THE LIMBER JIM CASE STUDY

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Title: THE LIMBER JIM CASE STUDY: Production and Economics of Line Logging in a Thinning / Fuels Reduction Setting of Mixed Conifer Stands in the Blue Mountains of Northeastern Oregon

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Dr. Loren D. Kellogg

Forest managers in the Blue Mountains of northeastern Oregon are currently faced with vast areas of forests with health problems and high fuel loadings. These conditions resulted from a combination of insect infestations, past management practices and the elimination of fire from the local ecosystems. These forests are now overstocked, diseased and contain vast amounts of dead woody debris on the forest floor posing a serious threat of large destructive fires. This paper presents an analysis of the economics and production of using a cable system to reduce fuel loading, stand density, and minimize soil impacts.

A combined thinning and salvage logging of the larger fuels from the forest floor was completed using a single-grip harvester to process the stems into logs and a medium sized swing yarder to transport the logs to landings. This combination of equipment was not common to the area and was chosen to minimize soil impacts. There were four units designated for skyline logging. Each unit had different terrain and stocking characteristics. Two units were logged uphill, one unit was logged downhill, and one unit was relatively flat.

The harvester processed into logs all designated standing timber and any solid stems on the forest floor. A Diamond D210 swing yarder using a standing skyline, tailtrees, and intermediate supports was used to transport the logs to the landing. Production estimates

for the harvester and yarder were 19.24 tons/pmh[1] (9.33 cunits/hr) and 10.40 tons/pmh (6.48 cunits/pmh) respectively.

Total logging cost for the system (stump to mill) was $169,602. This equated to $73/ton ($115/cunit) of material removed. On a per acre basis, the cost was $2827 ($6985/hectare). Net revenue from sawlogs was $39,163.75 or $663.79 per acre. Net revenue from pulpwood was $97,785.79 or $1657.39 per acre. This resulted in a net loss of $32,653 or $544 per acre. Sawlogs represented 28.6% of the revenue, while pulpwood represented 71.4%. Gross weight from the project was 2332.69 tons with sawlogs representing 10.7% of the material removed, and pulpwood representing 89.3%. At the time of the study, pulpwood prices were $97.50/bdu[2] ($46.93/green ton) and sawlogs prices were $425/mbf. Figure 6.2 gives an indication of the range of logging costs and the percentage of sawlogs needed to breakeven at different chip prices.

The use of a skyline system in a thinning / fuels reduction setting proved not to be cost effective. Costs for a skyline system are generally higher than traditional ground based systems of logging in the area, but appears to have resulted in less soil impacts. Therefore, in areas where soil protection is the most important consideration, this logging system may be used, but careful consideration needs to be given to the percentage of sawlogs designated to be harvested, the type of equipment used, and the current market conditions or the system may operate at a loss. For this study, in order for the operation to breakeven, the percentage of sawlogs removed from the project needed to be 21.5% or higher.

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[1] pmh = productive machine hours

[2] bdu = bone dry unit See Appendix H for conversion to $/green ton.

THE LIMBER JIM CASE STUDY:

Production and Economics of a Skyline System in a Thinning / Fuels Reduction Setting of a Mixed Conifer Stand in the Blue Mountains of Northeastern Oregon

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1. INTRODUCTION

A significant forest health and wildfire risk exists on forest lands in eastern, central and southern Oregon. The risk transcends ownership boundaries, and affects both private and federal forest lands. Without action, these forests will continue to show high mortality and some will burn. The effects of the recent spruce budworm and bark beetle epidemics can be lessened through the selective salvage harvesting of damaged stands. Long term strategies for improving forest health include thinning of dense stands, providing a diverse mix of tree species that are drought tolerant and less susceptible to insects and disease, and through sound forest practices, maintain the integrity of soils and riparian areas.

The number of acres of forest land burned by wildfire in Oregon since 1970 has risen alarmingly. In just over ten years, 7 million acres of forest have been affected by bark beetles and defoliating insects. This is 25 percent of Oregon's forest land base, and 60 percent of northeast Oregon's forests. Forest health problems have contributed to this trend. Millions of acres are excessively crowded with trees. Many have a different mixture of tree species than previous forest conditions making them susceptible to insect infestations, disease and wildfire.

As a result of the thousands of acres of trees killed by insects and disease, fires have been more intense and destructive. Wildfires in these dead and dying stands may be uncontrollable, posing a significant threat to human life, homes, and property. Also at risk are forest dependent resources, such as fish and wildlife, clean air and water, soils and other essential nutrient sources. Fish and wildlife habitat, timber and other valuable forest resources, and homes on the urban fringe are either threatened or destroyed each year. And fire fighting costs and damages are typically in the millions of dollars.

Current operational and financial constraints, and many federal laws and policies, have prevented federal land managers from completing necessary thinning, salvage, prescribed burning and species selection in order to achieve forest health. Forest health is a desired condition in which the forests are resilient to disturbance and sustainable for the long term

(Henshaw, 1996). The Blue mountains of northeastern Oregon have a multitude of conditions across the landscape. Resources include wildlife, fisheries, and forest stands. How people value these conditions and resources will determine the management direction for planners. There is no question that the Blue Mountain ecosystems are disturbance based ecosystems. Through activities in the past, these disturbances have been manipulated to exclude natural disturbances, but natural disturbances are very much a part of the system. Conditions today may not be the conditions of tomorrow, but it is desired to sustain forest lands for a wide range of conditions and uses.

The vegetation must be manipulated in order to return the forests to a state where the species mix and density of the stands is more tolerant to drought and insect attacks. One of the ways to manipulate the vegetation is by thinning. Once the silvicultural objectives have been established, then a timber harvesting technique can be chosen. There are four areas of consideration that determine which harvest system is selected (Henshaw, 1996). The first one is the kind of material harvested. As the volume per piece and volume per acre increase, the cost of removal decreases. The second is topography. Gentle topography generally has a lot more options of low cost systems. However, when ecological concerns are considered, for example soil compaction or soil disturbance, a more expensive system may be chosen that is easy on the soil. The third area of consideration is transportation, and the fourth is manufacturing.

In using timber harvesting as a forest health tool, the key to a successful operation is planning (Henshaw, 1996). The planner needs to know what type of silvicultural treatment is prescribed, how the vegetation will be manipulated in order to achieve the desired result, and what type of equipment is going to be used. Each consideration should be analyzed within the context of ecologic, economic, and social issues. Ecologic issues may be concerned about soil or site disturbance which may dictate when harvesting operations should occur. Soil compaction could be an issue which may lead to choosing one piece of equipment over another. Economics could make or break a project. If a profit cannot be made, there will be no contractors willing to do the job. Timing of the operation in relation to the disturbance is critical. Recently dead material has a higher value than material that has been left on the ground for a length of time.

In terms of economics, the value of the material harvested is a major concern. The volume of the material that is taken off the site, as well as the kind of material removed is important. For instance, following a major insect attack, there is a lot of recently dead trees with relatively high product value. However, as time passes, tree value changes from a high value use as in homes to a low value product, to finally chips, or even little to no value. Therefore, timing of the harvest is an important consideration. The cost of the harvest system used is also a major concern.

From the social aspect, planners are always interested in the visuals. The visual resource is a key resource just like others such as wildlife and soils. Different harvest systems leave the forest in different visual states. If the planning area is a high use and highly visible area, then this may be the deciding factor for the choice of harvest systems. There are amenity values associated with forests and needs/demands which cannot be ignored. Communities in the Blue Mountains have for a long time sustained themselves by the processing of wood from forests and will continue to do so in the future. But as people have more recreational time, the forests are being used for more than a supply of wood fiber. These needs must be recognized and planned for in any harvest planning.

Harvest systems can be classified in several ways (Hartsough, 1996). One is by the type of transport that is used to move the material from the tree to the landing where it is loaded on a truck. Most systems used east of the Cascades are tractor (ground based) systems, where the transport machine or animal travels on the ground. A second group, cable systems, rely on yarders - machines that stay at the landing and use winches and suspended cables to lift and transport the trees. Helicopters, which make up a third category, are versatile but expensive, so they are usually not economically feasible for small trees.

Systems can also be classified by the form of material moved to the landing. A system where the tree isn't processed at all before it is moved is called a whole tree system. A system where the tops and limbs are removed before transporting the wood to roadside is called a tree length system. This is accomplished by a chainsaw or a machine after the tree is felled. This residue is then left on the forest floor while the tree length material is

yarded to the landing. With a cut to length scheme, the trees are delimbed, topped, and cut into shorter sections before being transported to roadside.

Logging systems in the Blue Mountains of northeastern Oregon have traditionally been ground based systems, either using manual felling or felling with a feller-buncher, and yarding with a grapple skidder. This type of system is relatively inexpensive but is more prone to soil disturbance and compaction impacts than other logging systems. High organic matter content and other inherent properties make Pacific Northwest forest soils generally low in bulk density, high in porosity, and low in strength. As a consequence, these soils are susceptible to compaction by tractive machines, and stand growth may be decreased from 5 to 15 percent (Froehlich, McNabb, 1983). Another type of system that could be used in place of a ground based system is a cable yarding system. Cable systems are generally more expensive to operate but have little impact on soils as the logs are either fully suspended off the ground or at least have one end suspended.

Cable systems in the Blue Mountains are rare. The Deerhorn Project (Brown, 1995) was the first to look at the feasibility of using a cable system on gentle terrain in a salvage timber sale. This study indicated that it is feasible as long as the economics are closely watched. The material in salvage operations in the Blue Mountains generally consists of low value chip material. In order for the operation to be economically feasible, there must be a certain amount of sawlog material harvested from the sale (Brown, 1995).

The Limber Jim project was a multi-disciplinary project in which ecological, economical, and social aspects were considered. Ecological aspects were concerned with soil impacts and different silvicultural treatments affecting pine marten habit. Economical aspects were studied by comparing units that were harvested with a harvester/forwarder system and units that were harvested with a harvester/skyline system. Social aspects were studied in order to understand how the public viewed mechanical harvesting systems in a fuels reduction setting. The focus of this paper is on the economics and feasibility of using a cable logging system to reduce the fuel loadings in areas where ground based systems are normally used.

2. LITERATURE REVIEW

In the area of forest operations research, alternative methods of timber harvesting are being evaluated for there economic and environmental effectiveness. One such alternative is the use of a single grip harvester and a skyline system.

Currently, there is little research dealing with costs and production of combining a single grip harvester and a small skyline system on gentle terrain to remove small wood in a thinning operation. The Deerhorn Case Study (Brown, 1995) is the most recent study involving a single grip harvester and skyline system. This study was a cooperative research project between the US Forest Service, Louisiana Pacific Corporation, Oregon State University, and the PNW Research Station. The project was on private land owned by Louisiana Pacific Corporation and was located outside of Ukiah, in the Blue Mountains of northeast Oregon. This was a pilot study to investigate the feasibility of using a single grip harvester and a skyline system on flat ground. The study suggested that a component of sawlogs was necessary in order for the operation to be economical. Past studies in thinning operations on gentle terrain have been concerned with maximizing revenue and minimizing costs. As skyline systems are generally more expensive than ground based systems (i.e., harvesters and forwarders, skidders, etc.), they are not usually considered for thinning on gentle terrain.

The only past studies that evaluated the combination of a harvester and cable yarder on similar terrain as the Limber Jim study are the Deerhorn study and a study completed in South Africa by Howe Logging, Limited (Howe, 1994). The South African study used a small Bell TH120 harvester with a single grip harvester head to process and stack 19 foot Eucalyptus grandis logs into bunches of approximately 30 logs. This represented a single turn at maximum payload (2 tons) for the 33 foot tower rigged as a multi-span standing skyline. The carriage used with the system was a "remote controlled skyline clamping, load locking carriage, able to accept snaplink connectors and tag-lines" (Howe). The study area was relatively flat with maximum slopes of 25%. Single tree intermediate

supports were rigged with the jack rigged 25 feet above the ground. Supports were spaced at 260 feet along the corridor in order to maintain lift. There were as many as five intermediate supports per skyline corridor. Each support took "one man 17 minutes to rig with the final tensioning done manually with the assistance of two other people and a 'KITO' rope shortener locking the guyline". Each skyline corridor was approximately 1600 feet long with an average lateral yarding distance of 50 feet.

The harvester felled and processed four rows of trees in a pass and created bunches of about 30 logs on top of a non-marketable tree to allow the load sling to grasp the entire bundle. All trees were removed from the unit except for the intermediate support trees which were left for use in subsequent rotations in order to increase payloads because of there larger size.

The Bell TH120 harvester produced 8.4 tons per hour including the debarking and piling of the 19 foot logs. This was half the yarding capabilities of the HOWE-LINE MK111 yarder (34.72 tons/hour) so two harvesters worked double shifts to stay ahead of the yarding operation. A Bell three wheeled logger was used to clear the deck after each load was yarded to the landing. Howe also stated that yarding road changes were kept to under an hour.

The goal of this study was to minimize soil compaction. Howe states that, "Soil disturbance in the trial areas was so minimal that Mondi Forests (private timber company) deemed it unnecessary to quantify". This was due in part to the light (4.1 lbs/in^2) harvester maneuvering on the brush mat that it created while processing logs, and the use of many intermediate support trees.

2.1 SINGLE GRIP HARVESTERS

Single grip harvesters have been used extensively in Scandinavian countries for the felling and processing of timber on gentle slopes. The technology has now gained a foothold in the Pacific Northwest as the average tree size harvested has decreased. These machines consist of a carrier, a boom, and a hydraulic operated felling and processing

head. The machine is able to fall, delimb, buck and top a tree without ever releasing it (single grip). The harvester head contains a chain saw bar to make cuts, large rollers to feed the stem through the head, sensors to measure length and diameter, and large knives to delimb branches as the stem is forced through the head.

Single grip harvesters have proven to be extremely productive at felling, delimbing, and bucking small trees less than 22 inches in diameter. They also produce end products of higher quality and more consistent dimensions than do conventional systems (Anderson, 1991). The productivity of a harvester can vary widely depending on the individual tree size, operators' skill and motivation, the size of branches, merchantable trees per unit area, slope, ground conditions, and undergrowth density (Makkonen, 1991 and Raymond, Moore, 1989). A recent compendium of mechanized harvesting research (Kellogg, Bettinger, Robe, Steffert, 1992) summarize several studies showing that harvester production is closely related to tree size. As tree size increases, there is a rapid increase in harvester production (Anon, 1978). Stand density can also have a significant effect on production. The larger the number of stems that the harvester can process before having to move, as a result of higher stand density, will increase productivity, especially in thinnings and small wood (Baumgras, 1986).

2.2 SMALL YARDERS

The second portion of the project consists of the skyline yarding. This is generally a standing skyline where one end of the skyline is anchored to a stump, and the other end is attached to the yarder. A carriage travels back and forth on the skyline bringing to the landing a turn of logs, then returning to the brush for another turn of logs. When the carriage is stopped in the brush, a line is pulled off to the side and another turn of logs is attached and yarded to the landing.

Small cable yarders have been used successfully in thinning operations on steep slopes in the Pacific Northwest for many years because their small crew size and low investment costs are well matched to the size and value of wood being extracted in thinnings. Lower

value wood can be extracted economically because owning and operating costs are significantly lower than those of larger yarders and fewer workers are required to operate the system. These machines typically have two or three drums, tower heights between 20 and 30 feet, and are usually not self propelled. Small yarders have generally been limited to areas of small timber and where cable spans are relatively short (less than 1000 feet). Recently, the abilities of these yarders have been extended with increased tower heights, line sizes and yarding capacities.

There have been several studies of these skyline thinning systems in the Pacific Northwest reporting on the economic viability (Kellogg and Olsen, 1984, Hochrien and Kellogg, 1988, and Kellogg, Olsen, Hargrave, 1986)., but few have been on gentle terrain as in the Limber Jim study.

A technique for improving the efficiency of log extraction is to prebunch the logs into easily accessed piles. This technique has been shown to improve yarding efficiency in thinnings by placing logs in skyline corridors and then swinging them to the landing in separate phases (Kellogg, 1980). Several studies have shown that yarding costs are reduced with prebunching and swing yarding (Kellogg, 1976 and Zielinsky, 1980) while others have shown no change in yarding cost or an increase in yarding costs (Hochrein and Kellogg, 1988 and Keller, 1979) depending on stand conditions and logging technique.

The harvesting system used in the Limber Jim study is similar to the systems of the prebunching studies as the harvester piles logs on either side of it's path but not necessarily in the skyline corridor. The harvesters ability to stack logs in beneficial locations for yarding will likely have a large impact on the yarders production.

3. STUDY OBJECTIVES

objective 1. Determine production rates and cost for a single grip harvester and skyline system.

objective 2. Determine costs per unit volume of wood removed and value recovered.

objective 3. Determine the amount of wood fiber recovered and the types of wood removed (i.e. pulp vs. sawlog).

objective 4. Develop a regression model for the harvester operation and the skyline operation

objective 5. Determine sensitivity of cycle times and production rates with respect to terrain.

objective 6. Identify an economic breakeven point for sawlog / pulpwood mix.

4. FIELD STUDY DESCRIPTION

In this section, the study site, logging equipment specifications, logging techniques, and data collection methods are described in detail.

4.1 STUDY SITE

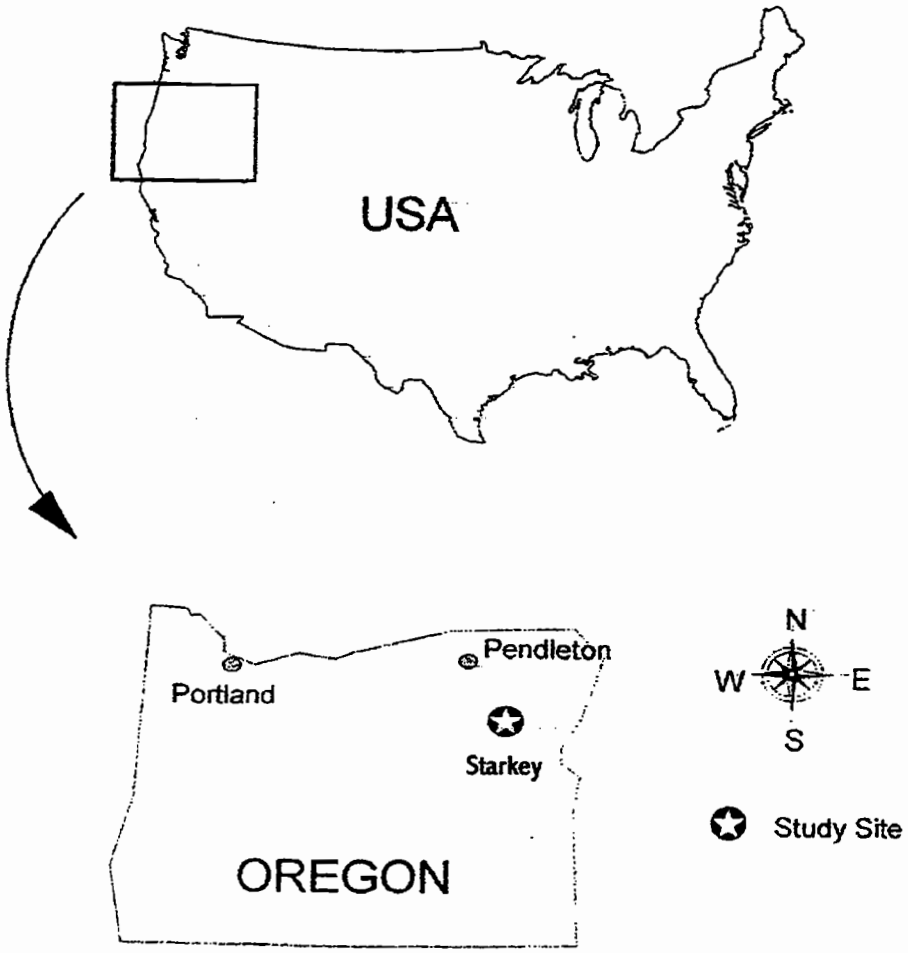


Figure 4.1 Location of Study Site

The study site was located in the Blue Mountains of northeastern Oregon (see figure 4.1) on either side of a main ridge top road which divides the Upper Grande Ronde drainage on the west from the La Grande municipal watershed on the east. The project area lies in the northeast corner of the western portion of the La Grande Ranger District, Wallowa-Whitman National Forest (T6S/T5S & R36E/R37E). The site is accessed from road 43 connecting to Ladd Canyon on the southeast, and also from road 51 connecting to the Starkey area on the northwest.

