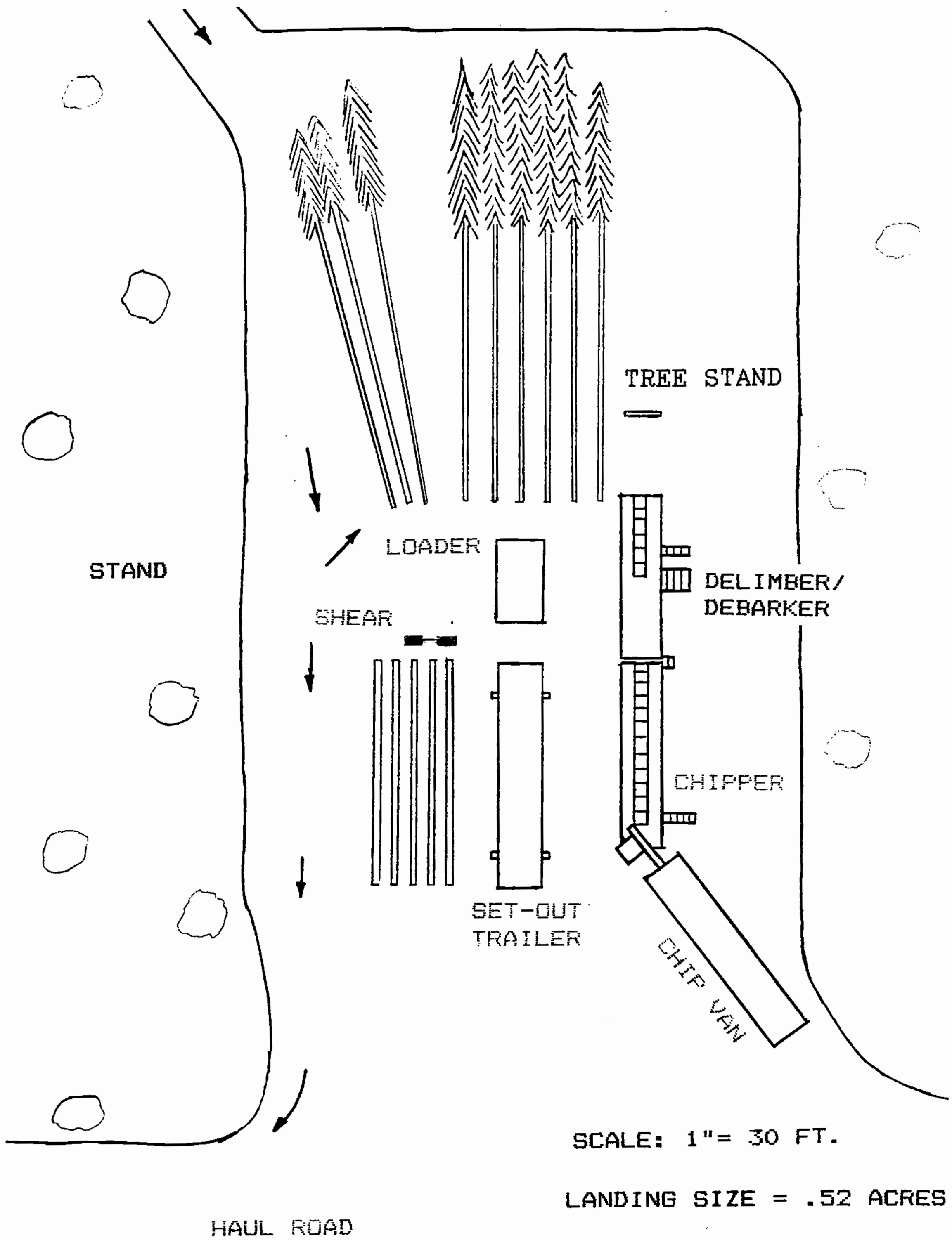


Figure 9. Landing layout of Mischel Brothers operation.

15.1 cunits (35.9 tons). The terrain was flat.

Gibson employed a three man crew to run the delimber-debarker, a Morbark Model 23 chipper, a hydraulic loader, and one shuttle truck. One person operated the hydraulic loader, which was used to feed multiple stem payloads into the delimber-debarker (Figure 10). The processed stems were fed automatically into the chipper; the hydraulic loader on the chipper was not used. The other two employees monitored the delimber-debarker and chipper, and shuttled chip vans between the landing and a staging area. Chips were hauled to Umatilla, a distance of 89 miles one way.

Felling, skidding, and landing cleanup were the responsibility of a subcontractor, whose two grapple skidders were used to bring whole-tree bunches to the landing deck.

Peterson Pacific Debarker with Hydro-Ax Delimber

The Edman Company, of Tacoma, Washington, uses a Peterson Pacific debarker mounted on a Morbark Model 22 chipper and a Hydro-Ax Model 521 chain flail delimber in their chipping operation. Edman's operation works in partnership with Mr. Russ Schillinger, a mechanized felling contractor. Two grapple skidders are used to transport the whole tree bunches to the landing.

At the time of the study, the operation was working in a thinning on Pope and Talbot land near Port Gamble, Washington. The stand was 35 to 40 years old, with a

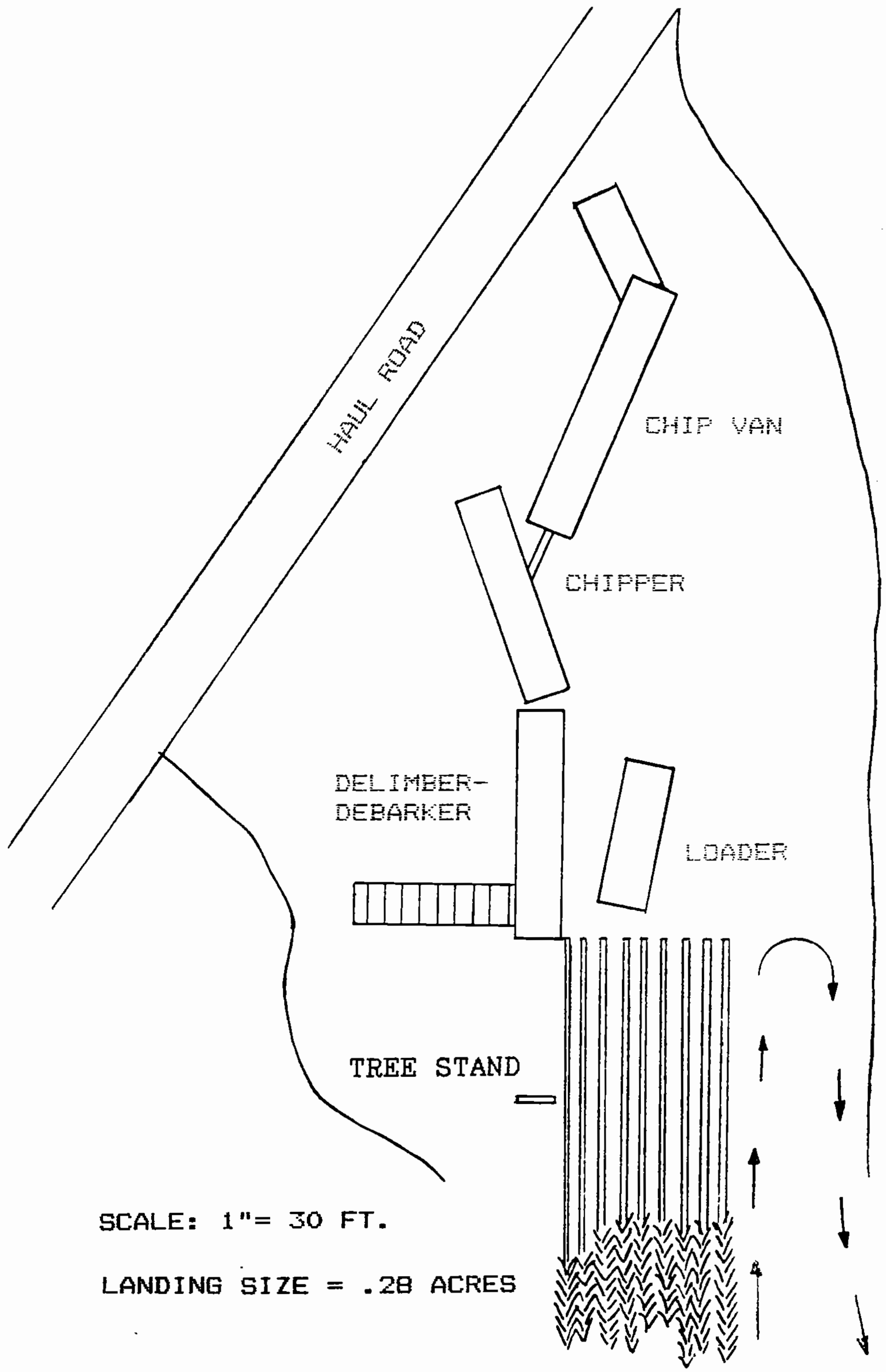


Figure 10. Landing layout of Gibson Chip Company operation.

Douglas-fir overstory. Understory vegetation consisted mainly of Western hemlock [Tsuga heterophylla (Raf.) Sarg.] with some Western redcedar [Thuja plicata Donn.] and Red alder [Alnus rubra Bong.]. Stand stocking ranging between 700 and 1500 stems per acre. The silvicultural prescription was to leave 175-200 of the larger (greater than 10 inches DBH) Douglas-fir trees per acre. The harvest volume, estimated to average 15.2 cunits (35 tons) per acre, consisted primarily of hemlock stems in the 1 to 12 inch DBH range. Leave-tree selection was up to the discretion of the feller-buncher operator. The terrain of the unit was generally flat.

The layout of the harvesting operation was very important. Whole tree bunches were grapple skidded to a series of short trails near the landing where they were delimbed by the Hydro-Ax (Figure 11). The Hydro-Ax made an average of 5 passes over the bunches, each time trying to spread the stems to get better flail coverage. Following delimbing, the bunches were skidded to the debarker/chipper infeed deck where the chipper's sliding boom loader fed the debarker. A Morbell logger was used at the landing to assist in sorting, skidding, and removing debris that accumulated around the debarker.