The area is currently occupied by a diverse array of mixed conifer stands, some dominated by lodgepole pine (Pinus contorta), others by grand fir (Abies grandis), western larch (Larix occidentalis), and Douglas-fir (Pseudotsuga menziseii var glauca). There is also Engelmann spruce (Picea engelmannii), and mountain hemlock (Tsuga mertensiana) scattered throughout some of the stands. Patches of lodgepole pine regeneration are interspersed with the more mature stands. Most of the mature Lodgepole pine and firs in the area were severely damaged by the mountain pine beetle (Dendroctonus ponderosae) attack in the 1970's, and by the Western spruce bud worm (Choristoneura occidentalis). These infestations resulted in substantial amounts of standing and down dead material. A mosaic of soils occupy the site, from shallow scabs to fairly deep ash soils. The Limber Jim area contains some of the highest fuel loads on the La Grande Ranger District, with many stands exhibiting class 10 fuels[3].

4.2 TREATMENT GOALS AND SILVICULTURAL PRESCRIPTION

The project was located on a ridge separating the LaGrande municipal watershed on the east from the upper Grand Ronde watershed on the west, an area of high frequency lightning strikes. The project intended to create a fuel break 1000 feet on either side of an existing ridge top road which would facilitate efforts in fighting fires in this area. The area

[3] This is a measure of how fast a fire will spread through a stand. A fire in a stand with class 10 fuels will spread at a rate of 7.9 chains per hour with a flame length of 4.8 feet (Anderson, 1982).

has been heavily damaged by insects and disease which has resulted in a significant amount of standing and down dead material.

Silvicultural prescriptions varied for each unit in order to understand how these different treatments impacted pine marten home range behavior and food base, and also, to meet the specific needs of each unit. The pine marten is a management indicator species that is known to depend on down wood for foraging and thermal refuge. Data on pine marten foraging habits and home range characteristics collected over two years will serve as a baseline against which to compare the two treatments and control during and after harvest. This will provide information on the abundance and distribution of down wood needed by pine marten to sustain viable populations (McIver, 1995). Specific unit silvicultural prescriptions are listed below.

Unit 4

All live and dead trees, standing or down, less than 15 inches DBH were harvested.

Unit 16

All live and dead lodgepole pine, standing or down, less than 15 inches DBH were harvested.

Unit 11a

All dead trees, standing or down, less than 15 inches DBH were harvested.

Unit 3

All dead trees standing or down and selectively marked standing live trees harvested.

4.2.1 *DESCRIPTION OF UNITS*

There were four units designated for skyline logging. Three of these units were matched with ground based skidding units for comparison. Two units were downhill logged, two units were relatively flat, and two units were uphill logged. A fourth unit was added to the skyline units in order to study the effects of steeper slopes on the operability of the harvester. Following is a detailed description of each unit. Stand information is from a U.S.F.S. timber cruise in 1995 prior to harvest and are for all tree species (table 4.1).

Table 4.1 Summary of Unit Statistics[4]

Unit #	Acres	Uphill Downhill	Ave Slope (%)	Merch trees/ac	Basal area/ac	Ave dbh (inches)	Ave ht (feet)	Fuel tons/acre	Standing Vol mbf/acre
4	13	D	-12	96.2	86	10.8	81.6	53.6	13.2
11a	23	flat	2	166.7	118	11.4	76.9	35.7	17.9
16	6.5	U	12	107.9	52.9	9.5	70.1	46.1	7.6
3	8	U	30	N/A	N/A	N/A	N/A	N/A	N/A

Unit 4

Unit 4 had a north aspect and was located at an elevation of approximately 5200 feet. The overstory consisted predominately of Western larch and Douglas-fir. There was very little understory except in the upper southern corner which was mostly larch and Douglas-fir. Skyline corridors were laid out in a parallel pattern except at each end of the unit where a radial pattern was used in order to reach the corners along the road. Only one

[4] Merchantable is defined as a tree with a diameter at breast height greater than 5 inches. N/A means this information is not available.

corridor needed an intermediate support. All corridors used tail trees rigged between 30 and 50 feet. The average external yarding distance was 541 feet.

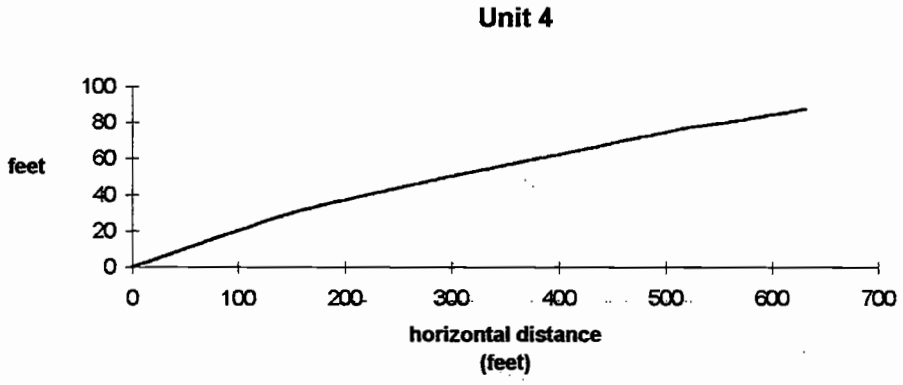


Figure 4.2 Ground profile of unit 4 with the landing at the origin

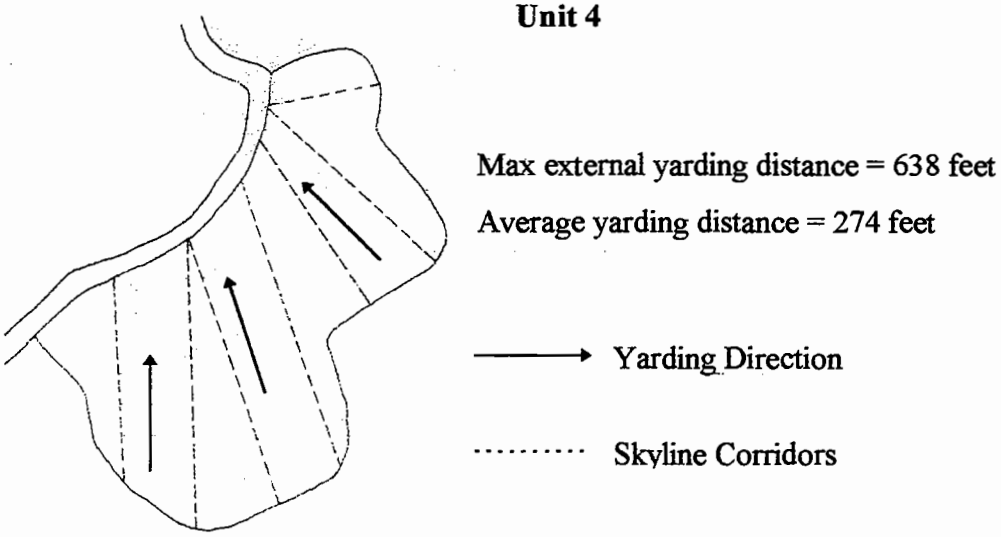


Figure 4.3 Diagram of unit 4

Unit 11a

The dominant overstory in unit 11a was Western larch with some Douglas-fir and a large understory component of Lodgepole pine. This unit was mostly flat with a slight northerly aspect located at an elevation of 6000 feet. A parallel skyline pattern was used with tail trees and intermediate supports on all corridors.

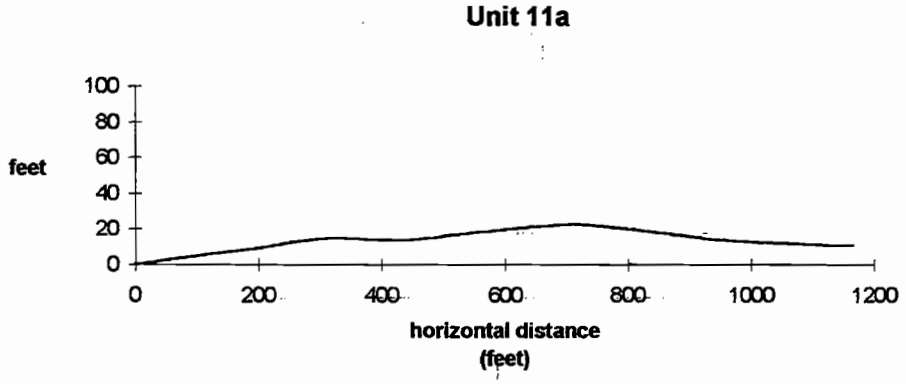


Figure 4.4 Ground profile of unit 11a with landing at origin

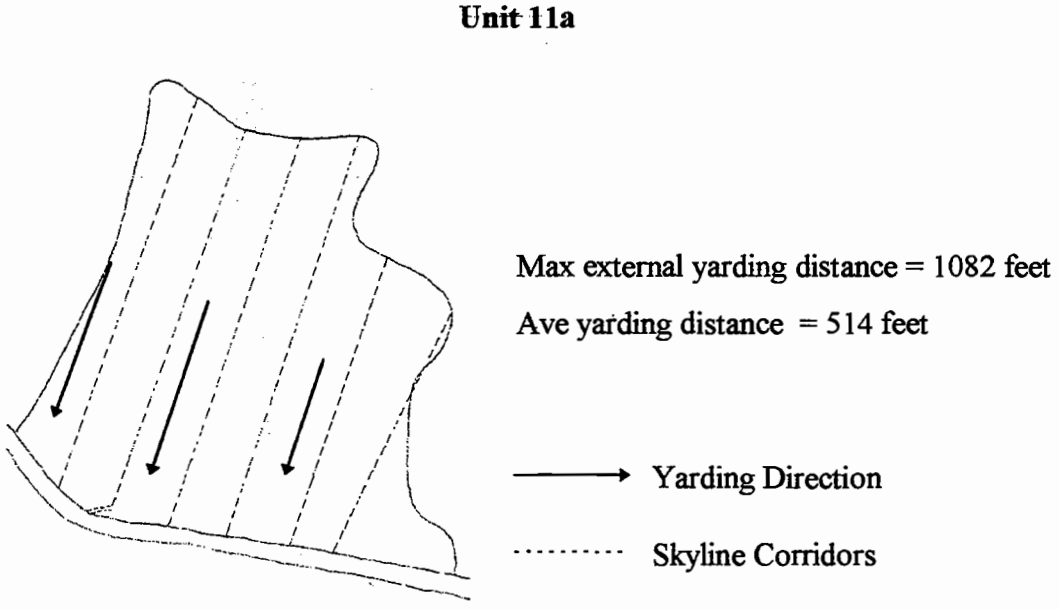


Figure 4.5 Diagram of unit 11a

Unit 16

The dominant overstory was western larch with a co-dominant component of lodgepole pine. There was some regeneration of lodgepole pine scattered throughout the unit. The aspect was northerly at an elevation of 6000 feet. A radial skyline pattern was used with tail trees but no intermediate supports. Tail trees were rigged at 40 to 50 feet.

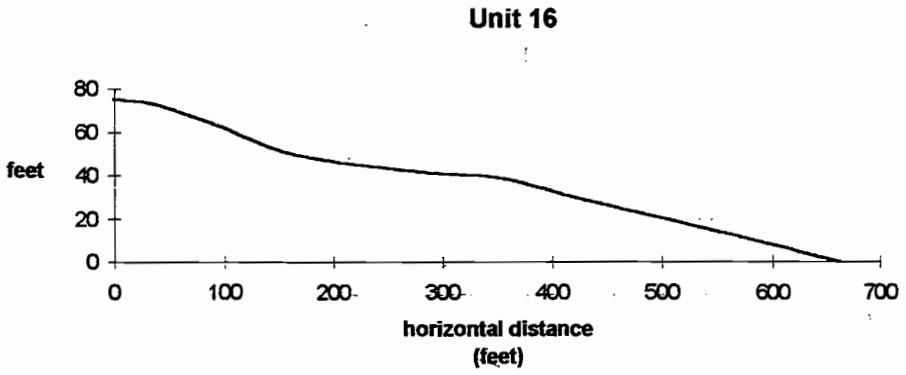


Figure 4.6 Ground profile of unit 16 with landing at left

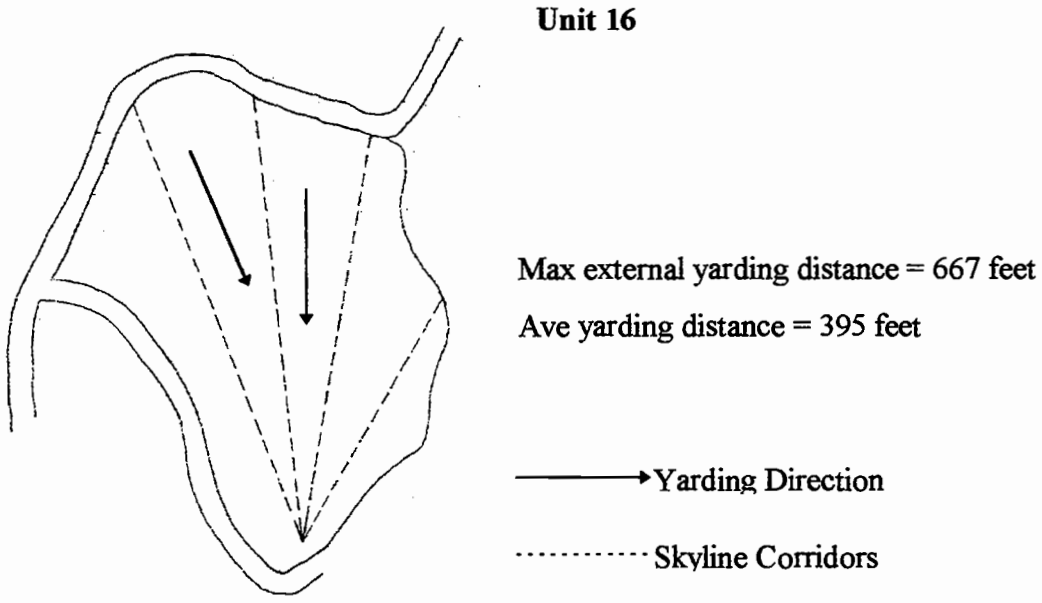


Figure 4.7 Diagram of unit 16

Unit 3

Unit 3 was predominately Douglas-fir and lodgepole pine with very little understory. The aspect was west at an elevation of 5900 feet. A parallel skyline pattern was used with tail trees rigged at 40 feet. No intermediate supports were needed.

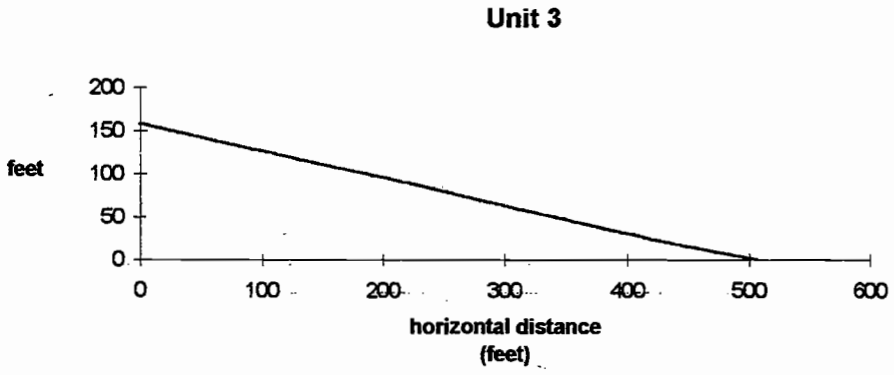
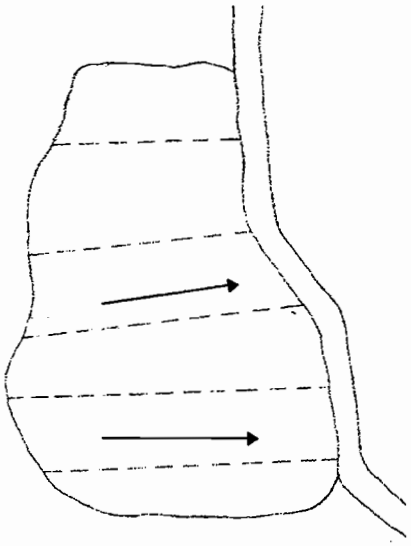


Figure 4.8 Ground profile of unit 3 with landing at left



Unit 3

Max external yarding distance = 531 feet

Ave yarding distance = 213 feet

Yarding Direction

Skyline Corridors

Figure 4.9 Diagram of unit 3

4.3 LOGGING LAYOUT AND PLANNING

The initial planning and layout of the timber harvest units was done by USFS personnel from the LaGrande Ranger District, Wallowa - Whitman National Forest, and the Pacific Northwest Research Station in Seattle. This included posting of unit boundaries, marking trees for harvest, fuel loading inventories, and stand inventories. The layout work for the yarding operation was completed by the contract logger. All skyline corridors, intermediate supports (see figure 4.10), and tail trees (see figure 4.11) were flagged prior to any harvesting operations. Landings were located first, then a tentative corridor was flagged. If tail trees and intermediate supports were available with this location, then the corridor was accepted and the flagging completed. If tail trees and intermediate supports were not available, then the location was adjusted and the flagging process repeated. Because of the scarcity of suitable tail trees and intermediate supports, most skyline corridor locations were adjusted more than once. Tail trees were not topped and were rigged at a height of 40 to 60 feet. Only one intermediate support was topped. This tree was close to the landing and presented a safety concern. Intermediate support jack heights were rigged at approximately 30 feet.

4.3.1 *DESCRIPTION OF LOGGING SYSTEM*

All units used a Diamond D210 swing yarder with a standing skyline and an Eaglet motorized carriage. A John Deere hydraulic loader was used on the landings to keep the chute clean and help feed logs into the chipper. A Moorbark 27 inch chipper was used on the landing to chip logs and blow the chips directly into chip trucks. These chip trucks then shuttled the chip vans approximately 10 miles to the paved highway where another truck would haul the chip van to town. This chip van shuttling was performed because only a few trucks were equipped to handle the curvy, steep logging roads. A Hitachi

EX200LC with a Keto 500 single grip harvesting head was used to do the harvesting in all units. No road construction was needed as all units were logged to an existing road.

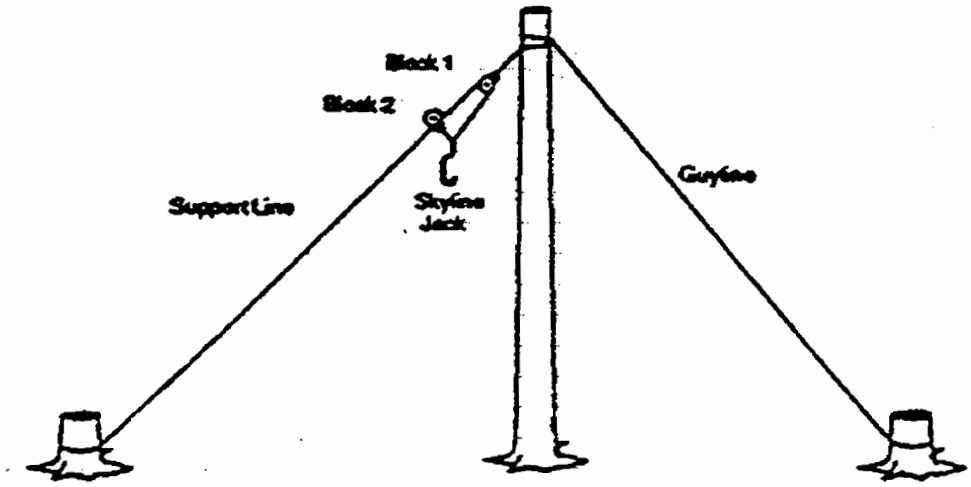


Figure 4.10 Single tree intermediate support used on project

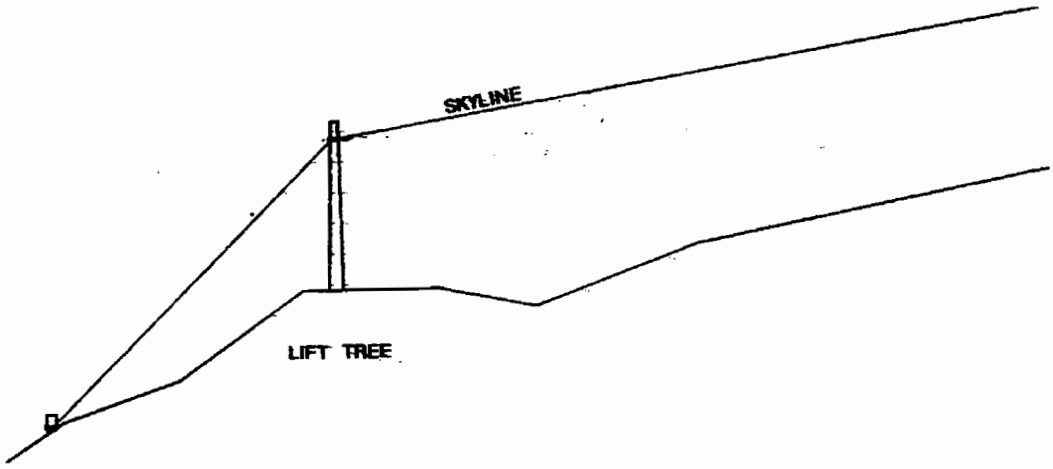


Figure 4.11 Diagram of typical tail tree (lift tree) used on project

4.4 LOGGING EQUIPMENT SPECIFICATIONS AND OPERATIONS[5]

The logging was contracted to Skyline Thinning Company of Springfield, Oregon. The harvesting was contracted to Bill Corley from Pendelton, Oregon. All crew members and logging equipment were supplied by the contractors. Trucking was supplied by the purchaser, Masonite Corp.

The logging contractor used a Diamond D210 swing yarder with an Eaglet carriage and a John Deere 690 hydraulic loader. The contractor had over 20 years cable logging experience in Oregon and Alaska, but this was the first time he had logged in eastern Oregon. The crew was experienced with logging on the west side of the Cascade mountains in thinnings and clearcuts, but was not familiar with logging in northeastern Oregon. The Diamond yarder was a relatively new piece of equipment and the crew and yarder had been together for about 18 months. The crew had past experience with this type of yarder and were accustomed to logging with this type of equipment. Generally, the crew was very experienced with cable logging.

The harvesting was done with a Hitachi EX200LC equipped with a Keto 500 single grip harvesting head. The operator was local and had owned and operated this piece of equipment in the area for the past five years. He was very experienced with harvesting in this type of timber but had never cut for a cable yarding system. Due to the time constraints for this project, an identical harvester was moved in to help finish the project by the deadline. All studies were done with the contract owner / operator.

[5] The mention of a specific brand of equipement does not indicate an endorsement.

4.4.1 *HARVESTER EQUIPMENT AND OPERATION*

Equipment Specifications

1992 Single Grip Harvester with Keto 500 harvesting head

-Hitachi EX200LC track mounted

-Keto 500 head

-3 feed rollers

-chainsaw bar for bucking

-computerized length measurements and piece counts

Equipment Operation

The harvester operation consisted of making parallel passes throughout the unit (see figure 4.12). The harvesting operation started with first cutting the yarding corridor. As the harvester worked it's way down the corridor, stems were processed and pilled in bunches on either side of the corridor (see figure 4.13). When this corridor was cut, the harvester would move approximately 60 feet to the next cutting path which was between yarding corridors. Yarding corridors were spaced approximately 150 feet apart. Therefore, the harvester had to make a pass between each yarding corridor.

The processing operation started when a standing tree was grabbed with the harvester head or a down tree was picked off the ground. The stem was then feed through the head while being delimbed, and was bucked to the proper lengths. The slash from the processing operation was deposited in the path of the harvester. When all the trees that could be reached from one spot were processed, the harvester moved ahead and started the cycle again.

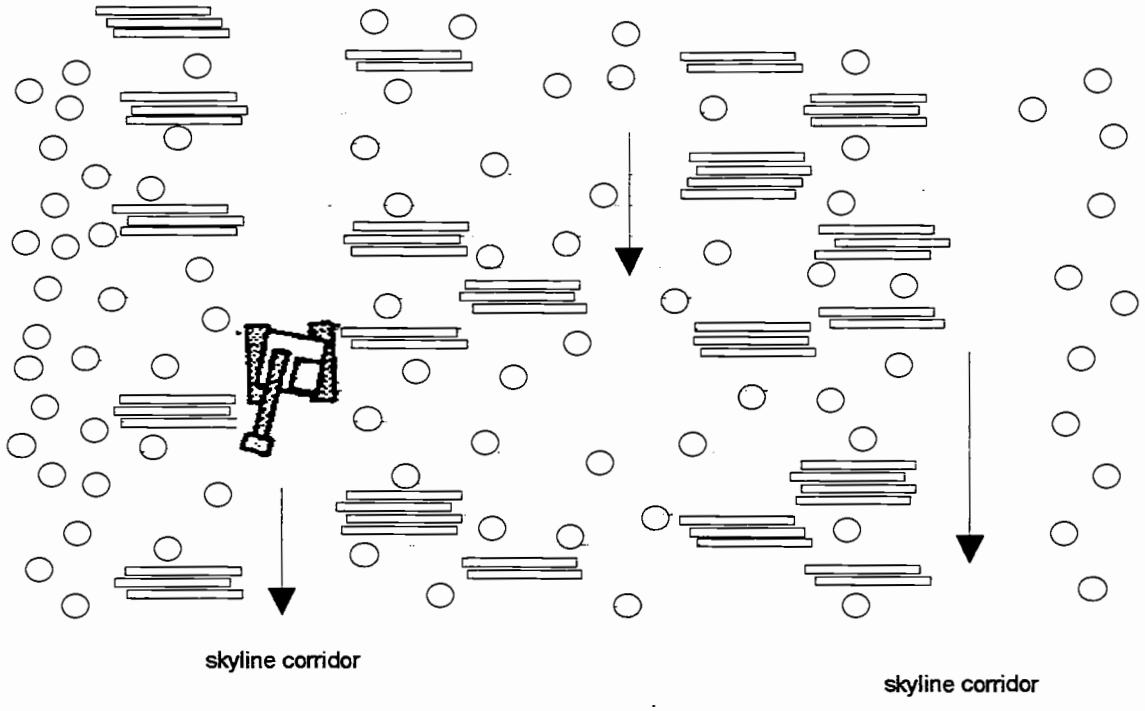


Figure 4.12 Diagram of harvester operation and direction of travel

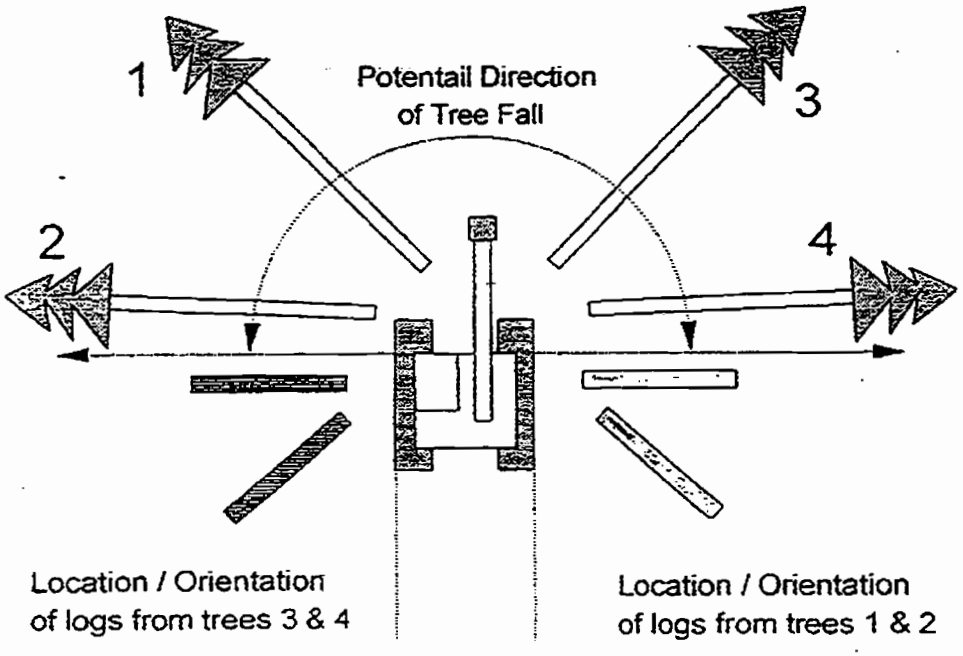


Figure 4.13 Typical orientation of harvested logs

4.4.2 *YARDER EQUIPMENT AND OPERATION*

Equipment Specifications

Diamond D210 Swing Yarder

Line Capacities

Skyline - 2000 feet of ¾ inch line

1550 feet of 7/8 inch line

Mainline - 1800 feet of 5/8 inch line

Haulback - 3100 feet of 7/16 inch line

Strawline - 3600 feet of 5/16 inch line

Guylines - three guyline drums with 100 feet of 7/8 inch line each

Working Tower Height - 42 feet

Eagle Eaglet Carriage

Radio controlled

Mechanical slack-pulling of mainline when clamped to skyline

9 horsepower diesel engine

Capable of passing over multi-span support jacks

Weight - 1200 lbs.

Two intermediate support jacks

John Deere 690 Loader

Track mounted

Uses hydraulic grapple combined with a heel boom

Miscellaneous Equipment Used With Yarding Operation

Crew pick-up Ford F-350 crew cab

Owner pick-up Ford F250 Silverado

Miscellaneous fire equipment (shovels, water backpacks, ploaski's, etc.)

2 Stihl 064 chainsaws

Climbing gear

Intermediate support rigging (straps, blocks, guylines)

Equipment Operation

Logs were yarded to the landing where they were either feed into a chipper or decked, depending if they were pulp logs or sawlogs. The loader worked in conjunction with the yarding to keep the landing chute clear. Chip hauling was not able to keep up with the yarding, therefore, there was usually a large deck of chip logs on the landing.

The cable system was rigged as a standing skyline system that utilized tailtrees (see figure 4.11) and intermediate supports (see figure 4.10) when needed to create multiple spans. A haulback line was used when yarding downhill or on flat terrain. The movement of the carriage along the skyline was controlled by the yarding engineer but all other carriage functions were controlled by the rigging slinger out in the unit.

A typical yarding cycle started with the engineer sending the carriage out into the unit and stopping its movement on a signal from the rigging slinger. Once the carriage was stopped, the load hook was lowered by radio controlled mechanical slackpulling (in the carriage) and then the chokers were removed so that the choker setters could preset the next turn on the opposite side of the corridor from the current turn. The rigging slinger took the load hook and fed it through the ring on the end of each preset choker as the carriage pulled the mainline off the yarder. Once everyone was in the clear, the yarding engineer was signaled to pull in on the mainline. When the load reached the carriage, the proper signal to release the skyline brake was sent to the carriage and the load then progressed toward the landing. The chaser was responsible for unhooking the turn.

There were six men working in this phase of the operation: a yarding engineer, a choker setter, a rigging slinger, a hook tender, and a loader operator. Usually, the hook tender was free to pre-rig future skyline corridors.

4.4.3 *CHIPPER EQUIPMENT AND OPERATION*

Equipment Specifications

Moor-Bark 27 inch disk chipper

Hydraulic boom

Table feed

Equipment Operation

Chipping operations were conducted simultaneously with the yarding operation if chip trucks were available. Each turn of logs was sorted by the loader into pulp or sawlogs. Chip logs were then fed directly into the chipper and blown into a waiting chip truck. If chip trucks were not available, the logs were decked until the next available truck arrived.

4.5 DATA COLLECTION METHODS

Data was collected by three methods: shift level, time studies, and truck tickets. Shift level data was collected daily by the logging contractors and provided the daily truck tickets, production, and hours worked for that shift. Truck tickets provided information on the amount of wood that was removed from each unit and whether the wood was pulpwood or sawlogs. Pulpwood logs were all logs that were down, dead, or showed any defects. Sawlogs were sound logs with a minimum small end diameter of 6 inches and a preferred length of 32 feet. Any delays and equipment breakdowns were also recorded.

Production rates for the equipment are provided per scheduled machine hour (SMH) and productive machine hour (PMH). Scheduled machine hours are those hours scheduled for that days shift. Productive machine hours are the scheduled machine hours minus any delays. Productive machine hours give an estimate of what the machine could produce if run with no delays.

Harvester time study statistics are given in table 5.6. Diameters at breast height (dbh) were measured for all standing trees in the time study plots. Diameters for down material was estimated. Tree heights are for standing trees in time study plots only. Total time does not include move time. Four 1/10 acre study plots were established in each unit. They were placed in the skyline corridors and spaced throughout the unit in a manner to cover any variations within that unit. Tree heights, tree diameters at breast height, number of standing trees within the plot, and fuel loading greater than 2 inches was measured in each plot. Fuel loading was measured by establishing a transect line in a random direction and measuring all the pieces greater than 2 inches that this line intersected, then calculating tons per acre by using Brown's equation for inventorying downed woody material (Brown, J., 1974) (see Appendix H for actual equation).

Time study data for the yarder and harvester was collected by one field personnel using a hand held Husky Hunter Data Collector with SIWORKS software. Time elements were recorded in centi-minutes. Data was later downloaded into a PC. This data provided information on yarding and harvesting cycle times and variables that affected these times.

There were six areas of data collection:

1. Layout and logging planning
2. Yarding operations
3. Harvester operations
4. Chipping operations
5. Loader operations
6. Types of products removed (i.e. sawlogs or pulplogs)

Each of these areas required a different combination of study types in order to acquire the desired information. The specifics of these studies are outlined in the following sections.

4.5.1 *LAYOUT AND LOGGING PLANNING*

Information on the layout and logging planning for this project was collected on a shift level form that was completed daily by the contractor. The form collected person hours spent doing layout or logging planning each day.

For this study, logging layout included the design and field work associated with identifying road locations, landings, skyline corridors, intermediate supports, and tailtrees (see unit maps in unit description section). The contract logger was responsible for all the layout and planning. The location of boundaries and the marking of the standing trees to be removed was not included in this study as this work was already completed by the US Forest Service prior to the start of this project. The objective of this portion of the data collection was to quantify total hours spent performing logging layout and planning so that a cost could be assigned to this activity.

4.5.2 *HARVESTER OPERATIONS*

Two types of studies were used to collect data on the harvester. A shift level form was used to collect daily production and a description of the shift's activities. A time study was used to collect data on cycle times in order to determine if the variability between units affected the harvester operation and also to develop a regression equation.

The shift level study required the harvester operator to fill out a form each day to record the following information (a copy of this form can be found in Appendix A):

1. Unit being felled and processed
2. Shift date, start, end, and break times
3. Name of operator
4. Production (number of logs and stems produced as counted by the harvesters on-board computer)
5. Delay time (time > 10 minutes when not actively processing trees)

6. Time spent on regular daily maintenance

Hours worked proved to be the most useful information obtained from this particular study because they were used to calculate the cost of harvesting in conjunction with the harvester's cost per scheduled machine hour. The production information turned out to be less useful because the number of logs produced each shift, provided by the on board computer, was somewhat questionable. The figures seemed too low when compared to the rest of the study information. The on-board computer counted the number of saw cuts. Consequently, if the last log from a tree being processed was not bucked, it was not counted. The production information used from the shift level data was used as a comparison against information from the time studies and from the final volume summaries supplied by the timber sale purchaser.

The time study data performed on the harvester proved to be very valuable for describing the actual production and the type of material that was processed (see figure 5.1).

The harvester time study elements were swing, fell, process, and move:

1. Swing (new cycle) started at end of processing.
2. Swing ended when either the saw started on a standing tree or the harvester head hit the ground when reaching for a piece of down material.
3. Felling ended when the top of the tree hit the ground, or if the piece was on the ground, then there was no felling time.
4. Process ended when the last log was bucked from the stem
5. Move started and ended with track movement to new work spot (minor moves during swing, process, or felling were not counted as moves.

The following tree classes were recorded in the time study:

1. Standing live
2. Standing dead
3. Down dead
4. Multiple trees processed at one time

Tree height and diameter were also recorded for numbered trees in each study plot. Diameters were estimated for down material. There were no tree heights recorded for down trees.

The delay codes used in the harvester time study were mechanical, personal, external, and other. A code was also used to reject an observation.

4.5.3 *YARDER OPERATIONS*

Two types of data were collected on the yarding operations: shift level data, and time study data. This information was used to determine the production and cost of the yarding operation. A shift level form was completed by the yarding engineer at the end of each shift that reflected the activities of the yarding crew for that day (see Appendix A for sample shift level form). The yarder engineer also had two mechanical counters which were used to count the number of logs in each turn and the number of turns. Many times, the number of logs was an estimate because there were more logs than could be counted in the available time before the carriage outhaul was started.