To minimize shuttling delays and congestion at the landing, a nearby staging area was used to store both empty and loaded chip vans. Two shuttle trucks were used to move the vans between the landing and the staging area. Trucks

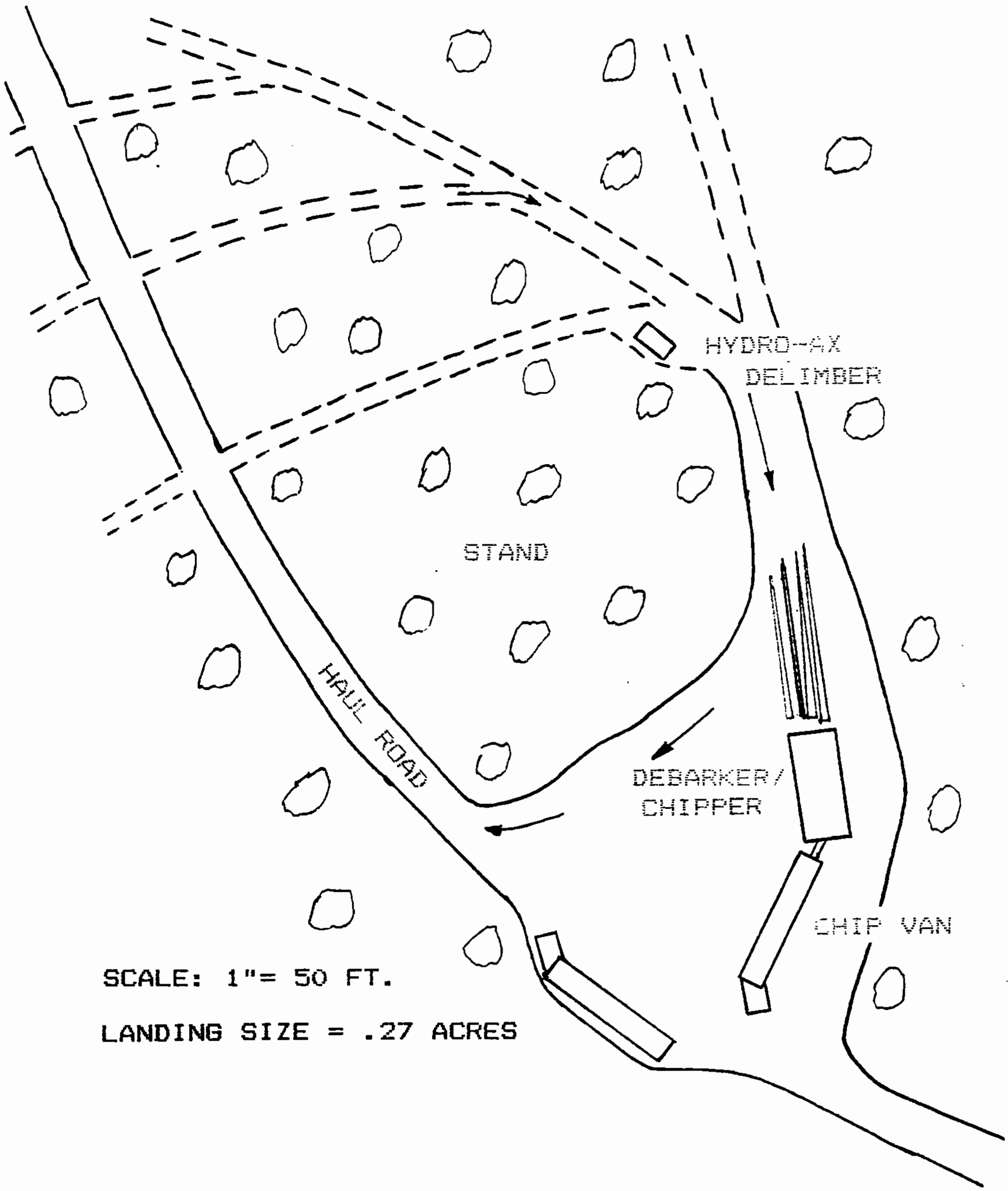


Figure 11. Landing layout of Edman Company operation.

hauling to the mill exchanged vans at the staging area, thus eliminating interference at the landing. Chips were taken to Port Townsend Paper in Port Townsend, WA., a distance of 35 miles one way.

The delimbing, debarking, and chipping phase of the operation required a three person crew. One person operated the Hydro-Ax delimber, another ran the Morbell logger and shuttled vans, and a third operated the debarker/chipper.

STUDY METHODS

BARK CONTENT ASSESSMENT

To determine the overall bark content in the chips being produced and how changes in stem size and stem count may affect it, chip samples were taken from approximately 50 debarker payloads at each site. This sample size was chosen as a compromise between accuracy and the need to minimize interference in each operation.

Sample debarker payloads were varied by the number of stems and the size of the individual stems they contained. Individual stems were measured for diameter, length, and the amount of bark missing bark prior to debarking. The payloads were fed into the debarker when its infeed was clear.

A reinforced salmon net, lined with a heavy woven canvas, was used to collect the chip samples. The deep, cone-shape of the net reduced sample stratification, by making it difficult for the chips to bounce back out. As soon as all of the stems in a sample payload were being chipped simultaneously, the net would be held behind the chipper blower until a 500 cubic inch sample had been collected.

Field studies on the three delimber-debarker systems were conducted during the months of July, August, and September 1986. A total of 50 chip samples were taken at both the Edman and Gibson operations. At Mischel Brothers' operation, only 39 debarker payloads were sampled since they had almost completed their harvesting operations.

The samples were sealed in air tight plastic bags and brought to the Forest Products Lab at Oregon State University for analysis. Each sample was weighed, and then oven dried for a 14 hour period to determine moisture content. Chip size stratification was examined using a Everett Metal Products Inc. classifier. Bark was separated manually, for each size class. Percent bark content was calculated on a weight basis from bark residues contained in the "acceptable", "over-size", and "over-thick" chip classes, using the following equation:

$$\text{Percent Bark} = \frac{\text{Oven Dry Weight of Bark}}{\text{Oven Dry Weight of Total Sample}} \times 100$$

Debarker payload volumes for the two studies in Washington were calculated using Smalian's formula. The inside bark scaling diameters were converted from diameter outside bark measurments using equations developed by Khan, Bell, and Berg, 1977. Oregon lodgepole pine volumes were calculated using a procedure outlined by Dahms, 1983.

In order to evaluate debarker performance, it was necessary to estimate the amount of bark missing on each sample payload prior to debarking. For an individual stem, missing bark was represented as the percentage of stem surface area on which the bark had been removed. This was estimated by measuring the lineal distance without bark along two sides of each stem, and then using the following equation:

Percent Missing Bark (per stem) =

$$\frac{\text{Total Length Missing bark (both sides)}}{\text{Measured stem length x 2 (total distance)}} \times 100$$

Stem surface area was approximated by calculating the surface area for a frustrum of a cone. Percent missing bark per debarker payload was then calculated by the following equation:

Percent Missing Bark (per payload) =

$$\frac{\text{Missing Bark Surface Area (all stems)}}{\text{Total Surface Area (all stems)}} \times 100$$

PRODUCTIVITY ASSESSMENT

Detailed time studies were conducted at the Gibson and Edman delimbing-debarking and chipping operations in order to determine each system's throughput capabilities and in-shift utilization. Each operation was monitored from startup to shutdown over a three day period, concurrent with chip sampling studies. Delays caused by chip sampling study interference were recorded and removed from the data set. A one day time study of Edman's Hydro-Ax was also completed.

At the Mischel Brothers site, the chip sampling study was so time-consuming that no detailed throughput information was obtained, prior to the completion of harvesting operations. Mischel Brothers did not use their delimber-debarker again until December, in winter bark adhesion conditions. Therefore, no follow-up study was conducted.

Time study work cycle elements were described as follows:

PRODUCTIVE TIME

Actual productive time:

Processing

The elapsed time taken to debark a given payload. This cycle element began when the butts of the payload entered the infeed roller. Since each debarker had a continuous infeed potential, an individual processing time element was considered to end when either the tops of the current payload disappeared under the infeed roller or the butts of the next payload entered the infeed.

Other productive time: Activities occurring during "feed gaps"-- those Productive Time intervals when the debarker infeed contained no fiber.

Loading

A time interval during which the loader was occupied with non-sorting activities.

Sorting

A time interval during which the loader was removing unacceptable pulp stems from the infeed deck.

Jamming

This occurred when either the debarker or the chipper became jammed.

NON-PRODUCTIVE TIME

Maintenance

In-shift time required for normal service, fueling, warmup, and chipper knife changes.

Repair

In-shift time actively repairing and awaiting repair.

Disturbance Time

Wait for Wood

This occurred when there was no more wood available for processing at the infeed deck.

Van Shuttling The time interval required to remove a full chip van from the chipper and replace it with an empty one.

Personal

Planning, supervisory, and unscheduled breaks.

Wait for Van

Idle time caused by the unavailability of empty chip vans.

Other

Minor interference delays such as clearing debris, researcher delay, and system delays.

Elemental times were measured with a stopwatch and recorded on data forms. Stem diameters were estimated for every debarker payload during the study. Height and diameter measurements were taken on approximately 450 stems at each study site, in order to obtain tarif information. Payload volumes were calculated from equations derived for the particular species and area, or tarif tables.

FIBER RECOVERY (WOOD LOSS) ASSESSMENT

All debarking tools remove a portion of stemwood fiber along with the bark. This is a concern since wood loss can seriously affect pulp chip yield. Chain flail delimber-debarkers reduce fiber yield in three ways:

1) Wood fiber is removed with (attached to) the bark, or when the chains hit bark-free areas along the stem.

2) The tops of whole trees can be broken off by the force of the flails and deposited in the debris pile.

3) The chain flail frays and brooms the stem surface, leading to a larger percentage of unacceptably sized chips.

One original intent of the research project was to quantify wood loss. Because of the need to minimize interference with each operation, conditions could not be controlled sufficiently to do so. The percentage of unacceptably sized chips is primarily a function of chipper knife wear, which was highly variable.

A small number of bark samples were removed from each machine's debris outfeed device, in order to estimate the amount of bole wood fiber removed with the bark. The flails tend to "mulch" the debris, making it difficult to separate bole wood fiber from branch wood fiber in the debris piles. Therefore, samples undoubtably contained some branch fiber.

RESULTS

CHIP QUALITY STUDY

Debarking Capabilities

Both four drum delimber-debarkers were capable of consistently producing conifer chips with under a one percent bark content in summer conditions (Table 2). For the Mischel Bigfoot delimber-debarker, chip sample bark content averaged 0.67%. Seventy-five percent of the sample payloads had a bark content below 1% (Figure 12). The Gibson Bigfoot prototype produced an average sample bark content of 0.51%, with 88% of the samples under a 1% bark content (Figure 13). Edman's Peterson Debarker/Hydro-Ax system did not remove bark as cleanly. Sample bark content averaged 1.51%. Only 34% of the chip samples had a bark content below 1% (Figure 14).

At the Mischel Brothers site, an average of 8% of the bark was removed from the stem surface area during felling and skidding operations. Prior to processing, the missing bark value at the Gibson site averaged 23% per stem (Figure 15). At Edman's operation, the Hydro-ax made an average of 5 passes per skidder turn, removing bark from approximately 41% of the individual stem surface area (Figure 16). Missing bark measurements prior to delimbing were not recorded at the Edman site.