The time study also collected data on the number of logs per turn and this was compared with the number of logs counted by the yarder engineer. The piece count (logs) was later converted to volumes using the average piece size determined for the unit. Average piece size was determined by randomly measuring logs throughout the unit and converting these measurements to cubic feet. The location of the day's yarding was also recorded by entering the skyline road(s) number that was yarded that day. This information was collected to allocate a day's yarding production to a particular skyline corridor in the setting. Time study data was collected on the yarding cycle in order to quantify the time spent on each segment of the production cycle with the intent of producing a predictive regression equation

Information collected on the shift level forms included:

1. Treatment unit being yarded
2. Shift date, start, end and break time
3. Number of hours each crew member worked
4. The days production (# of logs yarded, # of turns)
5. Delays greater than 10 minutes
6. Time spent on skyline road changes
7. Comments to help explain the days yarding production

Yarder time study elements are listed below:

1. Outhaul - Began when carriage left landing, ended when carriage was stopped at location of turn
2. Drop - Began when outhaul ended, ended when rigging slinger had the load hook and the chokers had been taken off
3. Lateral out - Began when drop ended, ended when the mainline toggle was placed through the choker ring on the first preset log
4. Hook - Began when lateral out ended, ended when the rigging slinger blew the go ahead whistle to the yarding engineer
5. Lateral in - Began when hook ended, ended when the load reached the carriage and the whistle was blown to release the skyline brake
6. Inhaul - Began when lateral in ended, ended when the carriage reached the landing and the whistle was blown to drop the logs
7. Unhook - Began when inhaul ended, ended when carriage left the landing for another turn

The yarder time study variables included:

1. Number of logs in each turn
2. Number of chokers used in each turn
3. Number of choker setters

4. Yarding distance - distance was estimated from the landing to where the carriage was stopped on the skyline (nearest 10 ft.). Prior to yarding, distances from the landing were measured and marked at 100 foot intervals along the skyline corridor to aid in the estimation of distances
5. Lateral yarding distance - distance was estimated as a straight line distance from the point where the furthest log in the turn lay to where the carriage sat on the skyline (nearest 5 ft.).
6. Height of skyline - this was estimated from the ground to the skyline (nearest 5 ft.).
7. Delay time - This was when the normal yarding operation stopped. Activities such as resetting chokers or repositioning the carriage were considered to be part of the normal yarding operations and were not recorded as delays.

Delay codes for the yarder time study were mechanical, personal, external, and other. Skyline road change times were also collected by the yarding engineer and the field personnel. Road change times started when the skyline was lowered to the ground and ended when it was up and ready for yarding on the next skyline road.

4.5.4 *LOADER OPERATIONS*

As production estimates for the loader were not within the scope of this study, it was only necessary to keep track of the loader's working hours to obtain a cost estimate. The length of the shift, break times, and any delays that occurred during the shift were recorded on a shift level form that was filled out by the operator at the end of each day.

4.5.5 *CHIPPER OPERATIONS*

All chip material was chipped on the landing and loaded directly into chip vans. The number of logs that were processed per chip van were randomly counted and an average was used for the entire project. It was desired to combine this data for the forwarder and skyline units. In order to do this, the number of logs per load was converted to linear feet per load by using the average log lengths from the forwarder units and the average log lengths from the skyline units (see following discussion). This was done because of the shorter log lengths required on the forwarder units. Truck weights (in green tons) for each load were supplied by Masonite Corporation and this information was used to convert to cunits.

4.5.6 *HARVESTED TIMBER*

Volume and other descriptive measures of the timber removed from the site were obtained from the harvester's time study data and from the final volume summaries. Two types of material were removed from the site: sawlogs, and chips. Chip vans were weight scaled and all sawlog loads were rolled out and scaled. Sawlog information was measured in gross mbf, net mbf, and tons per load. Chip van weights were converted to ft^3 by multiplying linear feet per load times cubic feet per linear foot. A conversion factor supplied by the La Grande Ranger District of 1.92 cunits per mbf was used to convert to cubic volume. Species and grade information was not available.

4.6 EQUIPMENT OWNING, OPERATING, AND LABOR COSTS

Hourly costs for the harvesting, yarding and chipping equipment were determined using computer software called PACE (Production and Cost Evaluation) developed at Oregon state University. This hourly rate is comprised of three parts:

1. Cost of Ownership - Depreciation, interest, taxes, licenses and Insurance
2. Cost of Operation - Fuel, lubricants, repair and maintenance, etc.
3. Cost of Labor - Hourly wage, fringe and burden factor, supervision

Labor rates used in the calculations came from 1996/1997 Oregon Loggers Association statistics. The other inputs used to determine the equipment costs can be found with a summary of the owning and operation costs in Appendix C. The equations internal to the PACE program that were used to calculate the owning and operating costs can also be found in Appendix B.

5. RESULTS

Results are based on the data collected by the methods described in Data Collection Methods (section 4.5). For conversion information, see Appendix H.

5.1 DESCRIPTION OF WOOD MATERIAL OBTAINED FROM PROJECT

Table 5.1 give the gross volumes in tons removed from each unit and the total tons removed from the entire project. Table 5.2 give the gross volumes from the project converted to other units of measurement. Table 5.3 gives the average log description for the entire project. Table 5.4 gives the type of material removed from the project with the contract prices and the revenue generated from each product type.

Table 5.1 Gross tons by sort removed from each unit

	Unit 4	Unit 11a	Unit 16	Unit 3	Total
Pulpwood	532.72	787.26	459.14	304.65	2083.77
Sawlogs	0	242.71	0	6.21	248.92
Project Total	532.72	1029.97	459.14	310.86	2332.69

Table 5.2 Gross volumes removed from project

	Pieces/Load	Cunits	Mbf	Tons	m^3
Sawlogs	101	176.93	92.15	248.92	5.01
Pulpwood	245	1477.14	769.34	2083.77	4180.30

Table 5.3 Average log description[6]

	Ave Dia (small end)	Ave Length	Ave Ft^3/log	Ave Bdft/log	Ave Tons/log	Ave m^3/log
Sawlogs	N/A	N/A	0.18	48.86	0.25	0.00
Pulpwood	N/A	N/A	5.29	19.59	0.08	0.16
All logs	4.88	23.02	2.73	34.23	0.16	0.08

The minimum small end diameter for sawlogs was 6 inches with a preferred length of 32 feet. There were no preferred lengths for pulpwood logs which were cut to lengths convenient for the harvester operator.

[6] Average bf/log for sawlogs is from scaled loads. Average bf/log for pulpwood is from log measurements.

The harvester's time study sampling provided an estimate of the proportion of dead material vs. live material that was removed from the site (Figure 5.1). This is only an estimate based on the material that the harvester processed. The actual proportion of dead vs. live material removed from the site may be slightly different depending on the amount of harvested material removed.

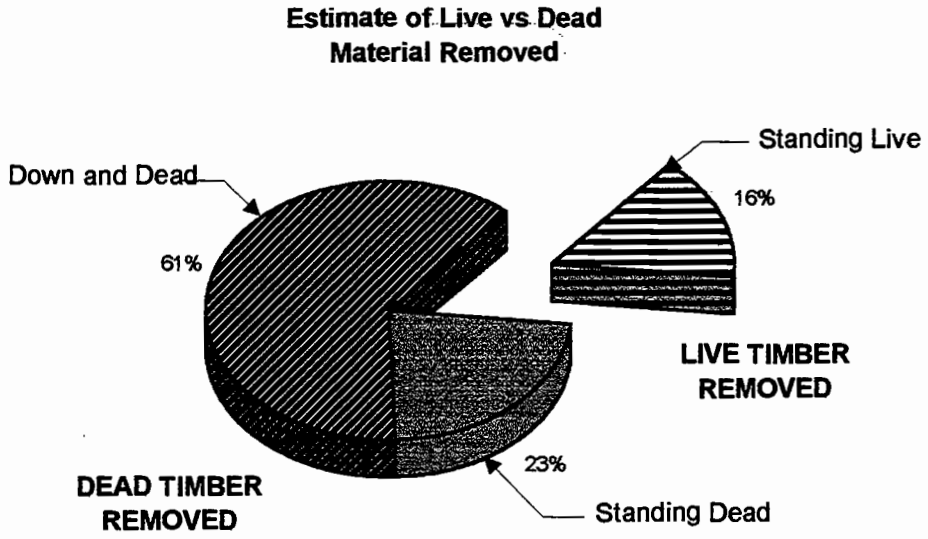


Figure 5.1 Harvested material felled and/or processed by the harvester

Table 5.4 Product type and value removed from project[7]

Product	Amount	Price	Gross Revenue
Sawlogs	92.15 mbf	$ 425.00 /mbf	$ 39,163.75
Pulpwood	1002.93 BDU	$ 97.50 /BDU	$ 97,785.68
Total Gross Revenue			$ 136,949.43

[7] Average moisture content for the entire project was 73.14% which converts $97.50/BDU to $46.93/green ton (see Appendix H).

5.2 EQUIPMENT PRODUCTION RATES

The production rates reported in this section represent an average for logging all four units. Production for each unit can be found in Tables 5.5 and 5.9. Figure 5.2 depicts the harvester's daily production and indicates very little correlation between production at the start of the project and at the end of the project. Scheduled machine hours (smh) are those hours that the equipment was scheduled to work. Productive machine hours (pmh) are the scheduled machine hours minus delays (1-%delays).

5.2.1 *HARVESTER PRODUCTION RATES*

Harvester production rates are based on shift level data and time study data. Shift level data provided accurate information for scheduled machine hours. The time study data was used to determine production per productive machine hour, while the actual volumes removed from the project were used to calculate rates per scheduled machine hour.

Stems and logs per productive machine hour were calculated from time study data, then a utilization rate of 66.83% was used to calculate stems per scheduled machine hour. Cubic feet per hour was converted from logs per hour. Board feet per hour was converted from ft^3 per hour. Tons per scheduled machine hour were calculated using scheduled machine hours from shift level data and actual tons removed from the project. Tons per productive machine hour were converted from tons per scheduled machine hours using the utilization rate. Cubic meters per hour were converted from ft^3 per hour.

Table 5.5 Harvester production rates for each unit and all units combined

		Stems/hr	Logs/hr	Ft^3/hr	Bf/hr	Tons/hr	m^3/hr
Unit 3	Scheduled Hours	79.67	109.27	578.06	3010.71	11.58	16.36
	Productive Hours	119.21	163.51	864.94	4504.89	17.33	24.48
Unit 4	Scheduled Hours	85.01	146.47	774.81	4035.45	5.88	21.93
	Productive Hours	127.20	219.16	1159.34	6038.20	8.80	32.81
Unit 11a	Scheduled Hours	65.07	96.39	509.89	2655.66	12.40	14.43
	Productive Hours	97.36	144.22	762.94	3973.64	18.55	21.59
Unit 16	Scheduled Hours	93.88	150.68	797.11	4151.59	16.01	22.56
	Productive Hours	140.47	225.46	1192.71	6211.97	23.96	33.75
All Units	Scheduled Hours	78.59	117.89	623.62	3247.98	12.86	17.65
	Productive Hours	117.59	176.39	933.11	4859.91	19.24	26.41

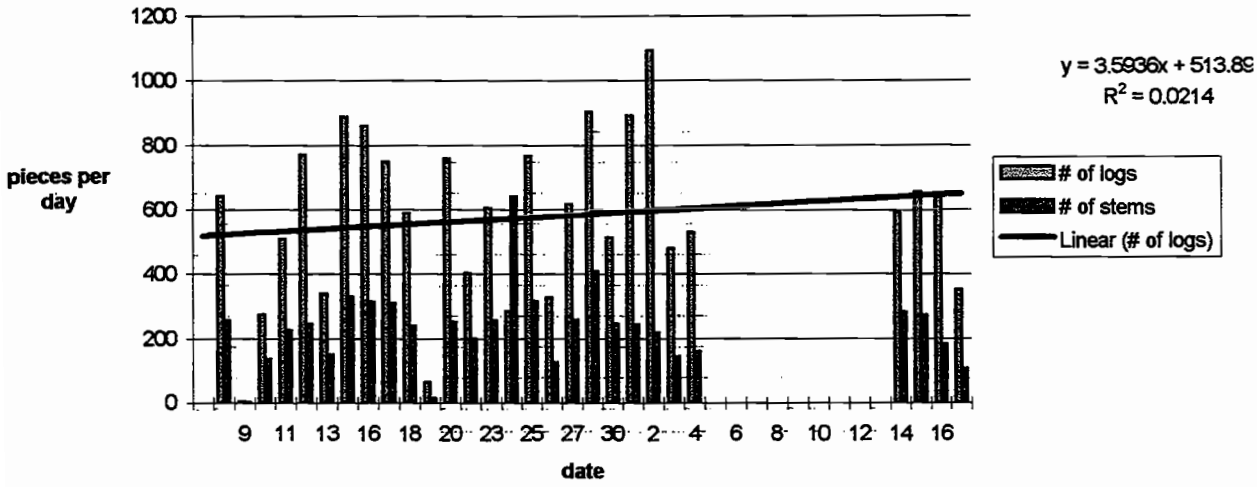


Figure 5.2 Chart of daily harvester production with trend line.[8]

[8] Gap indicates closure for a special hunting season.

Following are the descriptive statistics from the harvester time study data given for all units and also for each unit separately (table 5.6). Tree heights are for numbered trees in study plots only. Diameters are from measured trees in study plots and estimates for down logs.

Table 5.6 Descriptive statistics per cycle from time study data for each unit and all units combined. Times are in minutes and distances are in feet

		dbh	height	move	swng	fell	proc	total	dist	logs
all units	average	7.97	43.13	0.31	0.11	0.12	0.21	0.44	9.93	1.32
	maximum	19	82	2:13	0:23	0:73	0.43	1.39	20	2
	minimum	4.2	10	0.05	0.03	0.02	0.03	0.08	5	1
	std. dev.	2.35	13.79	0.26	0.05	0.08	0.09		3.63	0.47
unit 3	average	7.89	26.49	0.36	0.14	0.07	0.26	0.47	9.43	1.37
	maximum	30	38	1.15	0.97	0.3	0.03	1.3	20	5
	minimum	5	10	0.15	0.03	0.03	0.75	0.81	5	1
	std. dev.			0.28	0.11	0.08	0.18			
unit 4	average	7.80	43.10	0.15	0.15	0.07	0.24	0.46	10.56	1.72
	maximum	13.4	70	0.62	0.45	0.5	0.67	1.62	15	6
	minimum	5	28	0.08	0.05	0.03	0.03	0.11	8	1
	std. dev.			0.18	0.09	0.11	0.13			
unit 11a	average	8.21	44.65	0.06	0.22	0.08	0.27	0.57	9.22	1.52
	maximum	14.3	82	0.85	0.98	0.73	0.93	2.64	20	5
	minimum	4.5	12	0.07	0.03	0.05	0.03	0.11	5	1
	std. dev.			0.12	0.51	0.10	0.18			
unit 16	average	7.86	51.81	0.21	0.13	0.06	0.24	0.43	9.61	1.62
	maximum	14	68	0.38	0.76	0.42	0.8	1.98	20	4
	minimum	5	32	0.05	0.03	0.05	0.03	0.11	5	1
	std. dev.			0.09	0.13	0.06	0.13			

Regression Analysis For Harvester

The statistics in table 5.7 are from a statistical software package called STATGRAPHICS PLUS. Indicator variables were used to indicate whether the tree

being processed was a standing live, standing dead, or down dead, and whether the harvester was operating in unit 3, 4, 11a, or 16. The base case for trees was standing live and the base case for units was unit 3. There was no significant different between processing a standing live or a standing dead tree. There was a significant difference for processing a down dead tree and this variable is included as an indicator variable. There was no significant difference between units 3 and 4. Units 11a and 16 are included as indictor variables. The regression analysis for the harvester uses two regression equations. One equation is for the processing of trees, and the other equation is for moving. Move time was prorated on a per cycle basis for the number of observations. The prediction equation is: *Cycle time* = $Y_{harv} + Y_{move}$.

Table 5.7 Statistics for dependent and independent variables used in regression equations for harvester

Dependent Variable	Parameter	Estimate	Standard Error	T Statistic	P Value	R^2 adjusted
Yharv			16.1657			37.7267
	Constant	16.7061	2.7908	5.9861	0.0000	
	dbh	1.20303	0.1905	6.3164	0.0000	
	dndead	-6.70998	1.1996	-5.5936	0.0000	
	fuel	-0.117115	0.0297	-3.9426	0.0001	
	logs	12.049	0.8132	14.8168	0.0000	
	tpa	0.0327025	0.0093	3.5216	0.0005	
	unit11a	10.3455	1.7532	5.9009	0.0000	
	unit16	13.6920	4.5448	3.0126	0.0027	
Ymove			17.0058			
	dist	2.9484	0.3701	7.9658	0.0000	

Regression Equations for Harvester (centi-minutes)

Y_{harv} = 16.7061 + 1.20303*dbh - 6.70998*dndead - 0.117115 + 12.049*logs + 0.0327025*tpa + 10.3455*unit11a + 13.692*unit16

Y_{move} = 2.94837*dist

where:

Y_{harv} = total observation time for processing trees including operational delays

Y_{move} = total observation time for moves

dbh = diameter at breast height (inches)

dndead = down dead tree

fuel = fuel loading in tons per acre

logs = the number of logs processed from a tree

tpa = trees per acre

dist = distance traveled during move (feet)

5.2.2 *YARDING PRODUCTION RATES*

Table 5.9 gives production for the yarder from shift level data. Conversion from Logs/hr to other units uses average log descriptions from Table 5.3. Figure 5.3 displays the daily log production for the yarder with a trend line indicating an average increase in production of almost 13 logs per day over the length of the project.

Table 5.8 Yarding shift level production for each unit and all units combined

Unit 3	Logs/hr	Ft^3/hr	Bf/hr	Tons/hr	m^3/hr
Scheduled Hours	106.19	561.75	2925.74	9.11	15.90
Productive Hours	113.39	606.64	3159.54	9.73	17.17
Unit 4					
Scheduled Hours	74.92	396.33	2064.19	6.43	11.22
Productive Hours	98.52	527.08	2745.20	8.45	14.92
Unit 11a					
Scheduled Hours	102.34	541.38	2819.66	8.78	15.32
Productive Hours	133.61	714.81	3722.96	11.46	20.23
Unit 16					
Scheduled Hours	126.96	671.62	3497.99	10.89	19.01
Productive Hours	140.98	754.24	3928.32	12.10	21.35
All Units					
Scheduled Hours	97.80	517.36	2694.58	8.39	14.64
Productive Hours	121.20	648.42	3377.17	10.40	18.35

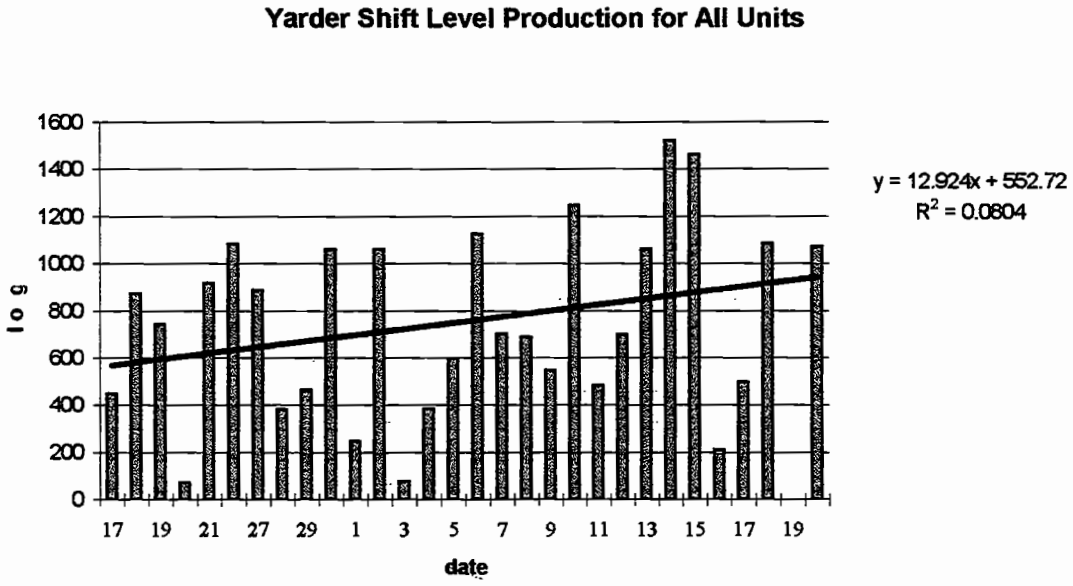


Figure 5.3 Daily yarder production with trend line

The yarding production cycle breakdown is based on 384 samples (turns) and can be found in Figure 5.4 with the other yarding statistics found in Table 5.10.

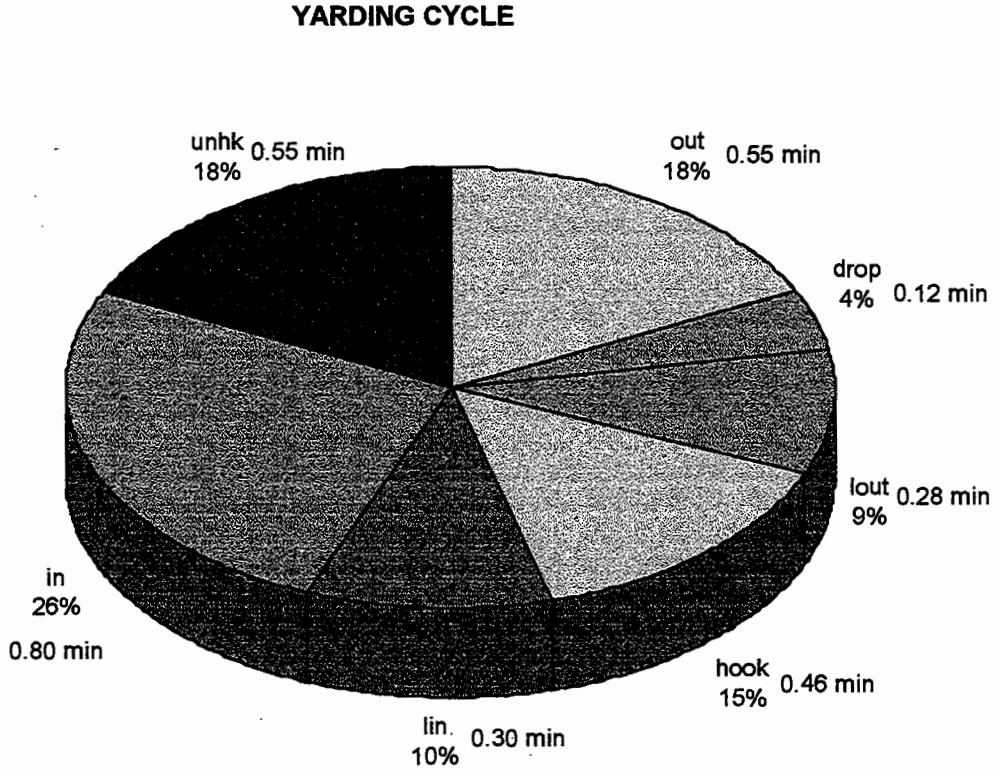


Figure 5.4 Yarding cycle components for each activity with the percentages and times associated with the average cycle time.

Table 5.9 Yarding statistics from time study data for each unit and for all units combined.[9]

UNIT 3	average	maximum	minimum	std. dev.
total turn time (min)	2.28	3.60	0.99	0.69
logs/turn	12.05	18.00	5.00	3.11
height of skyline (feet)	31.95	36.00	30.00	
chokers/turn	3.00	3.00	3.00	0.00
yarding distance (feet)	103.10	190.00	40.00	41.79
lateral yarding distance (feet)	34.05	60.00	10.00	19.15
skyline road lengths (feet)	426.00	518.00	307.00	
number of choker setters	2.00	2.00	2.00	0.00
road change times (min)	87.63	90.00	60.00	
UNIT 4				
total turn time (min)	3.46	6.38	0.60	1.08
logs/turn	12.02	35.00	2.00	4.23
height of skyline (feet)	34.42	50.00	20.00	
chokers/turn	3.09	6.00	3.00	0.53
yarding distance (feet)	440.94	800.00	40.00	178.21
lateral yarding distance (feet)	30.43	75.00	5.00	18.91
skyline road lengths (feet)	547.57	723.00	269.00	
number of choker setters	1.81	2.00	1.00	0.39
road change times (min)	71.67	90.00	30.00	
UNIT 16				
total turn time (min)	2.75	5.03	0.51	0.75
logs/turn	10.31	15.00	3.00	2.88
height of skyline (feet)	33.31	45.00	20.00	
chokers/turn	2.93	3.00	1.00	0.37
yarding distance (feet)	306.78	530.00	100.00	136.97
lateral yarding distance (feet)	23.90	70.00	5.00	16.06
skyline road lengths (feet)	790.00	921.00	551.00	
number of choker setters	2.66	3.00	2.00	0.48
road change times (min)	43.33	60.00	30.00	

[9] Average yarding distances are for the distances observed during the time study and are not the average yarding distance for that unit.

Table 5.10 continued

UNIT 11a	average	maximum	minimum	std. dev.
total turn time	3.06	5.91	0.70	0.76
logs/turn	11.31	20.00	3.00	3.84
height of skyline (feet)	37.02	65.00	15.00	
chokers/turn	2.96	3.00	1.00	0.23
yarding distance (feet)	314.69	500.00	50.00	136.04
lateral yarding distance (feet)	35.05	140.00	1.00	26.10
skyline road lengths (feet)	1028.50	1172.00	751.00	
number of choker setters	2.60	3.00	2.00	0.49
road change times (min)	96.00	150.00	70.00	
ALL UNITS				
total turn time (min)	3.07	6.38	0.51	0.97
logs/turn	11.39	35.00	2.00	3.82
height of skyline (feet)	34.98	65.00	15.00	
chokers/turn	3.01	6.00	1.00	0.39
yarding distance (feet)	343.15	800.00	40.00	176.51
lateral yarding distance (feet)	30.87	140.00	1.00	21.42
skyline road lengths (feet)	695.18	1172.00	269.00	
number of choker setters	2.26	3.00	1.00	
road change times (min)	73.53	150.00	30.00	

Regression Analysis for Yarder

The independent variables that were considered for the yarder regression equation were yarding distance (hdis), lateral yarding distance (ldis), height of skyline, number of chokers (chok), number of choker setters (men), whether the chokers were hot set or not (hset), number of logs per turn, and ground slope. The variables that proved to be significant are listed in Table 5.11. Squared terms for hdis and ldis were used because an inspection of the studentized residuals indicated a slight curve, and adding these terms gave a higher R^2 value.

Table 5.10 Statistics for dependent and independent variables used in regression equation for yarder

Dependent Variable	Parameter	Estimate	Standard Error	T Statistic	P Value	R^2 adjusted
Yyard			43.5686			71.3127
	Constant	145.4830	24.7850	5.8698	0.0000	
	chok	43.7715	7.9380	5.5242	0.0000	
	hset	45.8780	11.0111	4.1665	0.0000	
	ldis	0.6389	0.3140	2.0344	0.0428	
	men	-26.1233	4.8454	-5.3913	0.0000	
	hdis^2	0.00048	0.00002	22.8393	0.0000	
	ldis^2	0.007775	0.0035	2.2187	0.0273	

Regression equation for yarder (centi-minutes):

$$Y_{yard} = 145.483 + 43.7715*chok + 45.878*hset + 0.638854*ldis - 26.1233*men + 0.000480565*hdis^2 + 0.00777477*ldis^2$$

where:

Y_{yard} = total observation time including operational delays less than 10 minutes

chok = number of chokers

hset = hot set chokers (0=no, 1=yes)

ldis = lateral yarding distance (feet)

men = number of people setting chokers

hdis = yarding distance (feet)

5.2.3 *CHIPPER*

Production rates for tons per scheduled machine hours (table 5.12) were calculated using the final total weights and total scheduled hours for all harvest units combined. Production rates for productive machine hours were calculated using a utilization rate of 86.64%. Feet (linear feet) per scheduled machine hour were calculated using the average number of logs per load times the number of loads times the average cubic feet per linear foot then dividing by the scheduled machine hours (see Appendix H for conversion details). Cubic feet per scheduled machine hour was calculated by multiplying the average cubic feet per linear foot of log by feet per hour. Board feet per scheduled machine hour was calculated by multiplying a conversion factor by cubic feet per hour. Cubic meters per scheduled machine hour was calculated by multiplying a conversion factor by cubic feet per hour.

Using linear feet per hour allowed the use of pooled chipper data from the forwarder units and the skyline units. This gave a pool of 20 chip truck loads.
Pieces per load were randomly counted on the forwarder units and the skyline units. Logs from the forwarder units had an average length of 16.44 feet while the logs from the skyline units had an average length of 23.02 feet. In order to combine the average log data per load, data was converted to linear feet per load by multiplying the average number of pieces by the average piece length. This gave an average of 5536 feet per load.

Table 5.11 Chipper production rates from shift level data

All Units	Lineal Feet/hr	Ft^3/hr	Bf/hr	Tons/hr	m^3/hr
Scheduled Hours	6441.54	1481.56	7716.38	23.03	41.93
Productive Hours	7434.74	1709.99	8906.14	26.58	48.39

5.3 MOVE-IN COSTS

Move-in costs were $3000 to transport the yarder and loader from Springfield, OR to the study site at Limber Jim. Labor costs were $200. Total move-in costs were $3200. Because current markets and operator behavior would normally preclude contractors from moving from the west side, move in costs were prorated at $7.72 per mile and calculated at that rate from Pendleton, OR. This gives a move-in cost for the yarder and loader of $644.32. The total move-in cost for the harvester was $474.55 (see Appendix C for move-in summary).

5.4 LAYOUT COSTS

The time spent on layout was 90 hours. The current rate for layout work is $35 per hour. This gives a labor cost of $3150. The vehicle cost was $3.93 per hour which gives a total layout cost of $3503.70.

5.5 LOGGING COSTS

Logging costs per scheduled machine hour (SMH) presented here are based on an independent calculation of the owning , operating and labor costs associated with the equipment and personnel used in this study (see Appendix D for labor rates). The

calculated costs /SMH do not include any allowance for profit or risk and thus represent the lowest cost scenario for the operation.

Hourly rates / SMH were used in conjunction with the scheduled hours for each component of the logging operation to calculate a total cost from that component. The scheduled hours for each component of the logging operation was obtained from shift level studies and the results can be seen in the stump to mill logging cost summary table (Table 5.13) and the yarding cost summary table (Table 5.14).

Insufficient data was collected on the trucking component of the operation to do a cost calculation based on owning, operating and labor costs. Therefore, in order to provide a stump to mill cost for this report, the trucking contract rates of $397 per load were used to provide a total trucking cost. This cost included shuttle, hauling, and management.

Table 5.12 Stump to mill logging costs for each unit[10]

Unit	Area (acres)	AYD (feet)	Tons/smh	$/Ton
3	8	213	2.59	72.20
4	13	274	2.59	72.20
11a	23	514	2.87	67.08
16	15	395	3.57	57.80

Table 5.13 Yarding costs for each unit

Unit	Area (acres)	AYD (feet)	Tons/smh	$/Ton
3	8	213	9.87	31.31
4	13	274	7.40	41.75
11a	23	514	11.26	27.45
16	15	395	13.71	22.54

[10] Costs include layout, harvesting, yarding, chipping, and trucking. Scheduled machine hours are for all equipment.

Table 5.14 Stump to mill logging costs for entire project.[11]

	cost/hr	SMH's	total cost	$/ton	$/cunit	$/mbf	$/m^3	$/acre	$/hectare
Layout	$ 38.93	85.5	$ 3,328.52	$ 1.43	$ 2.25	$ 4.33	$ 0.80	$ 55.48	$ 137.08
Harvester	$ 114.94	397.26	$ 45,661.06	$ 19.57	$ 30.91	$ 59.35	$ 10.92	$ 761.02	$ 1,880.55
Yarder	$ 303.18	228.5	$ 69,276.63	$ 29.70	$ 46.90	$ 90.05	$ 16.57	$ 1,154.61	$ 2,853.16
Chipper	$ 52.16	101.31	$ 5,284.33	$ 2.27	$ 3.58	$ 6.87	$ 1.26	$ 88.07	$ 217.64
Trucking			$ 46,052.00	$ 19.74	$ 31.18	$ 59.86	$ 11.02	$ 767.53	$ 1,896.65
Total Costs	$ 478.54	812.57	$ 169,602.54	$ 72.70	$ 114.82	$ 220.45	$ 40.57	$ 2,826.71	$ 6,985.08

[11] Costs for yarder include loader and yarder (owning, operating, and labor costs).
SMH = scheduled machine hours

Table 5.15 Prices at time of project (1996/1997)[12]

Current Prices(1996/1997)		
sawlogs	$ 425.00	/mbf
pulpwood	$ 97.50	/BDU
	$ 46.93	/green ton

Table 5.16 Gross and net revenues from project

Gross Revenue		**Total**		**$/acre**
sawlogs	$	39,163.75	$	652.73
pulpwood	$	97,785.79	$	1,629.76
costs	$	(169,602.54)	$	(2,826.71)
Net Revenue	**$**	**(32,653.00)**	**$**	**(544.22)**

[12] The green ton price is converted from bone dry units using a moisture content of 73.14% (see Appendix H).

The following charts depict costs in $/ft^3$ from shift level, time study, and final summary data. Figure 5.5 and figure 5.7 used the regression equation for the yarding cycle where all variables were held constant while the variable of interest was varied. Figure 5.6 used the regression equation (centi-min/turn) divided by # of logs per turn divided by ft^3 per log times the operating cost in dollars per minute.

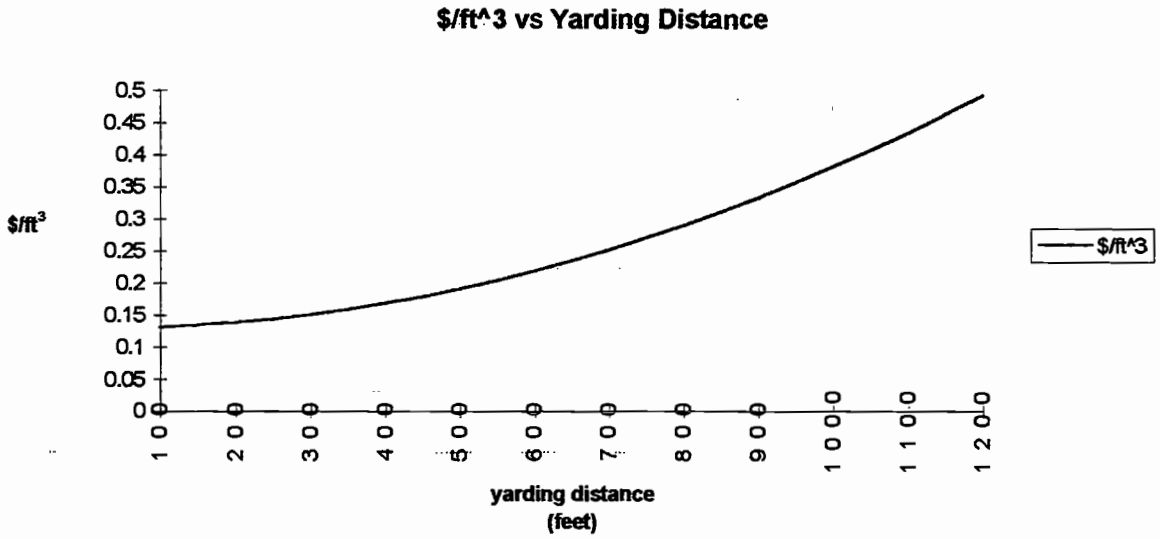


Figure 5.5 Cost in $/ft^3 vs. yarding distance (feet)

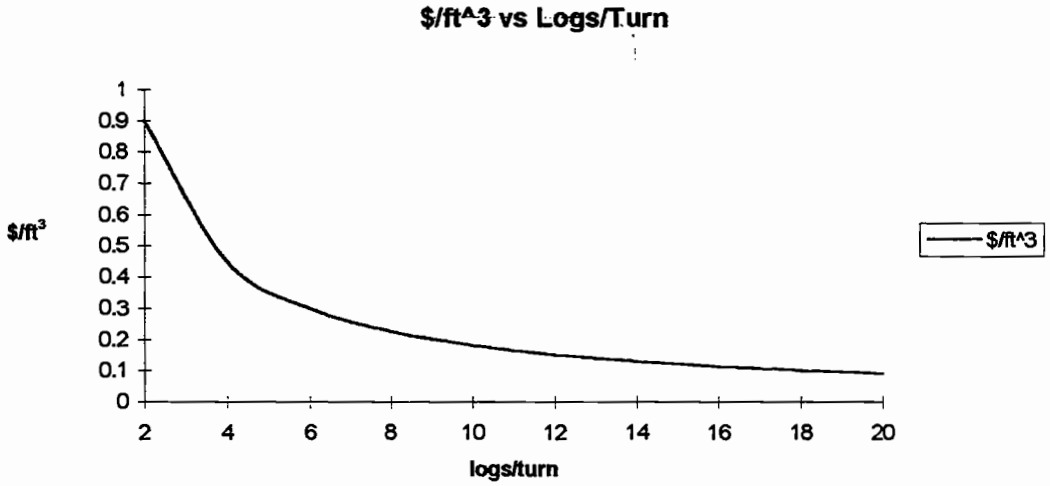


Figure 5.6 Costs in $/ft^3 vs. number of logs per turn

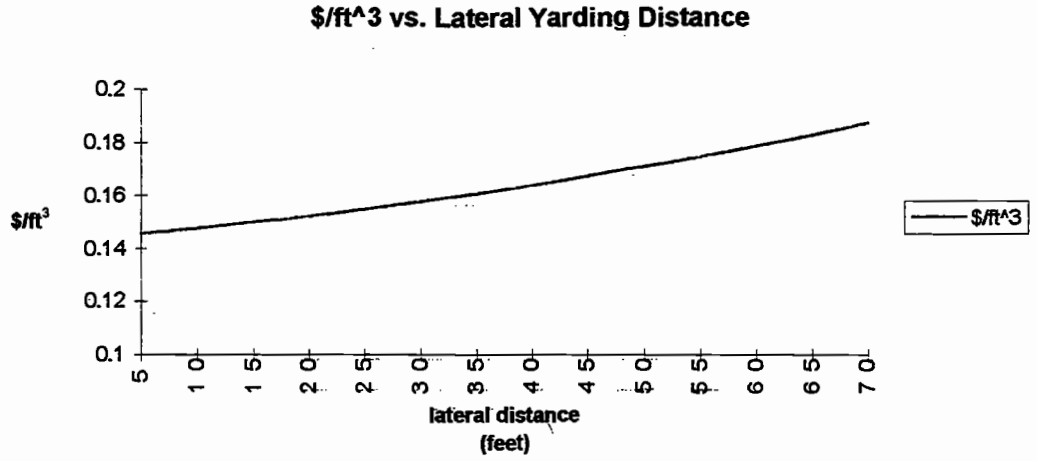


Figure 5.7 Cost in $/ft^3 vs. lateral yarding distance

6. DISCUSSION

Study results are discussed under the following framework:

1. Interpretation of results and comparisons to past studies,
2. Sensitivity analysis of results,
3. Other study issues,
4. Suggested improvements for future logging operations,
5. Opportunities for future research.