All but two of the Mischel Brothers sample payloads

Table 2. Chip sampling results for the Mischel Brothers, Gibson Chip Company, and Edman Company operations.

	Mischel		Gibson		Edman	
Parameter	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
	n = 39		n = 50		n = 50	
PIECE SIZE INFORMATION						
Volume/Piece (ft3)	6.1	3.6	8.7	6.7	5.1	5.8
Stems/Debarker payload	2.5	0.8	3.7	1.1	3.8	2.1
Volume/Debarker payload	15.1	4.1	32.8	8.4	19.63	9.82
Stem Diameter (d.b.h.)	6.4	1.5	7.1	2.3	5.1	2.2
DEBARKER CHIP QUALITY						
% Bark content	0.67	0.58	0.51	0.46	1.51	0.88
% Missing bark/stem	7.4	2.8	23.1	25.5	32.0	23.6
% Missing bark/debarker payload	7.6	5.2	26.3	17.9	40.7	12.8
Debarked Top diameter (in.)	2.1	.9	3.6	0.7	--	--

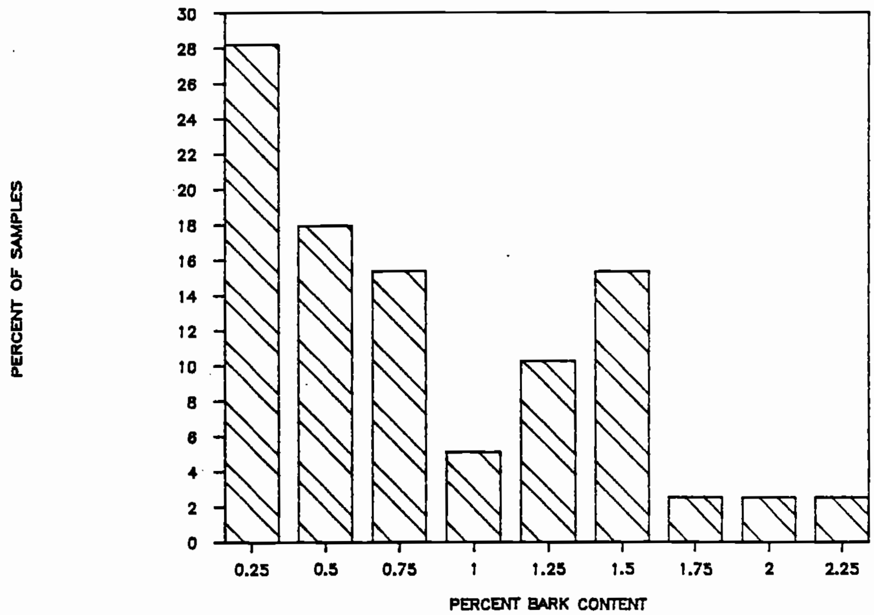


Figure 12. Bark content distribution for Mischel Bigfoot delimber-debarker.

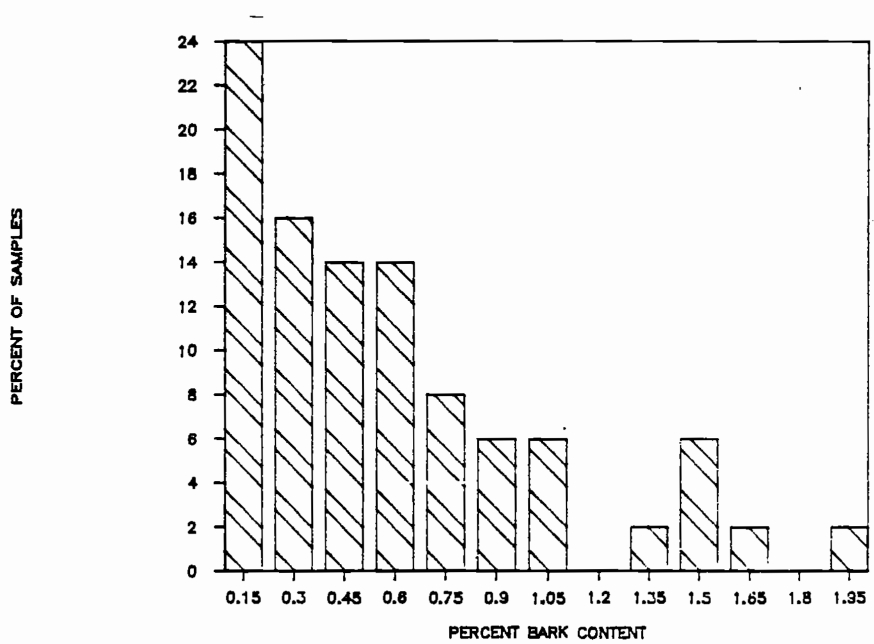


Figure 13. Bark content distribution for Gibson Bigfoot delimber-debarker.

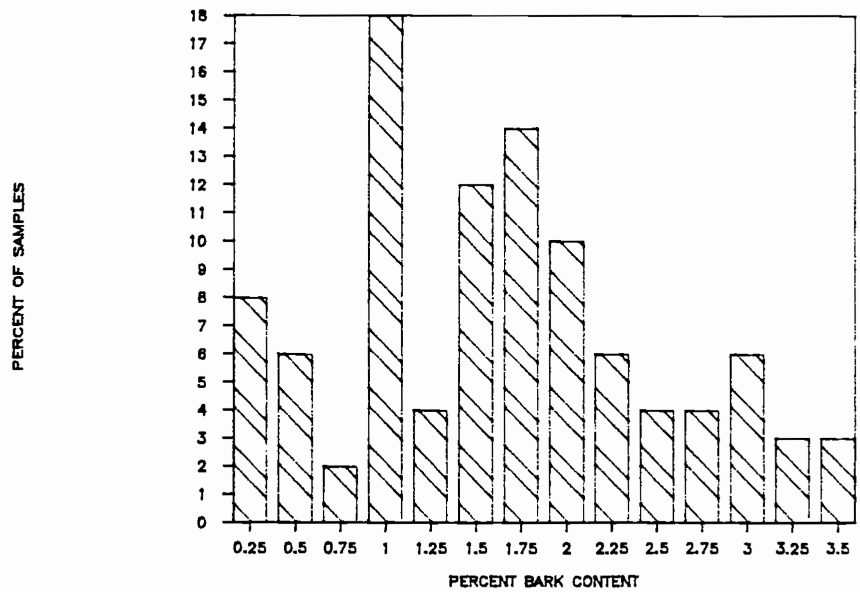


Figure 14. Bark content distribution for Peterson debarker/Hydro-Ax delimber system.

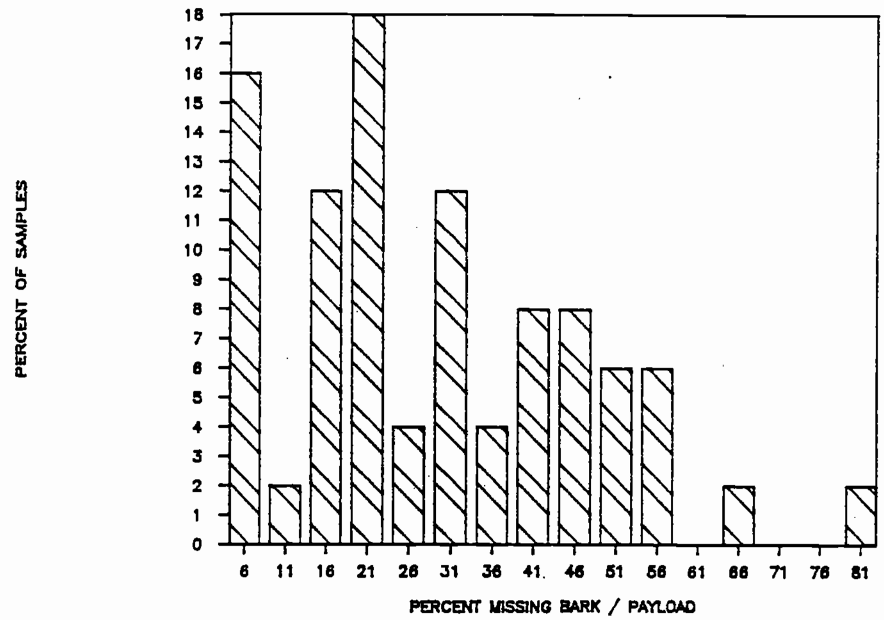


Figure 15. Missing bark distribution for Gibson Bigfoot delimber-debarker.

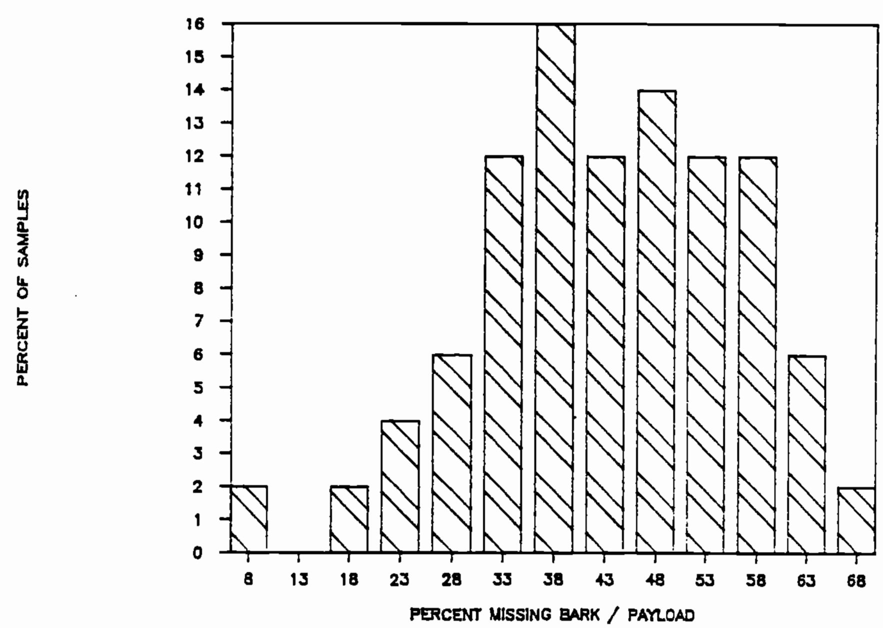


Figure 16. Missing bark distribution for Peterson debarker/ Hydro-Ax delimber system.

consisted solely of Douglas-fir. The Gibson payloads were entirely of Lodgepole pine. At the Edman site, Western hemlock accounted for 74% of the stems sampled.