6.1 INTERPRETATION OF RESULTS AND COMPARISON TO PAST STUDIES

6.1.1 *LOGGING LAYOUT AND PLANNING*

The layout work that was done prior to logging had a cost of $3328.52 ($55.48/acre) which represented 2.1% of the total logging cost. This investment was very important in

achieving the logging production and costs that are presented here as it gave the loggers a clear idea as to how the stand was to be logged before logging began.

Layout prior to any harvesting activities was necessary in order for the harvester operator to position the logs produced in relation to the corridor locations. The layout also prevented the harvester from removing any of the trees that were needed for intermediate supports or tailtrees during the yarding operation. This was of major significance because of the shortage of trees that were of adequate size and in appropriate locations to assist in the yarding operation. The yarding operation was heavily dependent on these trees for skyline lift and thus the protection of these trees was critical.

As well as ensuring that yarding was possible, layout also made yarding more efficient through the exploration of and selection from different alternatives. Once the best layout alternative for logging was identified, it was then possible for the yarding crew to move in and begin yarding operations without the need for the hooktender to locate corridors, tail trees, and intermediate supports. The hooktender's time was better spent keeping ahead of the yarding crew with the necessary rigging work. Thus, the preplanning of the yarding corridors made the operation more efficient than if preplanning was not performed.

In summary, dollars invested into layout and logging planning for this project were very well spent. If the investment in layout was to be eliminated, the result would likely be higher yarding costs due to a lack of lift trees in the proper locations and poor synchronization between the harvester and yarder (i.e. difficult or impractical logging).

6.1.2 *HARVESTER OPERATION*

The harvester operation in this project had a cost of $45,661 (owning, operating and labor) which represented 26.9% of the total logging cost. The harvester was operating in conditions typical for the region and did not encounter any unusual problems. The only difference from its usual operation was that the operator had to be conscious of how and where the logs were placed with respect to the skyline corridors in order to facilitate productive yarding. The bulk of this coordination with the yarder resulted from using the

marked skyline corridors as guides for the processing pattern of the stand (see Figure 4.12). The harvester traveled parallel to the skyline road and created rows of logs that were roughly perpendicular to the corridors. During the felling and processing activities, the harvester was able to do almost all of the positioning of logs and very little extra effort was spent to orient or reposition logs once they were processed. In order to facilitate the setting of chokers around the deck of processed logs, it was necessary to first place a log crosswise and then deck the end of the pile on this log. When this technique was followed, the logs were reasonably well oriented for the yarding operation and the decks were relatively easy to get a choker around. The only problem was some of the decks were too large to get a choker around and the choker setters had to pry the deck apart in order to grab a smaller portion of the pile. Another problem was the orientation of logs in the center strip between corridors (see figure 6.1). In order to orient the logs properly for presentation to the corridor (see figure 4.13), and have the ends of the decks flush, the harvester started at the back end of the corridor and worked towards the road. This worked well for the corridors but when processing the center strip, the logs were oriented too far away from the intended corridor. The exception to this was when corridors converged. In these cases, the harvester operator often chose not to follow the corridors as it was unproductive and this resulted in poorly oriented logs. This occurred only on unit 16 where a common landing was used. Thus, in most cases, the processed logs were reasonably well oriented for cable yarding with minimal extra effort from the harvester.

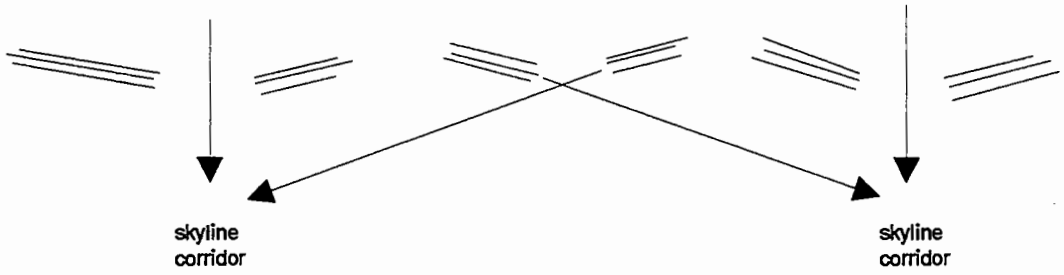


Figure 6.1 Orientation of logs in center cutting strip and the intended corridor to which they were to be logged

Because tree felling and processing represented a relatively low proportion of total cost, it might be cost effective to have the harvester reduce its productivity and spend more time positioning logs for yarding. This is assuming the harvester has sufficient lead time on the yarding operation. The reduction in harvester productivity could potentially be made up in yarding productivity which represents a much larger percentage of total cost. This concept is discussed in more detail later in this section.

Another observation from the harvester study is that dead and down stems on the ground processed faster than the standing live or standing dead trees. The average time for processing a standing live tree, a standing dead tree, and a down dead tree was 0.66 minutes, 0.56 minutes, and 0.45 minutes respectively. This is because the majority of the processing time for live trees was spent on delimbing the stem and the dead and down stems had very few limbs. In cases where they did have limbs, the material was so dry and brittle that the harvester was not slowed down at all. In addition to processing quickly, dead and down stems did not have to be felled and therefore production was improved in areas with large amounts of down wood. In general, the tangle of logs that lay on the ground did not offset this increase in production as the harvester head was able to efficiently extract stems from the piles while processing. The harvester was also very adept at working around the standing residual trees.

In comparison to the other harvester studies presented in the literature review, results from this study showed a lower production rate and a higher cost. The lower production and higher cost is likely due to the small average piece size on the Limber Jim site. For instance, when thinning a second growth Douglas-fir stand (avg. dbh=13.5") in the westside mountains of Oregon, the harvesting cost was $11.81 / cunit, while the harvesting cost on the Limber Jim site (avg. dbh = 4.88") was $30.91 / cunit. Production in the Douglas fir stand was 1087 ft^3 / PMH and 750 ft^3 / SMH, while the harvester's production on the Limber Jim site was 933.11 ft^3 / PMH and 623.62 ft^3 / SMH. In addition to the tree size differences, the Douglas fir thinning mainly involved felling and processing live trees with a minimal amount of stems on the ground. A more appropriate comparison would be

with the Deerhorn Project which produced 733.3 ft^3 / PMH and 589.4 ft^3 / SMH with a cost of $15.92 per cunit.

6.1.3 *YARDING AND LOADING OPERATIONS*

The yarding and loading operations had an owning, operating and labor cost of $69,276 which represented 40.8% of total logging cost. Yarding made up the majority of this cost as the loader was used only to keep the log chute clean and occasionally help feed logs into the chipper. There were no loading costs associated with the loader. These costs were included in the yarding costs. The cost of these two components are lumped together for purposes of comparison with other studies and because the two operations occurred simultaneously. The most efficient mode of operation was to have the loader work along side the yarder and clear the landing after every turn of logs. The loader was also used to move the skyline carriage between skyline roads.

There was not a large difference in the production rates per SMH and PMH for the yarder (17.36 ft^3/smh and 648.42 ft^3/pmh). This reflects the efficiency and expertise of the logging contractor and the logging crew. The amount of time spent on nonproductive activities such as skyline road changes and rigging delay times was not excessive.

The utilization rate is a measure of the percent of the scheduled hours that are productive. The utilization rate for the Diamond yarder was approximately 84.8%. Therefore, 84.8% of the scheduled hours were used to yard logs and the remaining 11.6% of those hours were spent on road changes and or mechanical, personal, rigging, or external delays. Typical utilization rates for this type of yarder is approximately 70%, while the Deerhorn Project had a utilization rate of 57%. An example of this can be seen in a 1995 COPE commercial thinning project conducted by OSU Department of Forest Engineering where a Koller K501 using tailtrees and intermediate supports had an average utilization rate of 74% for all treatment units logged (King, 1995).

Road Changes

Skyline road changes averaged 1.2 hours in length. The longest road change times were associated with unit 11a with an average time of 1.6 hours. This was due to the use of intermediate supports on every skyline corridor. The shortest average road change times were associated with unit 16 with an average time of 0.72 hours. This was because a common landing was used and the yarder, loader, and carriage did not need to move to a new setting. Also, there were no intermediate supports used on this unit. These are very efficient road change times when compared to the Deerhorn Project which averaged 2.1 hours per road change. The COPE study previously mentioned (King, 1995) had an average road change time of 1.4 hours while having to rig tailtrees and intermediate supports for a Koller K501 yarder.

Rigging Failures and Yarding Delay Analysis

There were no rigging failures on this project. This was due to the care and experience of the logging contractor who did his own layout. If a suitable tailtree and/or intermediate support was not available for the current location of the skyline corridor, then the corridor was re-run in a location where they were available.

Yarding delays were typically associated with mechanical, rigging, or external delays. There were no maintenance or personal delays recorded in the shift level data. Mechanical problems accounted for 60.6 % of the delays, while rigging and external delays accounted for 33.6% and 5.8% respectively.

Cost Comparisons

When the yarding and loading costs experienced on this project are compared to other studies using similar yarders in thinning operations, the costs are slightly less for the Limber Jim project which was $46.90 /cunit. The studies presented in the literature review on small cable yarders, showed yarding and loading costs between $60-$75/cunit when

thinning second growth stands in western Oregon on moderate to steep slopes. The yarding and loading cost for the Deerhorn project were $59/ cunit. The added expense of obtaining lift on flat terrain by using tailtrees and occasionally intermediate supports was likely offset by the improved yarding production that resulted from the presentation (grouping) of the logs by the harvester. The presentation of the logs allowed larger, more consistent payloads to be achieved with less effort when compared with the scattered pattern of logs generally found when cable yarding.

When comparing production rates with the same studies, the yarding in the Limber Jim project produced 6.48 cunits/pmh compared to 5.41 cunits/pmh for the Deerhorn Project, 3.57 cunits/pmh for a Koller K300 (Hochrien and Kellogg, 1988), but lower production than the best Madill 071 thinning results which were 7.15 cunits/PMH (Kellogg, Olsen, Hargrave, 1986).

The cost and production of yarding equipment used in the Limber Jim project can also be compared with other primary log transport systems that have traditionally been used in areas similar to the Limber Jim site. Grapple skidding or forwarding are both alternative methods of accomplishing the same task as Limber Jim's cable system. Studies on forwarder production and cost described in the literature review show that forwarding costs ($19.26/cunit) in the coast range of Oregon can be half of the yarding cost ($46.90/cunit) experienced in the Limber Jim project. If only pulpwood production rates and cost are considered from the same study (Kellogg, 1994), the difference is slightly less. Yarding production for the Limber Jim project was 517.36 ft^3 / smh or 648.42 ft^3/pmh while the forwarder production (pulpwood only) in the Kellogg study was 275 ft^3/smh or 359 ft^3/pmh. Using the FMG 910 forwarder's 1992 hourly owning and operating costs of $70.41/smh, a forwarding cost for pulpwood of only $25.60/cunit can be determined. Thus, Limber Jim's yarding operation had higher production than the forwarder but its hourly rate ($303.18 / SMH) is almost four times that of the forwarder's ($70.41 / smh), which results in considerably higher yarding costs per cunit.

Grapple skidding has also proven to be a cost effective method of primary log transport. The owning, operating, and labor cost for a John Deere 648E grapple skidder ($52.64/hr) is even less than that of the previously mentioned forwarder and production

can be just as good or better when the logs are bunched properly. A study from a flat site in South Carolina (Robe, 1989) showed that when a stand was thinned with a feller-buncher and the logs were skidded with a Franklin 105 grapple skidder to the landing, average skidder production was 28.3 tons/pmh. This can be compared to the Limber Jim yarding operations production of 10.40 tons/PMH. These figures are slightly misleading because the large component of dead and dry wood that was yarded in the Limber Jim project weighs very little when compared with the live stems and branches skidded in the South Carolina study. The drawback of this type of transport is the large number of passes over the setting that must be make to move a similar volume as a single forwarder trip. Forwarding and grapple skidding systems of log transport have generally proven to be less expensive than cable systems on flat ground, but their impact on soils is likely to be higher.

6.1.4 *TRUCKING*

Trucking had a cost of $46,052, which represented 33.0% of the total logging cost. The contract rate was $397 per load. This included shuttle, hauling, and management costs. Shuttle costs were for hauling the chip vans from the landing to the highway where the van was transferred to a highway truck. Hauling costs are from the van transfer point to the mill. Management costs are all other costs including profit and risk.

6.1.5 *THE LOGGING SYSTEM*

The total cost of logging (stump to dump) for this project was $169,602 based on owning, operating and labor costs of each segment of the operation (trucking based on contract rates). The production achieved by the entire system was not limited by any one operation. The chipper, which had the highest production rate, was able to move to other units if there weren't sufficient logs to chip.

When the results of this system are compared to that of the similar South African study (Howe, 1994) described in the literature review, there are several obvious differences. The production rate of the harvester component in the Limber Jim study was 9% lower than that of the Howe study, while the yarding production rate in the Limber Jim study was 70% lower than that of the Howe study. This can be explained by the marked difference in operating procedures in the two studies. In the Howe study, the harvester spent much more time bunching and presenting logs so that yarding operations would be very efficient. The logs were placed into carefully located bundles that maximized the yarder's payload capacity each turn and made the hooking of each turn very quick. Thus, when compared with the Limber Jim study, the harvester in the Howe study was more .productive and the yarder in the Howe study was also more productive. It is difficult to accurately compare overall efficiency of each of the logging techniques because they were performing different silvicultural treatments (clearcut vs. thinning) and there was no cost/unit volume logged provided in the Howe study. At best it serves to illustrate a different approach to equipment operations that may provide insight into opportunities for lowering total logging cost.

6.2 SENSITIVE VARIABLES IN THE SOLUTION

The Limber Jim project was a continuation of the Deerhorn project and studied different variables that might affect costs and production. Notably, the main difference between the study units was terrain. Two units were logged uphill, one unit was logged downhill, and one unit was on flat terrain. Comparing cycle times from regression analysis suggests there was no significant difference in cycle times related to slope. This section of the paper discusses how the results might be affected by variations in certain key variables.

6.2.1 *AVERAGE PIECE SIZE*

Average piece size dictates the number of pieces that must be handled to produce a unit volume of wood (i.e. Mbf or tons). Piece size can also define the log grade assigned to a given log. As the average log diameter increases, there will be a larger percentage of logs that make sawlog grade. As average piece size decreases (defined by diameter and/or length), more pieces must be handled to obtain a unit volume and the percentage of pulpwood will increase. Because each piece must be handled by the harvester, yarder and loader, the number of pieces that must be handled to produce a unit volume will have an impact on the production, and therefore logging system cost. The harvester must handle each stem separately, independent of its size, and will therefore experience a drop in production when there is a reduction in length and/or diameter. The yarding process requires that logs be choked individually or in groups so smaller diameter logs can be held together by a single choker. Choking groups of small logs with a single choker may mitigate the effects of small diameter logs but it is often more difficult than it sounds because the logs must be close enough together to quickly choke them all at once and there may also be problems in keeping the bundle of logs together all the way to the landing. A reduction in log length could have a more direct impact on yarding production because the same number of logs included in a single turn would contain less volume (shorter logs). This assumes that all chokers are hooked when logging the longer lengths and that it would not be possible to simply choke additional short logs. This suggests that log lengths should be as long as possible when using this system, but there are other factors to consider. Long log lengths are more difficult for the harvester to handle and they present more difficulties when yarding around residual trees. The log length that will maximize production of the entire system and meet the mill's standards is an important variable.

In this study, the preferred log length was only considered when the harvester was processing a possible sawlog. Because most of the material harvested went for chips, log lengths were not critical and the harvester bucked logs to a convenient length. Thirty two

foot logs were the preferred length for sawlogs in each unit with an average length for all logs of 23 feet.

In summary, larger diameter material will generally result in better production and lower logging costs. It will also result in higher revenues if the difference in diameter allows the material to be scaled as sawlogs.

6.2.2 *PROPORTION OF SAWLOGS VS PULPWOOD*

In this case study, the price of pulpwood was $97.50/BDU (bone dry unit) or $46.93/green ton and the price of sawlog material was $425/mbf. This generated pulpwood revenues of $97,785.79 and sawlog revenues of $39,163.75. Costs were $169,602 which resulted in a loss of $32,653. Pulpwood represented 71.4% of the gross revenue and 89.3% of the gross volume, while sawlogs represented 28.6% of the gross revenue and 10.7% of the gross volume. Because pulpwood was being logged at a loss (logging costs = $72.70/ton), an increase in the percentage of sawlogs to 21.5% was needed to break even. The profitability of the entire operation depended on the proportion of sawlog material that was removed because stump to mill logging costs were higher than pulpwood revenues. Thus, the pulp was being logged at a loss and the revenue from sawlogs was not sufficient to make up the difference.

At the market prices stated above, the proportion of total weight represented by sawlogs required to just meet logging costs is 21.5% (see figure 6.2). If the gross volume of the sawlogs is less that than 21.5% of the total volume removed, then the logging operation would be unprofitable. In the break-even scenario (21.5% of the volume is sawlogs), the sawlogs contribute 46.4% of the total revenue. In summary, if all other variables remain the same, the logging at the Limber Jim project would have been profitable as long as no more than 78.5% of the volume of the material removed was pulpwood.

It is not a good assumption that all other factors would stay the same if the proportion of sawlog material produced was altered. There is a correlation between the proportion of

sawlog material and the average piece size removed. These two variables can be seen as directly related because as piece size increases, the proportion of sawlog material in a setting also increases. The previous section discussed how changes in average piece size affect cost and suggested that as pieces get small, logging cost would increase. Thus a reduction in the proportion of sawlog material being logged would result in potentially higher logging costs and less revenue being generated. The relative proportion of sawlogs and pulpwood is an important factor when considering the economic feasibility of various salvage-thinning operations.

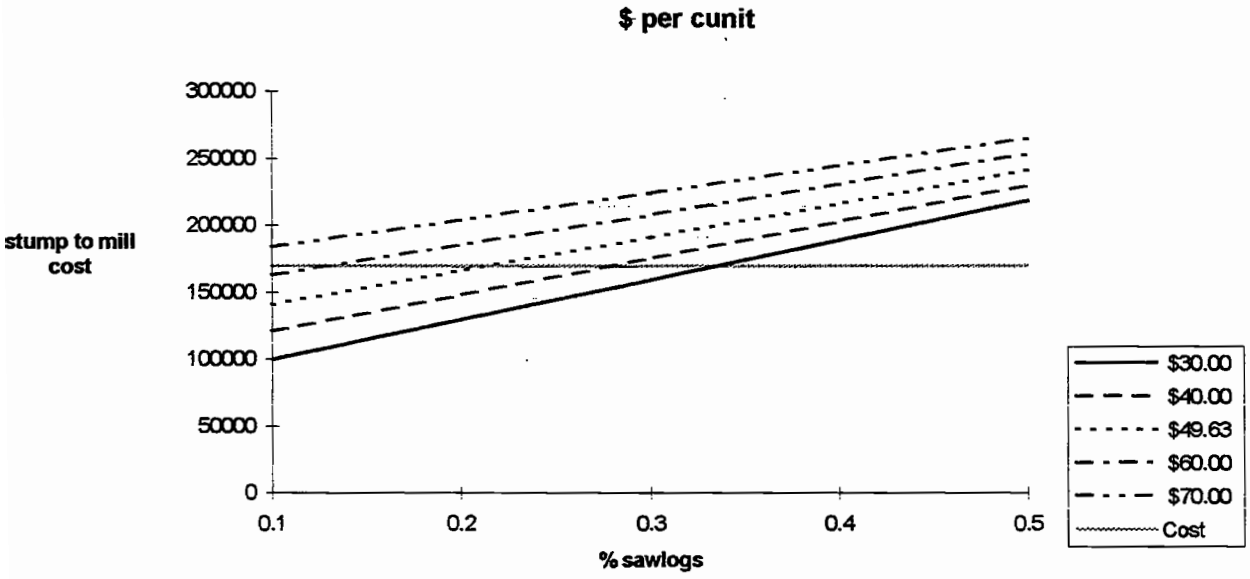


Figure 6.2 Percentage of sawlogs needed to breakeven given different chip prices per green ton

6.2.3 *GROUND SLOPES*

In the Limber Jim study where slopes ranged from -20% to 30%, slope did not seem to be a factor affecting production. Outside these ranges, it is hard to tell how logging

would be affected by different ground slopes without knowing more about the type of ground in question. It is easier to suggest what would change if the ground was not flat.