Regression Analysis

A number of stem and payload attributes were thought to potentially influence the debarking capabilities of each system. During chip sampling, the variables measured for each debarker payload included species, stem size, stem count, volume, moisture content, percent surface area missing bark, and the number of green or dead stems. With the NUMBER CRUNCHER STATISTICAL SYSTEM (NCSS) program, multiple regression techniques were used to determine the impact of each variable on bark content. Significant variables were identified by having a t-value greater than or equal to 2.00 in each regression, and by the marginal decrease in mean squared error (MSE).

In the regression equations that follow :

%BARK = Percent bark content per payload

STEMS = Number of stems per debarker payload

MISSBARK = Percent of total surface area per debarker payload missing bark.

DIFFDIA = Difference in diameter at breast height in inches from largest to smallest stem in the payload.

Mischel Brothers Bigfoot Prototype :

$$\%BARK = .4353 + .1616(DIFFDIA)$$

n = 39 MSE = 0.3008 R2 = 0.1227

Edman Company / Peterson Pacific-Hydro-Ax :

$$\%BARK = 2.1631 + .1576(STEMS) - .0308(MISSBARK)$$

n = 50 MSE = 0.5364 R2 = 0.3357

Gibson Chip Company Bigfoot Prototype :

$$\%BARK = .3087 + .1136(STEMS) - .0083(MISSBARK)$$

n = 50 MSE = 0.1589 R2 = 0.2871

Note:
All variables are significant at the 0.01 level.
R2 = Adjusted coefficient of determination.

The regression analysis identified stem count and percent missing bark per payload as significant variables affecting bark content for the Edman (Peterson) and Gibson prototypes. The difference in stem size within the payload was found to be significant in the case of the Mischel Bigfoot prototype. All other variables were insignificant at the 0.05 level.

Fiber Recovery (Wood Loss)

The amount of bole wood fiber contained in the debris samples, on a dry weight basis, averaged 19%, 17%, and 14%, for the Mischel, Gibson, and Edman (Peterson) prototypes, respectively. These figures represent wood fiber removed from the stem bole during debarking only, wood losses occurring at the chipper are not included. The Edman figure represents values for the Peterson debarker only--Hydro-Ax delimbing losses were not measured.

The ratio of bark fiber to bole wood fiber for Pacific Northwest tree species can be calculated from biomass equations developed by Gholz, et.al. (1979). For stems in the 4 to 8 inch DBH range, a 19% bole wood fiber content in the bark debris would correspond to an overall bole wood fiber loss in the 4.0 to 4.5% range (at 100% bark removal).

Mischel Brother's prototype caused very little top breakage, as opposed to Gibson's delimber-debarker. Prior to processing, stem top diameter measurements averaged 1.8 inches and 1.9 inches, at the Mischel and Gibson sites, respectively. Following delimbing-debarking, these values averaged 2.1 inches and 3.6 inches, respectively. There was no significant difference in the top diameter between green and dead stems at the Gibson operation. At the Edman operation, top diameters averaged 1.3 inches after delimbing. Since the Peterson debarker was mounted so closely to the chipper, top diameters could not be measured following debarking. There appeared to be little additional breakage during debarking, however.

PRODUCTIVITY AND COSTS

Gibson Bigfoot Delimber-Debarker System

The Gibson machine had an average production of 13.9 BDT per scheduled hour (Tables 3,4). Debarker utilization averaged only 36.5% over the three day study period. Thus, throughput averaged 38.1 BDT-- or 2.2 (18 unit) chip van loads-- per productive hour.

The debarker actively processed payloads during 85% of the productive time per shift. An additional 10% of productive time was spent removing jammed limbs and tops from the machine's debris conveyor. Loading time and chipper jamming accounted for the remaining 5% of productive time.

Disturbance, maintenance, and repair delays accounted for 63.5% of the total scheduled operating hours (Figure 17). The largest single delay component occurred during van shuttling operations. Rain and snow created poor traction for positioning and hauling vans at the landing. In combination with a limited landing size, the weather conditions ruled out the common practice of parking two vans side-by-side at the chipper blower. Double trucking eliminates shuttling time, since the chip flow can be directed to the empty van when the other becomes full.

Van scheduling problems formed an additional source of delay time. On two consecutive days, no more vans were available after the first 5 to 6 had been filled.

Table 3. Average Three day throughput results for Edman Company and Gibson Chip Company operations.

Element	Edman	Gibson
Loads/Day	8.7	10.0
Stems/Van Load	161.3	164.7
Volume/Day (Cunits)	92.4	90.1
Bone Dry Tons (BDT)/Van	12.1	17.0
BDT/Day	104.6	170.5
Green Tons/Day	202.5	230.5

Table 4. Average System Utilization for the Edman Company and Gibson Chip Company operations.[1]

Element	Edman	Gibson
	(Hrs.)	(Hrs.)
Actual Productive Time :		
Processing	3.40	3.78
Other Productive Time :		
Loading	0.17	0.13
Sorting	0.07	0.00
Debarker Jamming	0.01	0.45
Chipper Jamming	0.00	0.11
Clear debris	0.02	0.00
Total	3.67	4.47
Non-Productive Time :		
Repair	0.75	1.34
Maintenance Time		
Servicing	0.18	1.31
Change Knives	0.08	0.70
Warmup	0.40	0.76
Disturbance Delays:		
Wait for Wood	1.69	0.00
Personal	0.37	0.62
Van Shuttling	0.91	2.13
Wait for Vans	0.00	0.78
Other	0.05	0.14
Total	4.43	7.78
Scheduled Hours/shift	8.10	12.26
Utilization[2]	45%	37%
System Availability[3]	88%	78%
Chipper Availability	95%	91%
Debarker Availability	91%	83%

1Based on three shifts of observation.

2Productive Hours/Scheduled Hours.

3(Scheduled Hours - Repairs - Maintenance)/Scheduled Hours (warmup not included)

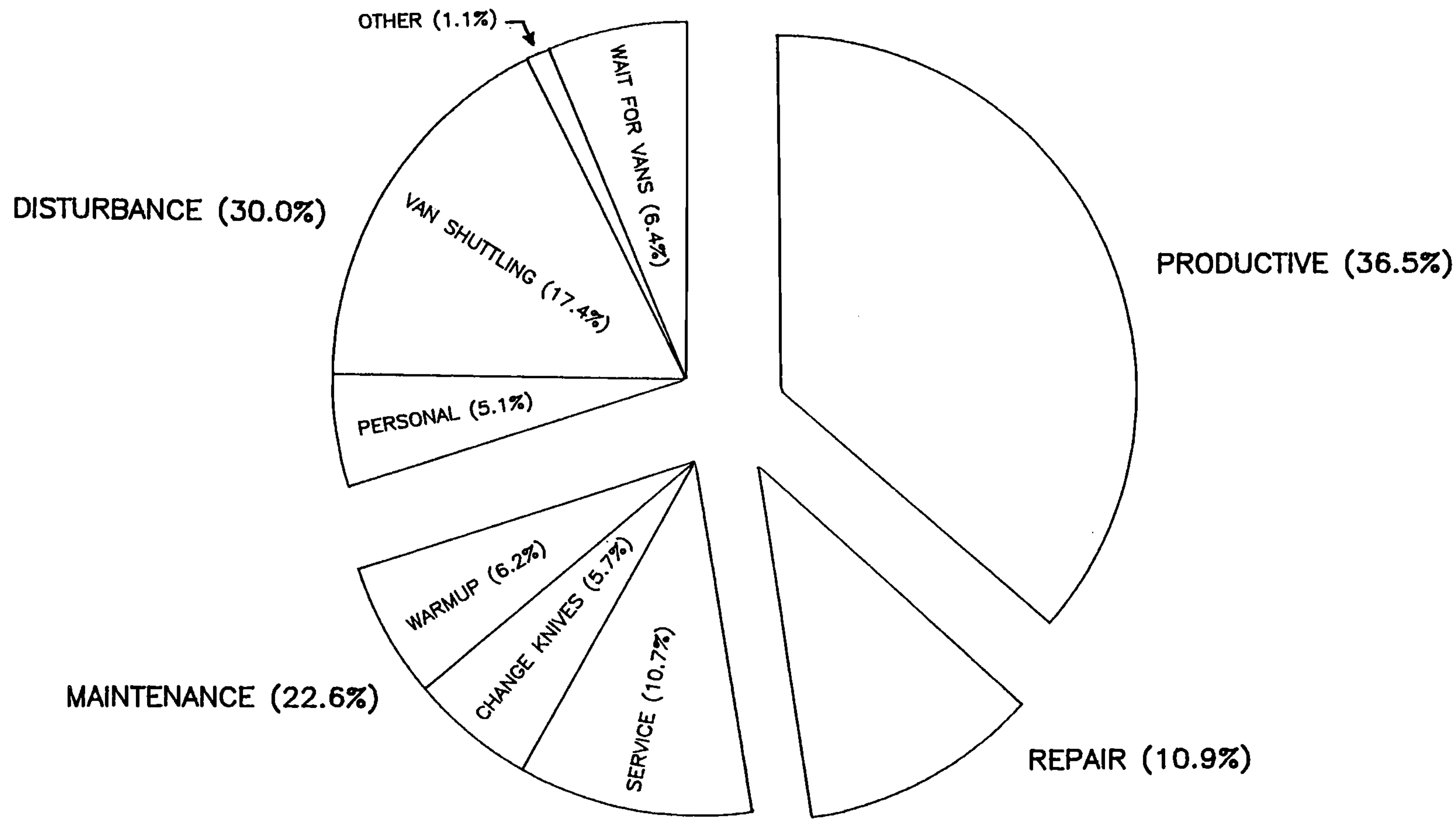


Figure 17. Debarker activities as a percent of total scheduled time for the Gibson operation.

Therefore, operations had to shut down and await the return of the first van from the delivery site.

Debarker maintenance and repair operations were also time consuming. The prototype was only in its third month of operation. Several mechanical problems, including a tendency for the debris conveyor to jam, and hydraulic oil cooling difficulties, were still being worked out. The mechanical availability of the debarker averaged 83%.

Total costs for delimbing, debarking, and chipping were $10.63/BDT (Table 5b), based on total owning, operating, and labor costs of $147.42 per scheduled hour.

<u>Peterson Pacific Debarker/Hydro-Ax Delimber System</u>

At the Edman operation, production averaged 12.9 BDT per scheduled hour (Tables 3,4). Debarker utilization averaged 45.3% during the study period. On a productive hour basis, throughput averaged 28.5 BDT.

The debarker spent 93% of productive time processing payloads. Loading activities accounted for approximately 5% of productive time-- slightly more than at the Gibson operation.

The major delay was due to waiting for wood to be delivered to the landing (Figure 18). Because of the very small stem sizes being harvested, the five feller-bunchers and two grapple skidders could not supply enough wood to keep the debarker busy. Van shuttling delays were also a problem, although much less of one than for Gibson.

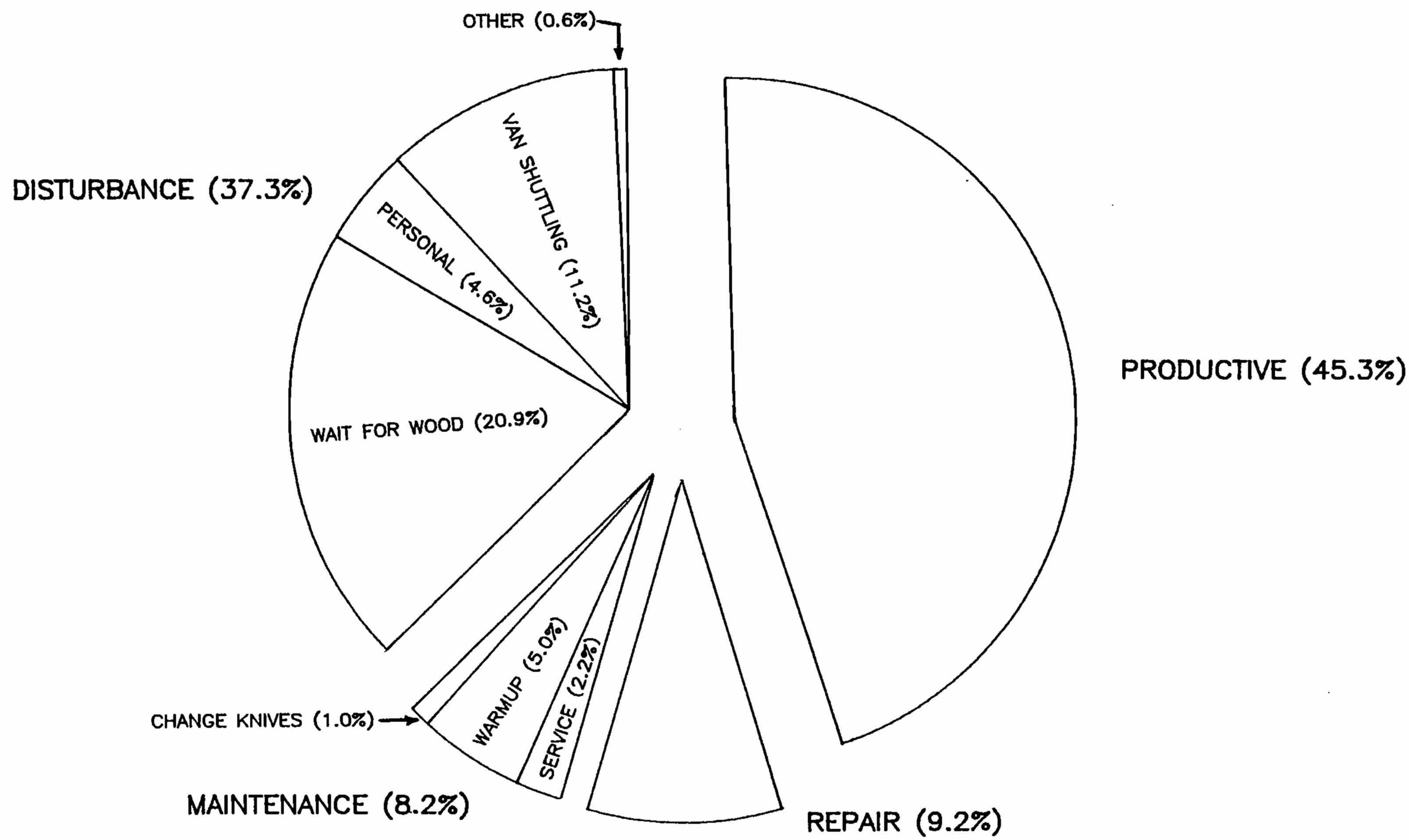


Figure 18. Debarker activities as a percent of total scheduled time for the Edman operation.

Debarker repair and maintenance delays accounted for 17.4% of the total scheduled operating hours. The mechanical availability of the debarker was quite high, at 91%. The only major repair occurred when a hydraulic pump powering one of the debarker flails failed. Edman had a replacement pump on-site, so the repair time was kept under two hours.

The Hydro-Ax delimber was studied for approximately three-quarters of one full shift. Machine utilization was 67% (Table 6), with waiting for wood the major source of delays. Had the skidders provided more wood, the operator would have probably spent less time delimbing individual bunches. Production would have increased accordingly.

Total delimbing, debarking, and chipping costs were $11.39 per BDT (Table 5c).

<u>Mischel Brothers Bigfoot Delimber-Debarker System</u>

At the time the chip sampling study was conducted, Mischel Brothers' operation produced an average of one stud log load and 2 to 3 van loads (12.5 BDT per load) of chips per day. Approximately one-half of the log loader's time was spent merchandizing the stud logs. The operator felt he could produce 4 to 5 van loads of chips per day (56 BDT total) if no stud logs were processed. However, it appeared that felling production limited the overall productivity at the site. Therefore, delimber-debarker utilization would not have exceeded 40% to 50%, unless a second feller-buncher

Table 5a. Production costs for the Mischel Bigfoot delimber-debarker system.

Element	Cost Basis $/BDT	$/Green Ton
Loading	3.80	2.28
Delimbing-Debarking	6.36	3.81
Chipping	2.29	1.37
Totals =	$12.45	$7.46

Table 5b. Production costs for the Gibson Bigfoot delimber-debarker system.

Element	Cost Basis $/BDT	$/Green Ton
Loading	2.31	1.71
Delimbing-Debarking	4.63	3.42
Chipping	3.69	2.73
Totals =	$10.63	$7.86

Table 5c. Production costs for the Peterson Pacific/Hydro-Ax delimber-debarker system.

Element	Cost Basis $/BDT	$/Green Ton
Delimbing with Hydro-Ax	3.42	1.77
Debarking[1]	1.32	0.69
Chipping	5.37	2.77
Morbark Logger at landing	1.28	0.66
Totals =	$11.39	$5.89

[1]Estimate from operators since no information was obtainable from the manufacturer.

Note:
Production cost estimates for each system are based on general figures provided by the contractors themselves and equipment dealers. For proprietary reasons, the contractors were unable to provide precise cost information.

Table 6. Activity distribution of Edman's Hydro-Ax delimber.

Element	Time
	(Hrs.)
Productive Time :	
Processing	3.43
Traveling	0.87
Total	4.30
Non-Productive Time (Hrs.):	
Repair	0.00
Maintenance	0.18
Disturbance Delays:	
Wait for Wood	1.09
Personal	0.07
System delay1	0.73
Total	2.07
Study Period	6.37

1System delay includes waiting for skidder and other equipment to clear out of work area.

was added.

Based on a 50% utilization rate and a production rate of 5.6 BDT (9.4 green tons) per scheduled hour, the total cost for delimbing, debarking, and chipping was estimated to be $12.45/BDT (Table 5a). For comparison purposes, fixed and variable costs were calculated on the basis of an 1850 hour operating season. Normally, the debarker is only operated for about 1000 hours per season, depending on the amount of work available.

DISCUSSION

Chip Bark Content

It had originally been hypothesized that there was an inverse relationship between the average stem size and chip bark content. In general, this appeared to be true. The Gibson delimber-debarker, which worked with the largest materials, produced the lowest average chip bark content. The Peterson debarker, on the otherhand, processed the smallest stems and had the highest average chip bark content. However, regression analysis failed to find a significant relationship between the two variables. It may be that the sample size for each stem size class was not statistically sufficient to validate the relationship.

Payload stem count and the percentage of surface area missing bark (prior to debarking) were the only significant regression variables for the Edman and Gibson operations. Chip bark content decreased when the number of stems per payload was reduced or the percentage of missing bark increased. Although both operations' debarkers averaged the same number of stems per payload, the results suggest that the Peterson's debarking capabilities were more heavily influenced by this variable.

Both Gibson and Edman had relatively high missing bark figures. The missing bark values at Edman's operation reflect the degree of preliminary processing accomplished by the Hydro-Ax. The fact that this variable is a strong indicator of chip bark content for the Edman system demonstrates the importance of adequate pre-processing by the Hydro-ax. The Gibson machine's debarking capabilities were less sensitive to the missing bark variable. Dead stems, which were missing large portions of bark, made up a substantial portion of sample payload volumes. Interestingly, Gibson found that the residual bark on the dead stems was more difficult to remove than a similar portion of bark on freshly cut, green stems. This problem has been documented in the literature (Erickson, 1979).

Stem count and missing bark variables were not significant predictors of chip bark content at the Mischel Brothers operation. Mischel Brothers processed fewer stems per debarker payload than the other two operations, and had very little bark missing prior to processing. Given the low missing bark average, the Mischel Bigfoot's debarking capability was very good.

The only significant regression variable at the Mischel Brothers operation was stem size difference. As the difference in stem sizes within the debarker payload increased, chip bark content increased. Large stems tend to shield the smaller stems from chain impact forces. It is unclear why this variable was not a significant predictor at the Edman and Gibson operations.

Overall, the coefficient of multiple determination (R2) values for the bark content regression equations were low. Several factors affecting debarking quality could not be quantified. If stems were clumped rather than spread out while passing through the flails, debarking quality would suffer. Similarly, the position of individual stems, with respect to chain spacing, would have an effect. Stem characteristics such as sweep, forks, and fissures also increase debarking difficulty.

Debarker Design Considerations

Flail Design

Chain flails remove limbs and bark on impact and through a scraping action which occurs when they wrap around and slide along the stem boles. These impact and scraping forces are influenced by a number of interacting design parameters, including chain spacing, chain length, flail drum diameter, and flail drum rotational speed.

To account for the differing levels of bark adhesion between species and operating seasons, flail impact force and impact frequency must be adjustable. The Gibson Bigfoot prototype accomplished this by changing drum speeds. Mischel Brothers changed chain spacing, adding more chains per row when encountering tighter bark. Flail design must also be tailored to the range of stem sizes encountered.

To minimize wood fiber losses, the energy imparted by the chain flails should be no more than what is required to remove bark from the stem. The two Bigfoot prototypes offered an illustration of how chain flail design can affect wood loss. Mischel Brothers' machine caused a substantial amount of bole surface damage, while such damage was barely visible at the Gibson site. Although species undoubtedly played a role, the major factor contributing to this form of wood loss appeared to be flail speed. The Mischel Bigfoot flails turned at nearly twice the speed of those on Gibson's prototype. Gibson's machine, on the other hand, caused a much greater amount of bole top breakage, a factor apparently related to the chain length. The chain length on Gibson's machine was 2 to 3 times longer than that on Mischel's Bigfoot. In fact, the severe top breakage caused by the Gibson design would limit its productively in 4-5 inch DBH timber, as much of the bole wood fiber would be destroyed by the flails.