Moderate to steep slopes would define the layout of the setting to a larger degree than when the terrain is flat because the cable system needs to be properly oriented with the slopes. Anything beyond moderate slopes would likely define landing and road locations so that yarding could be done in a cost effective manner. If the terrain was shaped so that the elimination of tailtrees and/or intermediate supports was possible(i.e. concave profiles), yarding would likely be more efficient with less time spent on road changes. With flat ground, the layout of skyline corridors was unrestricted and the goal of not entering the setting with roads was used as a guiding principle. This would not likely be possible if moderate to steep ground slopes were present in the stand.

If slopes were not consistent and the setting had undulating terrain, the layout would again be more restrictive and very critical to successfully logging the area. Intermediate supports would need to be strategically placed to obtain lift over humps in the terrain and this could potentially increase costs.

One of the keys to using this system successfully is to coordinate the harvesters presentation of logs with the yarding corridors. This is best accomplished by having the harvester work parallel to skyline corridors. In moderate to steep slopes with fan shaped settings, this may not always be possible due to the harvester's inability to work on side slopes. Parallel skyline corridors would be better. With self-leveling machinery, harvester operations can be performed on slopes up to 55% but it is more expensive and the harvester is restricted to running straight up and down the slopes. Any setting that will limit the harvester's movement will likely have a detrimental effect on logging production and cost.

6.2.4 *PROPORTION OF DEAD VS LIVE MATERIAL REMOVED*

Another variable that could potentially affect revenue, production, and costs associated with this logging system is the proportion of material removed that is dead.

Dead material was able to be processed faster by the harvester because most of it did not have to be felled and because of the lack of branches and/or brittleness of the branches that made delimbing quick. The amount of time spent processing a down dead stem was almost always less than that of a similar size standing live or standing dead stem and this resulted in improved volume production. However, this did not always translate into an improvement in weight production (contract payment measure) because dead material was much lighter than live stems. Also, all dead material went for chips which was logged at a loss. It might be thought that because of the lighter log weights, more logs could be included in a yarded turn before the payload of the system was exceeded, but there is an operational limit to the amount of material that can be put in one choker, regardless of weight. The handling of dead material was generally more efficient than the handling of live material.

The proportion of dead material may affect the revenue generated from a sale because dead wood can only create pulpwood material. Anything that increases the percentage of pulpwood will reduce the net revenue generated from the sale. It will only have an effect on areas that would have otherwise been able to provide sawlogs. For example, if an entire sale contains only pulpwood, the proportion of dead material will have little consequence on revenue.

6.3 OTHER STUDY ISSUES

The following information is part of the comprehensive Limber Jim project that looked at several resource issues, namely soil impacts, the effect on fuel loading, and the effect on stand health and pine marten habitat. The soil impact and fuel loading information presented here are the opinions of this researcher. These results are not part of this logging study but are included here to more fully describe the study for the benefit of the reader.

Soil impacts on the study site can be broken down into two types: disturbance and compaction. The main goal of the harvesting operation was to minimize both of these

impacts by eliminating the use of ground based logging machinery for primary transportation of the logs.

The harvester was able to walk on the layer of slash that it created in front of itself as it worked and therefore the soil was somewhat protected. It also generally made one pass over any given spot on the site because it only required one pass through the stand to complete its job. The main occurrences of soil disturbance from the harvester were when it was changing direction by rotating one of its tracks. These situations occurred occasionally and created small isolated berms of soil. More detailed information can be found in the report on soil compaction and disturbance on some of these units that will be prepared by Dr. Paul Adams and Mark Taratoot of OSU Department of Forest Engineering.

The yarding operation caused various degrees of soil disturbance along the skyline corridors, depending on the amount of clearance the front end of the log had above the ground and the amount of slash available to protect the ground. In general, there were small paths that were scraped clean of debris and duff under the skyline corridor. Because of the lack of vehicle traffic on the soil in this phase of the operation, compaction did not appear to be an issue, although some local increase in density is possible where logs dragged over the ground.

The salvage logging of merchantable dead and down material was expected to dramatically decrease the amount of fuel loading that was on the ground's surface. The logging did cause a significant reduction in fuels between 3 and 9 inches in diameter but also significantly increased the amount of fine fuels on the forest floor. The branches that were delimbed during harvester operations served to protect the soil from the harvester but also created a different type of fuel loading. These fine fuels will likely decay much faster than larger material and thus will result in a much lower fuel load in the near future.

Pre-harvest fuel loading was calculated by the PNW Research Station. All fuels were measured down to fine materials. For the fuel loading calculations in each study plot for the harvester, a random transect line was established and only fuels larger than 2 inches were measured.

Stand density was effectively reduced at the completion of logging and there was little incidence of scarring on residual trees. Both the harvester and yarder did some minor damage to residual trees as they performed their tasks but it did not appear to be significant enough to cause any serious harm to the stand. The silvicultural prescription appeared to have been well executed. The damaged and dying trees were removed and the healthiest trees were left as residuals.

6.4 SUGGESTIONS FOR FUTURE LOGGING OPERATIONS

Future applications of a single-grip harvester and skyline yarding system can learn from this project and hopefully improve on the production rates and logging costs. The following suggestions may help to make the system more productive and cost efficient.

1. Improve the presentation of logs for the yarding system.

The harvester operation's cost represented 20.3%of the total logging cost and its hourly rate is significantly lower than that of the yarding operation. In order to improve production of the yarding system, the harvester should spend additional time positioning logs so that they are reasonably well grouped and oriented for removal by the yarding crew. In order to define the amount of additional time the harvester should spend facilitating yarding, several variations should be explored. These variations on the harvester's operation are presented in the Opportunities for Future Research section of this paper. In general, the harvesters pattern of movement through the stand should not change because it is simply a matter of being conscious of where each skyline road is located, knowing the landing location, and being aware of logs already cut in the area. Logs should be grouped as best possible. This additional effort should save the yarding crew more time than the harvester had to invest but even if the time is simply transferred from the yarding to the harvesting phase, it will be assessed at a lower hourly rate. In order to facilitate this, skyline corridors would need to be extremely well marked.

2. Use of intermediate supports.

During skyline yarding, the use of intermediate supports was necessary in order to mitigate soil disturbance in areas where logs would not be at least partially suspended off the ground. In this project, intermediate supports were marked where needed and were used. The use of profile analysis in the layout stage could help predict which corridors will require intermediate supports and their associated rigging heights, but this is an added expense. Enforcing the use of intermediate supports in sensitive areas may be necessary for some logging contractors. The use of these supports may also improve production in some yarding corridors because higher payloads can be carried to the landing in comparison with not using a support. This potential improvement in production and the protection of soils must be weighed against additional road change time that occurs from rigging an intermediate support. Pushing the limits of tailtrees does not always provide a way around this decision as rigging failures from broken tailtrees can be costly, especially if there are few suitable tailtrees in the area.

3. Ensure contractor cooperation and availability of equipment.

The ideal contractor owns all necessary equipment and is not dependent on other parties to operate efficiently. This eliminates conflicts between different phases of logging and ensures that total logging cost is minimized. For example, a contractor hired for just the harvester operations may be tempted to do the minimum necessary to fulfill his contract and may not make the extra effort needed to improve yarding efficiency. If different contractors must be hired for each phase, it is important that the contracts are written to require a high level of coordination and cooperation between them.

4. Use a less expensive loader.

The loader used in this study was a new 1994 John Deere 640 ELC that had an hourly rate of $71.96. This size of loader was not really necessary for the size of wood being handled and was quite expensive. Also on this project, the loader was used only to keep the log chute clear and to assist in feeding chip logs into the chipper. If possible, a less expensive, smaller loader would likely do the same job for less cost and not have a negative effect on production.

5. Use a less expensive yarder

The Diamond D210 swing yarder used on this project had an hourly rate of $210.47. Although this yarder performed well, a smaller yarder such as a Koller K-510 with a smaller hourly rate could have performed as well.

6.5 OPPORTUNITIES FOR FUTURE HARVESTER RESEARCH

There are several opportunities for future harvester research in areas related to the Limber Jim project. The following areas would yield the most interesting information in the opinion of this author:

Balancing Harvester Effort with Yarding Efficiency

As mentioned previously in this paper, the amount of effort (hours) that the harvester expends at bunching and presenting logs for yarding can have an affect on yarding costs. Determining the optimal amount of harvesting effort that minimizes total logging costs is an important relationship to determine. In order to define the relationship between harvester effort and total yarding costs, a research trial should be established with various levels of harvester effort that allows yarding to be more efficient, and therefore less costly. With respect to the study presented in this paper, the harvester could be asked to do three

different levels of bunching/presenting logs, each on a separate treatment unit so that the harvester operation, yarding operation, and total costs could be calculated for each unit.

Following are suggestions from the Deerhorn project for better efficiency between harvester and yarder operations and how they were dealt with on the Limber Jim project.

1. The harvester operates as in this study but makes a distinct effort to follow the marked skyline roads and row the logs so that they are oriented at 90 degrees or more to the corridor (preferably a herringbone pattern). No bunching will be done but special care is taken to ensure proper orientation of the logs to a specific corridor.

2. Same as (#1) above but the harvester makes an effort to stack logs into piles approximately the size of a single turn for the yarder. If logs are scattered after processing, the head can be used to pick up logs and place them into an orderly pile. The harvester operator must be aware of the lateral yarding direction to each corridor.

3. Same as (#2) above but the harvester only creates piles of logs on the side of the machine that is closest to the skyline corridor. Each skyline corridor yards logs from three passes of the harvester, one in the corridor, and one on either side. When the harvester works in the skyline corridor, logs can be stacked on either side of the machine. Then as the two passes on either side of the corridor are made, logs are placed on or near existing stacks so that the yarder only has to work with two rows of piles per corridor. Logs would first be processed to the side that is most convenient for processing and then picked up and moved to the side closest to the corridor. This may mean less volume per corridor and more road changes, but it provides for very efficient yarding.

These suggested trials provide data points with which to understand the relationship between harvester effort and yarding costs. Once a relationship has been defined, it will only be valid in situations where hourly costs for the harvester and yarder are in the same proportion as those that defined the relationship.

On the Limber Jim project, the harvester used a combination of #2 and #3. One pass was made down the corridor and logs were decked on either side of the harvester. However, many of the decks were too large to be handled by one choker and time was wasted attempting to choke a smaller portion of the deck. The next pass of the harvester was made down the center between corridors. When decking logs, the harvester made an attempt to keep one end of the deck flush in order to facilitate choking the logs at one end. This resulted in decks that were closer to one corridor being yarded from another corridor (see figure 6.1).

7. CONCLUSION

This paper evaluated the production and costs resulting from a single grip harvester and medium size swing yarder used to thin and salvage logs in an eastern Oregon stand with different terrain characteristics for each unit. Production of the harvester and yarder were found to be 9.33 cunits/pmh (4.86 mbf/pmh) and 6.48 cunits/pmh (3.38 mbf/pmh) respectively. For the circumstances found in this project, the cost of logging from stump to mill was $114.82 / cunit ($40.57 / m^3) or $72.70 / ton which represented a per acre cost of $2826.71 ($6985.08 / ha). The landowner was not able to make a profit from pulpwood, but if the percentage of sawlogs had been increased to at least 21.5%, then the landowner would have realized a profit. Pulpwood prices at the time of the study were $46.93/ton and thus a loss of $25.77/ton of pulplogs removed was incurred. Conversely, the sawlogs removed received $425/mbf which was approximately $180.81/ton and thus a profit of $108.11/ton was made on every ton of sawlogs removed. Total logging cost was $169,602 which resulted in a loss of $32,653.

Future management implications from this study are that a harvester and medium sized cable yarder can be combined to successfully thin and salvage-log flat terrain only if the percentage of sawlogs is enough to cover the cost of logging pulpwood. In areas where soil impacts are of critical importance, this harvesting system may provide a method of harvesting where it might not otherwise be allowed. Further research is necessary to

evaluate the site impacts and economics of a range of conventional and new logging systems in order to determine the most cost effective method of protecting forest soils.

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APPENDIX A

Shift Level Forms

OSU Forest Engineering

Limber Jim

DAILY CHIPPER PRODUCTION

General Information

Date _____ Unit _____ Operator _____

Start Time _____
End Time _____
Breaks (hrs) _____
(only time spent in study unit)

Production

Total # of Loads	Truck Ticket Numbers	
	_____	_____
_____	_____	_____
	_____	_____
	_____	_____
	_____	_____

Delays (greater than 10 minutes)

Circle one of Mechanical, Maintenance, Personal, or External and describe. (Definitions are below)

Length (min)	_____	Mech / Main / Per / Ext (problem)	_____
Length (min)	_____	Mech / Main / Per / Ext (problem)	_____
Length (min)	_____	Mech / Main / Per / Ext (problem)	_____
Length (min)	_____	Mech / Main / Per / Ext (problem)	_____
Length (min)	_____	Mech / Main / Per / Ext (problem)	_____

Comments (Provide any additional information that may help to explain the day's production)

_____
_____
_____
_____
_____

Delay Definitions (>10 min)

Mechanical - Any delay caused by mechanical failure of the chipper
Maintenance - any time spent on regular maintenance of the chipper during the shift.
Personal - any delay caused by the operator (greater than 10 minutes).
External - Any delay caused by sources outside of the chipping system
(I.e. weather, waiting for other equipment, researchers, etc.)

OSU Forest Engineering

Limber Jim

Daily Loader Production

GENERAL INFORMATION

Date _____ Unit _____ Operator _____

Start Time _____ Approx. time loading/decking _____
End Time _____ Approx. time shovel logging _____
Breaks(hrs) _____ Approx. time other _____
(ONLY time spent in study unit)

PRODUCTION

Total # of loads _____

Truck Ticket Numbers

_____ _____
_____ _____
_____ _____
_____ _____
_____ _____

DELAYS (Greater than 10 minutes)

Circle one of Mechanical, Maintenance, Personal, or External and describe. (Definitions are below*)

Length _____ (min) Mech / Main / Per / Ext (problem) _____
Length _____ (min) Mech / Main / Per / Ext (problem) _____
Length _____ (min) Mech / Main / Per / Ext (problem) _____
Length _____ (min) Mech / Main / Per / Ext (problem) _____
Length _____ (min) Mech / Main / Per / Ext (problem) _____

COMMENTS (Provide any additional information that may help to explain the day's production)

_____
_____
_____
_____
_____

Delay Definitions (> 10 min):

Mechanical - Any delay caused by mechanical failure of the loader.
Maintenance - Any time spent on regular maintenance of the loader during the shift.
Personal - Any delay caused by the operator (greater than 10 minutes).
External - Any delay caused by sources outside of the loading system. (ie weather, waiting for other equipment)

OSU Forest Engineering

Limber Jim

Daily Harvester Production

GENERAL INFORMATION

Date _____ Operator _____

Start Time _____

End Time _____ Length of Shift (hrs) _____

Breaks (hrs) _____ (ONLY time spent in study unit)

Treatment Unit [Circle one]: Unit # 3, 4A, 4, 6A, 11, 11A, 16, 16A

DELAYS (Greater than 10 minutes)

Daily Regular Maintenance

# of Chains Broken _____

Time Spent on Daily Maintenace _____ (min)

# of Bars Broken _____

Production Delays (Circle one of Mechanical, Personal, External and describe)

Length _____ (min) Mech / Per / Ext (problem) _____

Length _____ (min) Mech / Per / Ext (problem) _____

Length _____ (min) Mech / Per / Ext (problem) _____

Length _____ (min) Mech / Per / Ext (problem) _____

Length _____ (min) Mech / Per / Ext (problem) _____

PRODUCTION

Total Logs produced _____ Sawlogs produced _____

Stems felled _____ Pulplogs produced _____

COMMENTS (Provide any additonal information that may be needed to justify the day's production)

_____

_____

_____

_____

_____

Delay Definitions: Mechanical - Any delay caused by mechanical failure of the harvester.
Personal - Any delay caused by the operator (> 10 min).
External - Any delay caused by sources outside of the harvesting system.

OSU Forest Engineering

Limber Jim

Daily Yarding Production

GENERAL INFORMATION

Date _____ Landing # _____

Start Time _____

End Time _____ Treatment Unit: Unit # 3, 4A, 4, 6A, 11, 11A, 16, 16A

Breaks(hrs) _____ (Indicate which treatment unit the yarder is working in.)

CREW AND PRODUCTION

Crew	Hours	#2	#3	
Yarding Engineer	_____			Turns/day _____
Hook Tender	_____			
Rigging Slinger	_____			Logs/day _____
Chaser(s)	_____	_____	_____	
Choker Setter(s)	_____	_____	_____	

DELAYS (Greater than 10 minutes)

Production Delays * Circle one of Mechanical, Rigging, Maintenance, Personal, or External and describe briefly.

Length _____ (min) Mech / Rig / Main / Per / Ext (prob) _____

Length _____ (min) Mech / Rig / Main / Per / Ext (prob) _____

Length _____ (min) Mech / Rig / Main / Per / Ext (prob) _____

Length _____ (min) Mech / Rig / Main / Per / Ext (prob) _____

Length _____ (min) Mech / Rig / Main / Per / Ext (prob) _____

Road Change Times (Estimate to the nearest 10 minutes)

Time Length _____ (min) From Landing #_____ to Landing #_____

Time Length _____ (min) From Landing #_____ to Landing #_____

COMMENTS (Provide any additional information that may help to explain the day's production)

_____

_____

_____

_____

_____

*** Delay Definitions:**

Mechanical - Any delay caused by mechanical failure of the yarding system.

Rigging - Any delay resulting from the rigging (other than road changes).

Maintenance - Any time spent on regular maintenance of the yarding system during the shift.

Personal - Any delay resulting from one of the crew members(greater than 10 minutes).