For a given chain length and flail drum diameter, the vertical spacing between a drum and the infeed deck is critical. A few months after the study, Edman modified his Peterson debarker by lowering the bottom flail drum approximately 4 inches. Originally, stems passed over this drum so closely that they were not receiving the full impact and wrap-around force of the chains. This modification seemed to improve debarking slightly.

Flail drums should be located for the easy access and removal of chains. Chains wear quickly and require frequent replacement. Depending on flail drum location, chain life averaged one to two weeks for the Mischel Bigfoot and

Edman's Peterson debarker. Gibson put new chain on his top two flail drums every two weeks. Since his lower two flail drums used shorter chain, he was able to re-use the old top-drum chains on the lower flails.

Number of Flail Drums: Two versus Four

For the first few months of operation, while working in stand and seasonal conditions similiar to those in our study, the Gibson Bigfoot prototype used only two flail drums. During this time, chip bark content averaged 1.5%, which is comparable to the study results for the Peterson debarker/Hydro-Ax delimber system. When Gibson added the two additional flails, bark content decreased by 1%.

In comparison, Weyerhaeuser's delimber-debarker achieved under a 1% chip bark content in both winter and summer conditions with just two flail drums. The fact that the Weyerhaeuser machine was processing rake-delimbed tree-length Loblolly pine may explain in part its excellent results. However, through extensive research and testing, Weyerhaeuser engineers are convinced that two properly designed flails provide enough energy to satisfactorily delimb and debark Pacific Northwest species (Hammerstad, 1987).

In light of this, both Bigfoot prototypes may be using energy inefficiently, by relying on four flails to do the work that two properly designed ones could do. Nevertheless, they debark satisfactorily.

Infeed and Outfeed Design

Several important design considerations should be incorporated into the debarker infeed deck. A long infeed deck or a tree stand should be used to support and position the stems for horizontal passage through the flails. Both Bigfoot prototypes used a tree stand, placed approximately one-third to one-half the average stem length away from the debarker infeed roller. The infeed roller of each Bigfoot machine was mounted above the infeed deck, which allowed them to spread the stems for better flail coverage. Edman's Peterson prototype used neither an infeed deck, tree stand, or an above-deck infeed roller, factors which contributed to its relatively high chip bark content. Stems were fed into the debarker at an angle until the chipper's above-deck infeed roller forced them into a horizontal plane (Figure 19). A below-deck infeed roller was used, but did little to spread the clumped stems.

Similarly, a wide infeed deck allows stems to be spread out for maximum flail coverage. Deck width dimensions depend on throughput requirements. The deck width for the Mischel Brothers machine was 2.5 feet, while that for the Weyerhaeuser prototype was 5 feet.

The debarker design should allow loosened bark to fall off before entering the chipper. Since the Peterson debarker was mounted directly to the chipper infeed deck, some of the bark loosened by the flails was carried onto the deck and into the chipper knives. The tendency of the stems

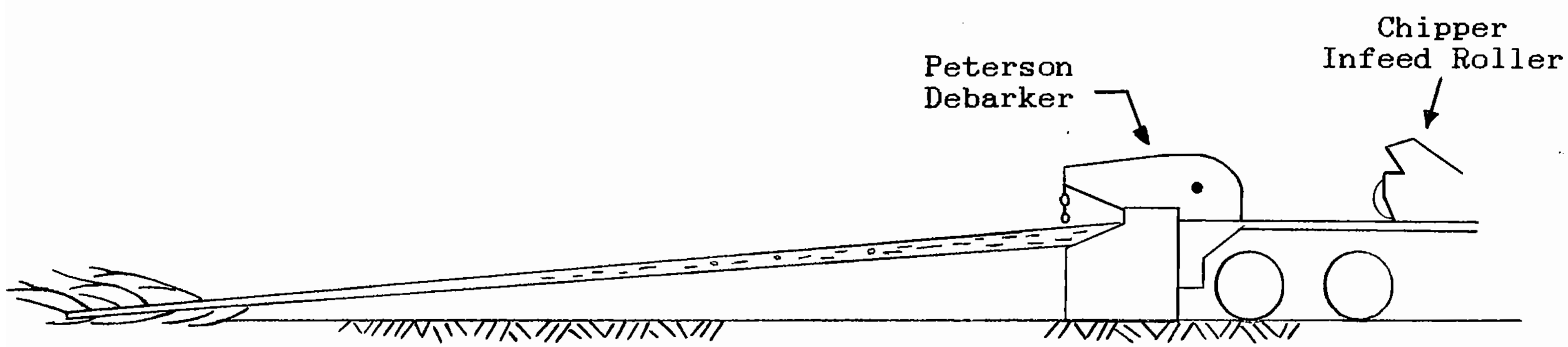


Figure 19. Peterson debarker load angle.

to clump due to poor infeed design aggravated this problem. Although some of the bark was screened out by a chip separator, a portion was blown into the vans. This isn't a problem for the two Bigfoot prototypes and the Weyerhaeuser delimber-debarker, since the debarking and chipping tools are mounted on separate units. Any loose bark which is carried out of the debarker falls off in the gap between the two machines.

Debris Handling Design

Of the devices employed by the three study debarkers, the simple hydraulic ram utilized by the Peterson machine appeared to be the most efficient at removing debris. However, it is not clear how well the ram would have worked if the Hydro-Ax hadn't pre-processed the stems.

Gibson's design used a simple drag-chain conveyor underneath the drumsets to remove limb and bark debris. This conveyor emptied into an elevating conveyor, which facilitated the piling or truck-loading of debris. Typically, an entire vanload of chips could be processed before the debris pile had to be removed. Unfortunately, the conveyor system jammed occasionally, requiring the entire debarking system to be shut down.

Mischel Brothers' Bigfoot design employed several underpowered debris conveyors to remove and pile materials from under the machine. The largest of these jammed frequently, causing much debarker downtime. Because the conveyors were relatively short, debris piles had to be removed by the skidder frequently.

Due to poor market conditions, and processing and hauling costs, none of the operations marketed debris for hog fuel. Residue processing is complicated by the need to remove chain fragments from the materials.

Production Considerations

Delimbing, debarking, and chipping costs for all three operations fell between $10.50 to $12.50 per BDT. Whole tree chipping costs would have been roughly one-half the cost per BDT. In many instances, the value of clean chips exceeds that of dirty chips by more than $30.00 per BDT. Thus, the additional value gained by delimbing and debarking greatly exceeds the additional costs incurred.

In-woods processing and chipping operations are not always practical, however. In-woods chipping requires good access, with roads negotiable by chip trucks and a staging area for van storage. Landings must be fairly flat, about one half acre in size, with enough space for piling bark and limb debris. In addition, harvest units must contain sufficient volume to minimize moving and set-up delays.

Harvest system balancing is also important. A substantial amount of productive time was lost to van scheduling (van shuttling and/or wait for van) delays at both the Edman and Gibson operations. If the van scheduling delay time could have been completely converted to productive time, Edman and Gibson would have produced an additional 2.1 and 6.5 vanloads per shift, respectively. Edman also had trouble keeping enough wood supplied to the landing. If the time Edman lost while waiting for wood could have been converted to productive time, production would have increased by an additional 4 loads per day. Overall, these utilization increases might have lowered delimbing-debarking-chipping costs to $6.68 per BDT and $6.45 per BDT, for the Edman and Gibson operations, respectively.

One method of system balancing would have been to downsize each delimber-debarker and chipper. The machines need only be large enough to handle the wood and van flow that can be supplied to them consistently. The Mischel Bigfoot system, with its much lower throughput capacity, offers an example of this approach.

An alternative way to improve delimber-debarker utilization would be to move processing operations to a central woodyard location, as Weyerhaeuser has done. Several logging operations could supply enough wood to the site to allow a large, high-throughput delimber-debarker to be used. The Gibson Bigfoot would be well suited to a central woodyard location, where it would be far easier to limit van scheduling delays. Debarker residues could easily be processed into hog fuel at the site.

While central site processing offers a number of advantages, additional handling costs are incurred. Stems must be limbed and topped to conform with state highway hauling restrictions, unless the material is hauled on privately owned roads. There is also a potential loss of recoverable bole wood fiber. The Mischel Bigfoot, for example, was able to delimb and debark stems down to a two-inch top. It may not be cost-effective to merchandise stems to such a small diameter, prior to hauling to a central debarking-chipping site.

CONCLUSIONS

The three delimber-debarker systems studied in this paper, built by relatively undercapitalized fabricators, were only approximations of what an efficient chain-flail machine should be. However, within the conditions studied, each was able to turn small, low quality stems into marketable pulp quality chips. With further design revisions, productivity and utilization could be substantially improved.

By consolidating delimbing, debarking, and topping functions, chain-flail debarkers have changed the entire cost structure of roundwood harvesting and processing operations. Pulp quality chips can be manufactured in-woods, eliminating the need to load and transport pulpwood to a central processing site.

Depending on local market and stand conditions, chain-flail delimber-debarkers have improved the profitability of intensive stand management practices. Materials which previously had little market value have become an additional source of pulp quality fiber for the pulp and paper industry.

RECOMMENDATIONS FOR FURTHER STUDY

Results from the following studies would justify their costs:

1. Assess the debarking capability of these machines in fall and winter bark conditions.

2. Look into the effects of flail design characteristics, such as chain spacing, chain length, flail drum diameter, and flail drum speed, on debarking capabilities.

3. Conduct an economic evaluation of in-woods versus central site processing with chain-flail delimber-debarkers.

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APPENDIX A

MACHINE RATE CALCULATIONS

Table	Machine
A1	Hydro-Ax Chain Flail
A2	Peterson Pacific Debarker
A3	Morbark Model 22 Chipper
A4	Morbell Logger
A5	Drott 40 Loader
A6	Mischel Bigfoot Debarker
A7	Sumner Two Knife Chipper
A8	Barko 160 Loader
A9	Gibson Bigfoot Debarker
A10	Morbark Model 23 Chipper

Table A1

Hydro-Ax Chain Flail Model 521 Machine Rate Calculation

I. **EQUIPMENT OWNERSHIP COSTS**:

Delivered equipment cost	$ 97,020
Less Salvage Value	- $ 20,000
Depreciable value	$ 77,020
Estimated life : 5 yrs. Scheduled Hours/Year (SH): 1850 hrs.	
Annual Depreciation	$ 15,404
Average Annual Investment (AAI) = $66,212	
Interest expence : (10%) * AAI	+$ 6,621
Insurance : (1.0%) * AAI	+$ 662
Annual Ownership Cost	$ 22,687
Hourly Ownership Cost =	**$ 12.26/SH**

II. **OPERATING COSTS**:

Utilization : 75%	
Fuel Costs :(3.1 gal/hr consumption * $.60/gal)	$ 1.40 /SH
Oils & Lubricants : Engine oil and lubrication ($0.52/hr.) =$0.52 Hydraulic oil :(.45 gal/hr x $3.3/gal) =$1.11	$ 1.22 /SH
Repair & Maintenance : (parts and labor)	$ 9.29 /SH
Chain costs : Cost/chain =$1.95 + $.95/bolt=$2.90 Replace 8 chains/day	$ 4.28 /SH
Hourly Operating Cost =	**$ 31.95/SH**

III. **LABOR COSTS**:
(wages, taxes, and fringe benefits) **$ 15.76/SH**

TOTAL OWNING, OPERATING, & LABOR COST = **$ 44.21/SH**

Table A2

Peterson Pacific Debarker Machine Rate Calculation

I. **EQUIPMENT OWNERSHIP COSTS**:

Delivered equipment cost	$ 75,000
Installation costs (retrofitting to chipper)	$ 3,000
Less Salvage Value (20% of Purchase Price)	- $ 15,600
Depreciable value	$ 62,400

Estimated life : 5 yrs.
Scheduled Hours/Year (SH): 1850 hrs.

Annual Depreciation	$ 12,480

Average Annual Investment (AAI) = $ 53,040

Interest expence : (14%) * AAI	+$ 7,426
Taxes, licence, insurance : (2.5%) * AAI	+$ 1,326
Annual Ownership Cost	$ 21,232

Hourly Ownership Cost = **$ 11.48/SH**

II. **OPERATING COSTS**:
Utilization: 45%

Oils & Lubricants :
Hydraulic oil :(.02 gal/hr x $3.5/gal) =$0.07 — $ .04 /SH

Flail Maintenance :
Chain Cost: $6.45 /foot
Chain replacement :
_ Put new chain on top drum every week
_ Put new chain on bottom drum every 2 wks.

Chain replacement cost :
5 links (1.08 ft.)= $7.00 /chain
30 chains/drum =$210.00 — top drum $ 2.22 /SH
bottom drum $ 1.24 /SH

Chain attachment bars :
Unit Cost : $10.30 /bar
Estimated bar life : 1 wk top, — $ 0.44 /SH
2 wks. bottom — $ 0.22 /SH

Repair & Maintenance :
(Debarker parts, labor)
50 % of depreciation — $ 1.52 /SH

Hourly Operating Cost = **$ 5.68 /SH**

TOTAL OWNING & OPERATING COST = **$ 17.16 /SH**

Table A3

Morbark Model 22 Chipper Machine Rate Calculation

I. **EQUIPMENT OWNERSHIP COSTS**:

Delivered equipment cost	$ 250,000
Less Salvage Value	- $ 97,500

Depreciable value	$ 152,500
Estimated life : 5 yrs. Scheduled Hours/Year (SH): 1850 hrs.	
Annual Depreciation	$ 30,500
Average Annual Investment (AAI) = $189,000	
Interest expence : (14%) * AAI	+$ 26,460
Taxes, licence, insurance : (2.5%) * AAI	+$ 4,725

Annual Ownership Cost	$ 61,685
Hourly Ownership Cost =	**$ 33.34/SH**

II. **OPERATING COSTS**:

Utilization : 45%

Fuel Costs :(15 gal/hr consumption * $1.00/gal)	$ 6.75 /SH
Oils & Lubricants : Engine oil :(.05 gal/hr * $4.00/gal) =$0.20 Hydraulic oil :(.01 gal/hr x $3.5/gal) =$0.04	$ .11 /SH
Repair & Maintenance : (Change knives, sharpening, parts, labor) ($1.00/ton * 214 tons/shift)	$ 12.04 /SH

Hourly Operating Cost =	**$ 18.90/SH**

III. **LABOR COSTS**:

Operator wages, taxes, and fringe benefits	$ 17.07 /SH

TOTAL OWNING, OPERATING, & LABOR COST = **$ 69.31/SH**

Table A4

Morbell Logger Machine Rate Calculation

I. **EQUIPMENT OWNERSHIP COSTS**:

Delivered equipment cost	\$ 45,000
Less Salvage Value	- \$ 9,000
Depreciable value	\$ 36,000
Estimated life : 5 yrs. Scheduled Hours/Year (SH): 1850 hrs.	
Annual Depreciation	\$ 7,200
Average Annual Investment (AAI) = \$30,600	
Interest expence : (14%) * AAI	+\$ 4,284
Insurance : (1.0%) * AAI	+\$ 306
Annual Ownership Cost	\$ 11,790
Hourly Ownership Cost =	**\$ 6.37/SH**

II. **OPERATING COSTS**:

Utilization : 35%	
Fuel Costs :(1.0 gal/hr consumption * \$.60/gal)	\$ 0.21 /SH
Oils & Lubricants : Engine oil and lubrication =\$0.03 Hydraulic oil :(.02 gal/hr x \$3.3/gal) =\$0.07	\$ 0.04 /SH
Repair & Maintenance : (parts and labor @ 50% of depreciation)	\$ 0.68 /SH
Hourly Operating Cost =	**\$ 0.93/SH**

TOTAL OWNING AND OPERATING COST = **\$ 7.30/SH**

Table A5

Drott 40 Loader Machine Rate Calculation

I. **EQUIPMENT OWNERSHIP COSTS**:

Present Worth	$ 10,000
Less Salvage Value	- $ 2,500
Depreciable value	$ 7,500

Estimated life : 5 yrs.
Scheduled Hours/Year (SH): 1400 hrs.

Annual Depreciation	$ 1,500

Average Annual Investment (AAI) = $6,000

Interest expence : (14%) * AAI	+$ 840
Taxes, licence, insurance : (2.5%) * AAI	+$ 150
Annual Ownership Cost =	$ 2490
Hourly Ownership Cost =	**$ 1.78/SH**

II. **OPERATING COSTS**:

Utilization : 65%

Fuel Costs :(2.5gal/hr consumption * $1.00/gal)	$ 1.63/SH
Oils & Lubricants : Engine oil :(.05 gal/hr * $4.00/gal) =$0.20 Hydraulic oil :(.02 gal/hr x $3.5/gal) =$0.07	$ .18/SH
Repair & Maintenance : (100% of depreciation)	$ .70/SH
Hourly Operating Cost =	**$ 2.51/SH**

III. **LABOR COSTS**:

Operator wages, taxes, and fringe benefits	$ 17.07/SH

TOTAL OWNING, OPERATING, & LABOR COST = **$ 21.36/SH**

Table A6

Mischel Brothers Bigfoot Delimber-Debarker
Machine Rate Calculation

I. **EQUIPMENT OWNERSHIP COSTS**:

Delivered equipment cost (shopbuilt)	$ 130,000
Less Salvage Value (20% of Purchase Price)	- $ 26,000
Depreciable value	$ 104,000
Estimated life : 5 yrs. Scheduled Hours/Year (SH): 1000 hrs. Ave. No. of Hrs. Worked/Day :10 hrs.	
Annual Depreciation	$ 20,800
Average Annual Investment (AAI) = $ 88,400	
Interest expence : (14%) * AAI	+$ 12,376
Taxes, licence, insurance : (2.5%) * AAI	+$ 2,210
Annual Ownership Cost	$ 35,386
Hourly Ownership Cost =	**$ 35.39/SH**

II. **OPERATING COSTS**:
Utilization = 50%

Fuel Costs :(6.6 gal/hr consumption * $1.00/gal)	$ 3.30 /SH
Oils & Lubricants : Engine oil and grease =$0.07 Hydraulic oil :(.02 gal/hr x $3.5/gal) =$0.03	$ .05 /SH
Flail Maintenance : Chain Cost: $4.00 /foot Chain replacement : _ Put new chain in center of row on 1 drum/day _ Move used to outside of rows, switch ends Chain replacement cost : 5 links (1.08 ft.)= $4.32 /chain 6 chains replaced/day	$ 2.88 /SH
Repair & Maintenance : (Debarker, conveyors, parts, labor) 50 % of depreciation	$ 10.40 /SH
Hourly Operating Cost =	**$ 16.63/SH**

TOTAL OWNING & OPERATING COST = **$ 52.02/SH**

Table A7

Sumner Two Knive Chipper Machine Rate Calculation

I. EQUIPMENT OWNERSHIP COSTS:

Present Worth	$ 15,000
Less Salvage Value	- $ 3,000
Depreciable value	$ 12,000

Estimated life : 5 yrs.
Scheduled Hours/Year (SH): 1000 HRS.

Annual Depreciation	$ 2,400

Average Annual Investment (AAI) = $10,200

Interest expence : (14%) * AAI	+$ 1,428
Taxes, licence, insurance : (2.5%) * AAI	+$ 255
Annual Ownership Cost =	$ 4,083
Hourly Ownership Cost =	**$ 4.08/SH**

II. OPERATING COSTS:

Utilization : 65%

Fuel Costs :(4.0gal/hr consumption * $1.00/gal)	$ 2.60 /SH
Oils & Lubricants : Engine oil :(.03 gal/hr * $4.00/gal) =$0.12	$ 0.08 /SH
Repair & Maintenance : (Change knives, sharpening, parts, labor) ($1.00/ton * 94 tons/shift)	$ 6.11 /SH
Hourly Operating Cost =	**$ 8.79 /SH**

TOTAL OWNING AND OPERATING COST = **$12.87/SH**

Table A8

Barko 160 Loader on Mack RL700 Carrier
Machine Rate Calculation

I. **EQUIPMENT OWNERSHIP COSTS**:

Delivered equipment cost	$ 87,500
Less Salvage Value (25% of Purchase Price)	- $ 21,875
Depreciable value	$ 65,625

Estimated life : 5 yrs.
Scheduled Hours/Year (SH): 1900 hrs.
Ave. No. of Hrs. Worked/Day : 12 hrs.

Annual Depreciation	$ 13,125
Average Annual Investment (AAI) = $ 61,250	
Interest expence : (14%) * AAI	+$ 8,575
Taxes, licence, insurance : (2.5%) * AAI	+$ 1,531
Annual Ownership Cost	$ 23,231
Hourly Ownership Cost =	**$ 12.23/SH**

II. **OPERATING COSTS**:
Utilization = 50%

Fuel Costs :(2 gal/hr consumption * $1.00/gal)	$ 1.00 /SH
Oils & Lubricants :	
Engine oil :(.02 gal/hr * $4.00/gal) =$0.08	
Hydraulic oil :(.02 gal/hr x $3.5/gal) =$0.07	$ 0.08 /SH
Grease: ($1.20/60 hrs.) =$0.02	
Repair & Maintenance : (50 % of depreciation)	$ 1.73 /SH
Hourly Operating Cost =	**$ 2.81/SH**

TOTAL OWNING & OPERATING COST = **$ 15.04/SH**

Table A9

Gibson Delimber-Debarker Machine Rate Calculation

I. **EQUIPMENT OWNERSHIP COSTS**:

Delivered equipment cost (shopbuilt)	$ 225,000
Less Salvage Value (20% of Purchase Price)	- $ 56,250

Depreciable value	$ 168,750
Estimated life : 5 yrs.	
Scheduled Hours/Year (SH): 1000 hrs.	
Ave. No. of Hrs. Worked/Day : 9 hrs.	
Annual Depreciation	$ 33,750
Average Annual Investment (AAI) = $157,500	
Interest expence : (14%) * AAI	+$ 22,050
Taxes, licence, insurance : (2.5%) * AAI	+$ 3,938

Annual Ownership Cost	$ 59,738
Hourly Ownership Cost =	**$ 31.44/SH**

II. **OPERATING COSTS**: Utilization = 50%

Fuel Costs :(14 gal/hr consumption * $1.00/gal)	$ 7.50 /SH
Oils & Lubricants :	
Engine oil and grease =$0.13	
Hydraulic oil :(.02 gal/hr x $3.5/gal) =$0.03	
	$ .08 /SH
Flail Maintenance :	
Chain Cost: $4.00 /foot	
Chain replacement :	
_ Put new chain on top drums every two weeks	
_ Put used top chain on bottom drums	
Chain replacement cost :	
15 links (2.5 ft.)= $10.00 /chain	
40 chains/drum x 2 drums =$800.00	$ 3.34 /SH
Chain attachment bars :	
Unit cost : $50.00/bar Est. bar life : 1 yr.	
No. of bars = 16	$ 0.21 /SH
Repair & Maintenance :	
(Debarker, conveyors, parts, labor) 50% dep.	$ 4.44 /SH

Hourly Operating Cost =	**$ 15.57/SH**

TOTAL OWNING & OPERATING COST = **$ 47.01/SH**

Table A10

Morbark Model 23 Chipper Machine Rate Calculation

I. **EQUIPMENT OWNERSHIP COSTS**:

Delivered equipment cost	$ 200,000
Less Salvage Value	- $ 97,500
Depreciable value	$ 102,500

Estimated life : 5 yrs.
Scheduled Hours/Year (SH): 1900 hrs.
Ave. No. of Hrs. Worked/Day :12 hrs.

Annual Depreciation	$ 20,500
Average Annual Investment (AAI) = $159,000	
Interest expence : (14%) * AAI	+$ 22,260
Taxes, licence, insurance : (2.5%) * AAI	+$ 3,975
Annual Ownership Cost	$ 46,735
Hourly Ownership Cost =	**$ 24.60/SH**

II. **OPERATING COSTS**:

Utilization : 50%

Fuel Costs :(15 gal/hr consumption * $1.00/gal)	$ 7.50 /SH
Oils & Lubricants : Engine oil :(.05 gal/hr * $4.00/gal) =$0.20 Hydraulic oil :(.01 gal/hr x $3.5/gal) =$0.04	$ .12 /SH
Repair & Maintenance : (Change knives, sharpening, parts, labor) ($1.00/green ton) Ave. 230.48 tons/day	$ 10.48 /SH
Hourly Operating Cost =	**$ 18.10/SH**

TOTAL OWNING & OPERATING COST = **$ 42.70/SH**

APPENDIX B

CHIP STRATIFICATION DATA

1. OVERALL CHIP QUALITY
2. BARK CONTENT FOR EACH FRACTION

Chip Size Stratification

The chip size distribution found when classifying samples is dependent on the chipper type, knife sharpness, stem surface damage, and the size and moisture content of the stems chipped. Overall quality is measured by the percentage of acceptable chips, which decreases as moisture content and size of the stems decrease.

Chip quality results for all three portable whole tree disc chippers were very good considering the relatively small sizes of the stems being processed. Mischel Brothers and Edman Company had very similar results, averaging 83% and 84% acceptable chips, respectively. Chip quality for Gibson Chip Company was lower, at 73% accepts, due to a low average moisture content of 29% (wet basis). The amount of dead stems and the fact that stems are felled several weeks before processing (which allows for some drying to occur) explain the low moisture content. Chipping drier wood is more difficult, and often results in more pin chips and fines being produced. Chipper knives dull faster, thus Gibson was changing knives every four van loads. Mischel and Edman changed knives every 18 to 20 van loads.

Chip quality results for Mischel Brothers, Gibson Chip Company, and Edman Company operations.

	Mischel		Gibson		Edman	
Parameter	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
	n = 39		n = 50		n = 50	
% Moisture content (Wet basis)	40.7	7.1	28.8	10.7	42.8	12.8
% Oversize	4.1	1.8	5.1	3.6	5.1	2.5
% Accepts1	83.3	3.9	73.1	6.3	84.0	3.3
% Pins	11.2	3.5	17.6	4.6	9.6	2.2
% Pans (Fines)	1.3	0.8	4.2	1.3	1.1	0.4

1 Determined using the Stalsvets Chip Size Classification Method and a Everett Metal Products Inc. classifier.

Chip bark content for each size class for Mischel, Gibson, and Edman operations.

	Mischel				Gibson				Edman			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
% Oversize	1.1	2.7	0	11.3	0.4	1.0	0	4.1	0.6	2.0	0	12.5
% Accepts	0.7	0.6	0	1.5	0.6	0.5	0	1.9	1.5	0.9	0	2.6
% Pins	2.0	1.4	0	5.7	2.0	0.9	0	8.7	4.8	3.2	0	11.8
% Pans (Fines)	17.6	8.8	1	40.0	3.1	3.5	0	10.0	28.0	11.8	5	40.0

APPENDIX C

DEBARKER PAYLOAD DISTRIBUTIONS

1. AVERAGE PIECE SIZE VS BARK CONTENT
2. STEM COUNT VS BARK CONTENT

BARK CONTENT VS. AVERAGE DIAMETER OF DEBARKER PAYLOAD

Mischel Brothers
(39 payloads sampled)

Ave. Dia.	Ave. Bark Content (%)	Std. Dev.	N
4	.85	.70	2
5	.79	.37	4
6	.62	.58	18
7	.72	.55	8
8	.43	.00	1
9	.00	.00	2
10	1.85	.00	1
11	.97	.83	2
12	.00	.00	1

Gibson Chip Company
(50 payloads sampled)

Ave. Dia.	Ave. Bark Content (%)	Std. Dev.	N
5	1.03	.61	4
6	.68	.43	16
7	.42	.42	12
8	.32	.26	6
9	.55	.57	5
10	.51	.00	1
11	.23	.01	2
12	.00	.00	1
13	--	--	--
14	.04	.00	1
15	.00	.00	1
16	.00	.00	1

Edman Company
(50 payloads sampled)

Ave. Dia.	Ave. Bark Content (%)	Std. Dev.	N
3	1.74	1.04	3
4	1.98	.68	9
5	1.74	.96	17
6	1.44	1.10	6
7	1.15	.31	8
8	.35	.44	3
9	.92	.49	4

BARK CONTENT VS. NUMBER OF STEMS/PAYLOAD

Mischel Brothers
(39 payloads sampled)

No. of Stems	Ave. Bark Content (%)	Std. Dev.	N
1	0.39	.67	5
2	0.66	.61	15
3	0.75	.54	15
4	0.70	.60	4

Gibson Chip Company
(50 payloads sampled)

No. of Stems	Ave. Bark Content (%)	Std. Dev.	N
1	0.01	.02	3
2	0.16	.13	3
3	0.48	.50	14
4	0.45	.32	16
5	0.77	.41	12
6	1.05	1.11	2

Edman Company
(50 payloads sampled)

No. of Stems	Ave. Bark Content (%)	Std. Dev.	N
1	1.21	1.46	3
2	0.98	.57	10
3	1.24	.84	13
4	1.73	.72	8
5	1.97	.79	12
6	3.07	.00	1
7	0.78	.00	1
11	2.84	.00	1
12	1.59	.00	1

from Producing Pulp

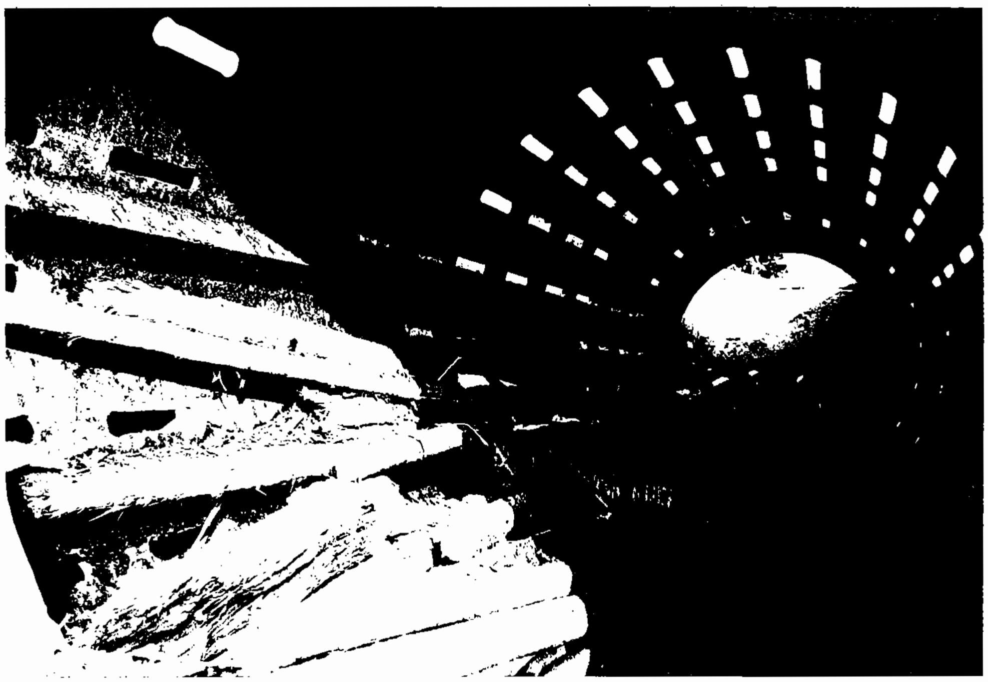

Figure 3. Price Industries portable drum debarker.

Figure 5. Mischel Brothers Bigfoot delimber-debarker.

Figure 6. Gibson Bigfoot delimber-debarker.

Figure 7. Peterson Pacific Corporation debarker.

Figure 8. Hydro-Ax chain flail delimber.