External - Any delay caused by sources outside of the yarding system. (ie weather, other equipment in the wa

APPENDIX B

Cost Equations used in PACE

Ownership Cost: Equations and Variables

P = purchase price
S = salvage value
RC = replacement cost of tires, tracks, line or rigging
N = estimated life of equipment
SH = scheduled hours / year
i = percentage of AAI for interest, taxes, licences, and insurance
% = borrowing rate + percent of AAI for insurance, licences, and tax

1. Straight-line Depreciation ($/year)

$$D = \frac{P - S - RC}{N}$$

2. Average Annual Investment ($/year)

$$AAI = \frac{(P - S) \cdot (N + 1)}{2N} + S$$

3. Interest, Taxes, Insurance, and Licence ($/year)

$$I = \% \cdot AAI$$

4. Ownership Cost ($/hour)

$$Ownership\ Cost = \frac{D + I}{SH}$$

Operating Cost: Equations and Variables

D = yearly depreciation, determined in Ownership Cost($/year)
d = percent of depreciation for repairs and maintenance
F = fuel consumption (gallons per hour)
f = fuel cost per gallon
L = percent of fuel consumption for oil and lubricants
l = cost of oil and lubricants per gallon
x_i = cost of major item on machine with a shorter life span than the machine
s_i = life span of the above item (hours)

1. Repair and Maintenance ($/hour)

$$RM = \frac{D \cdot d}{SH}$$

2. Fuel ($/hour)

$$Fuel = F \cdot f$$

3. Oil and Lubricants ($/hour)

$$OL = F \cdot L \cdot l$$

4. Other costs such as lines, rigging, tires, and tracks

$$Items = \Sigma \frac{x_i}{s_i}$$

5. Total Operating Cost ($/hour)

Operating Cost = RM + Fuel + OL + Items

Labor Cost: Equations and Variables

TW = total crew wage ($/hour)
F = percent for fringe benefits
T = travel time per day (hours)
OP = hours worked per day (hours)
SV = percent of direct labor cost for supervision(%)

1. Direct Labor Cost ($/hour)

$$Direct\ LC = TW \cdot \frac{OP + T}{OP} \cdot F$$

2. Supervision and Overhead ($/hour)

$$Supervision = Direct\ LC \cdot SV$$

3. Total Labor Cost

Total Labor Cost = Direct LC + Supervision

APPENDIX C

Owning, Operating, and Move-in Summary

Equipment Owning and Operating Costs

	owning cost/hr	operating cost/hr	labor cost/hr	move-in cost	rate per smh	
yarder	$ 47.88	$ 20.84	$ 141.75	$ 1,288.64	$ 210.47	
carriage	$ 5.22	$ 3.27			$ 8.49	
talkie tooter	$ 0.78	$ 0.24			$ 0.89	
chainsaw	$ 0.32	$ 0.91			$ 1.23	
pickup #1	$ 3.81	$ 2.39			$ 6.20	
pickup #2	$ 2.13	$ 1.80			$ 3.93	
loader	$ 28.68	$ 18.21	$ 25.07		$ 71.96	$ 303.17
harvester	$ 22.43	$ 12.62	$ 31.01	$ 949.09	$ 95.66	
fire truck	$ 0.12	$ 0.01			$ 0.13	
keto head	$ 5.43	$ 1.90			$ 12.68	
pickup	$ 2.13	$ 1.80			$ 3.93	
shop truck	$ 0.96	$ 1.59			$ 2.55	$ 114.95
TOTALS	$ 119.89	$ 65.58	$ 197.83	$ 2,237.73	$ 418.12	

Move In and Out Costs

	Labor Cost	Move Distance	Trucking Cost	Move in Cost	Move out Cost	Total Cost
Yarder & Loader	$ 2.07	83.40	$ 7.24	$ 644.32	$ 644.32	$ 1,288.64
Harvester	$ 2.07	83.40	$ 3.62	$ 474.55	$ 474.55	$ 949.09

Yarder (assumes move in from Pendleton)

transport: one low-boy for yarder and one low-boy for loader at $7.24 per mile combined

labor: flag vehicle at $2.07 per mile

Harvester (assumes move in from Pendleton)

transport: low-boy at $3.62 per mile

labor: flag vehicle at $2.07 per mile

APPENDIX D

Wage Summary

Labor Rates for Equipment Operators[13]

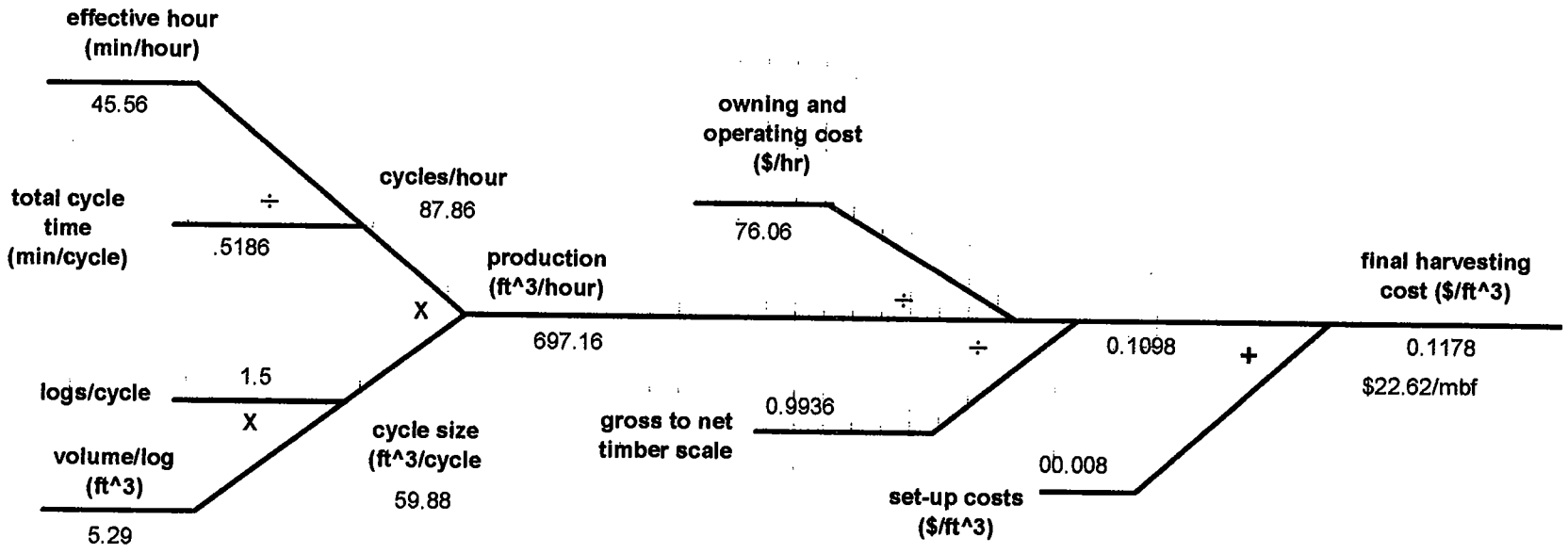
Employee	Base Wage	
Hooktender	$ 14.01	
Rigging slinger	$ 12.94	
Yarder Engineer	$ 13.48	
Chokersetter	$ 11.48	(all wages are increased by 40% for fringe benefits)
Loader operator	$ 13.84	
Harvester operator	$ 12.84	
Chipper operator	$ 12.00	

[13] Labor rates are from the Associated Oregon Loggers 1996 Annual Wage Survey

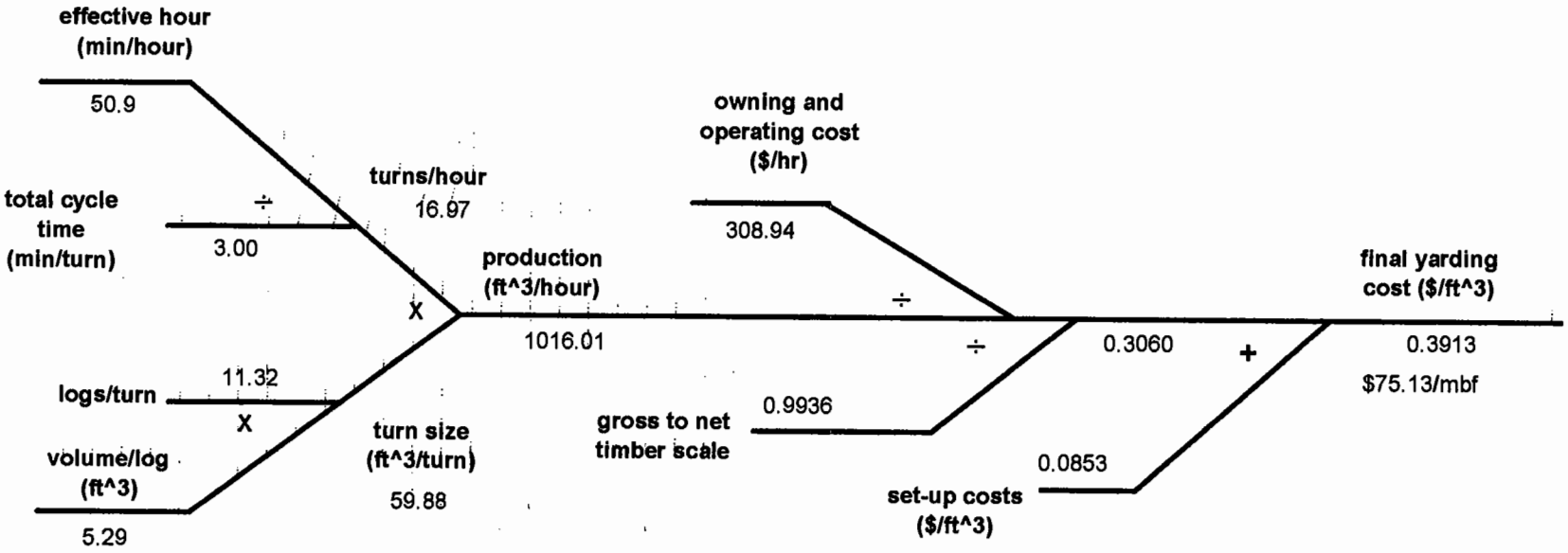
APPENDIX E

Cost Trees

Cost tree for Harvester - All Units



Cost Tree for Yarder - All Units



APPENDIX F

Owning, Operating, and Labor Sheets from PACE

Eagle Eaglet Carriage

Equipment Ownership Cost Inputs			
Delivered equipment cost	$	34,500.00	
Minus line and rigging cost	$	250.00	
minus tire or track replacement cost	$	0.00	
minus residual (salvage) value	$	8,000.00	
Life of equipment	#	5.00	
number of days worked per year	#	200.00	
Number of hours worked per day	#	8.00	
Interest Expense	%	10.00	
Percent of average annual investment for:			
taxes, license, insurance, and storage	%	3.00	
Equipment Operating Cost Inputs			
Percent of equipment depreciation for repairs	%	50.00	
Fuel amount (gallons per hour)	#	1.00	
Fuel cost (per gallon)	$	1.10	
Percent of fuel consumption for lubricants	%	7.00	
Cost of oil and lubricants (per gallon)	$	3.50	
cost of lines	$	250.00	
Estimated life of lines (hours)	#	1,000.00	
Cost of rigging	$	150.00	
Estimated life of rigging (hours)	#	4,000.00	
Cost of tires or tracks	$	0.00	
estimated life of tires or tracks (hours)	#	0.00	
Summary			
Ownership			
Depreciable value:	$	26,250.00	
Equipment depreciation:	$	5,250.00	/ Year
Interest expense:	$	2,390.00	/ Year
Taxes, license, insurance and storage:	$	717.00	/ Year
annual ownership cost:	$	8,357.00	/ Year
Ownership cost (subtotal):	$	5.22	/ Hour
Machine operating cost			
Repairs and maintenance:	$	1.64	/ Hour
Fuel and oil:	$	1.35	/ Hour
Lines and rigging:	$	0.29	/ Hour
Tires or tracks:	$	0.00	/ Hour
Equipment operating cost (subtotal):	$	3.27	/ Hour
Labor			
Direst labor cost:	$	0.00	/ Hour
supervision and overhead:	$	0.00	/ Hour
Labor cost (Subtotal):	$	0.00	/ Hour
OWNERSHIP COST	$	5.22	/ Hour
OPERATION COST	$	3.27	/ Hour
LABOR COST	$	0.00	/ Hour
Machine rate (Ownership + Operating + Labor)	$	8.50	/ Hour

Talkie Tooter

Equipment Ownership Cost Inputs			
Delivered equipment cost	$	6,000.00	
Minus line and rigging cost	$	0.00	
minus tire or track replacement cost	$	0.00	
minus residual (salvage) value	$	1,200.00	
Life of equipment	#	7.00	
number of days worked per year	#	200.00	
Number of hours worked per day	#	8.00	
Interest Expense	%	10.00	
Percent of average annual investment for:			
taxes, license, insurance, and storage	%	3.00	
Equipment Operating Cost Inputs			
Percent of equipment depreciation for repairs	%	25.00	
Fuel amount (gallons per hour)	#	0.00	
Fuel cost (per gallon)	$	0.00	
Percent of fuel consumption for lubricants	%	0.00	
Cost of oil and lubricants (per gallon)	$	0.00	
cost of lines	$	0.00	
Estimated life of lines (hours)	#	0.00	
Cost of rigging	$	0.00	
Estimated life of rigging (hours)	#	0.00	
Cost of tires or tracks	$	0.00	
estimated life of tires or tracks (hours)	#	0.00	
Summary			
Ownership			
Depreciable value:	$	5,000.00	
Equipment depreciation:	$	714.29	/ Year
Interest expense:	$	405.71	/ Year
Taxes, license, insurance and storage:	$	121.71	/ Year
annual ownership cost:	$	1,241.71	/ Year
Ownership cost (subtotal):	$	0.78	/ Hour
Machine operating cost			
Repairs and maintenance:	$	0.11	/ Hour
Fuel and oil:	$	0.00	/ Hour
Lines and rigging:	$	0.13	/ Hour
Tires or tracks:	$	0.00	/ Hour
Equipment operating cost (subtotal):	$	0.11	/ Hour
Labor			
Direst labor cost:	$	0.00	/ Hour
supervision and overhead:	$	0.00	/ Hour
Labor cost (Subtotal):	$	0.00	/ Hour
OWNERSHIP COST	$	0.78	/ Hour
OPERATION COST	$	0.11	/ Hour
LABOR COST	$	0.00	/ Hour
Machine rate (Ownership + Operating + Labor)	$	0.89	/ Hour

Diamond D210 Swing Yarder

Equipment Ownership Cost Inputs			
Delivered equipment cost	$	375,000.00	
Minus line and rigging cost	$	10,000.00	
minus tire or track replacement cost	$	0.00	
minus residual (salvage) value	$	112,500.00	
Life of equipment	#	6.00	
number of days worked per year	#	200.00	
Number of hours worked per day	#	8.00	
Interest Expense	%	10.00	
Percent of average annual investment for:			
taxes, license, insurance, and storage	%	3.00	
Equipment Operating Cost Inputs			
Percent of equipment depreciation for repairs	%	50.00	
Fuel amount (gallons per hour)	#	4.00	
Fuel cost (per gallon)	$	1.10	
Percent of fuel consumption for lubricants	%	7.00	
Cost of oil and lubricants (per gallon)	$	3.50	
cost of lines	$	5,000.00	
Estimated life of lines (hours)	#	3,200.00	
Cost of rigging	$	3,000.00	
Estimated life of rigging (hours)	#	4,000.00	
Cost of tires or tracks	$	0.00	
estimated life of tires or tracks (hours)	#	0.00	
Summary			
Ownership			
Depreciable value:	$	252,500.00	/ Year
Equipment depreciation:	$	42,083.33	/ Year
Interest expense:	$	26,562.50	/ Year
Taxes, license, insurance and storage:	$	7,968.75	/ Year
annual ownership cost:	$	76,614.58	/ Year
Ownership cost (subtotal):	$	47.88	/ Hour
Machine operating cost			
Repairs and maintenance:	$	13.15	/ Hour
Fuel and oil:	$	5.38	/ Hour
Lines and rigging:	$	2.31	/ Hour
Tires or tracks:	$	0.00	/ Hour
Equipment operating cost (subtotal):	$	20.84	/ Hour
Labor			
Direst labor cost:	$	123.26	/ Hour
supervision and overhead:	$	18.49	/ Hour
Labor cost (Subtotal):	$	141.75	/ Hour
OWNERSHIP COST	$	47.88	/ Hour
OPERATION COST	$	20.84	/ Hour
LABOR COST	$	141.75	/ Hour
Machine rate (Ownership + Operating + Labor)	$	210.47	/ Hour

Crew Pick-up Truck

Equipment Ownership Cost Inputs			
Delivered equipment cost	$	25,665.00	
Minus line and rigging cost	$	0.00	
minus tire or track replacement cost	$	400.00	
minus residual (salvage) value	$	500.00	
Life of equipment	#	6.00	
number of days worked per year	#	200.00	
Number of hours worked per day	#	8.00	
Interest Expense	%	10.00	
Percent of average annual investment for:			
taxes, license, insurance, and storage	%	3.00	
Equipment Operating Cost Inputs			
Percent of equipment depreciation for repairs	%	50.00	
Fuel amount (gallons per hour)	#	0.75	
Fuel cost (per gallon)	$	1.10	
Percent of fuel consumption for lubricants	%	1.75	
Cost of oil and lubricants (per gallon)	$	4.00	
cost of lines	$	0.00	
Estimated life of lines (hours)	#	0.00	
Cost of rigging	$	0.00	
Estimated life of rigging (hours)	#	0.00	
Cost of tires or tracks	$	400.00	
estimated life of tires or tracks (hours)	#	1,800.00	
Summary			
Ownership			
Depreciable value:	$	24,765.00	/ Year
Equipment depreciation:	$	4,127.50	/ Year
Interest expense:	$	1,517.96	/ Year
Taxes, license, insurance and storage:	$	455.39	/ Year
annual ownership cost:	$	6,100.85	/ Year
Ownership cost (subtotal):	$	3.81	/ Hour
Machine operating cost			
Repairs and maintenance:	$	1.29	/ Hour
Fuel and oil:	$	0.88	/ Hour
Lines and rigging:	$	0.00	/ Hour
Tires or tracks:	$	0.22	/ Hour
Equipment operating cost (subtotal):	$	2.39	/ Hour
Labor			
Direst labor cost:	$	0.00	/ Hour
supervision and overhead:	$	0.00	/ Hour
Labor cost (Subtotal):	$	0.00	/ Hour
OWNERSHIP COST	$	3.81	/ Hour
OPERATION COST	$	2.39	/ Hour
LABOR COST	$	0.00	/ Hour
Machine rate (Ownership + Operating + Labor)	$	6.20	/ Hour

Chainsaw

Equipment Ownership Cost Inputs			
Delivered equipment cost	$	1,000.00	
Minus line and rigging cost	$	0.00	
minus tire or track replacement cost	$	0.00	
minus residual (salvage) value	$	200.00	
Life of equipment	#	2.00	
number of days worked per year	#	200.00	
Number of hours worked per day	#	8.00	
Interest Expense	%	10.00	
Percent of average annual investment for:			
taxes, license, insurance, and storage	%	3.00	
Equipment Operating Cost Inputs			
Percent of equipment depreciation for repairs	%	75.00	
Fuel amount (gallons per hour)	#	0.25	
Fuel cost (per gallon)	$	1.30	
Percent of fuel consumption for lubricants	%	15.00	
Cost of oil and lubricants (per gallon)	$	4.00	
cost of lines	$	30.00	
Estimated life of lines (hours)	#	120.00	
Cost of rigging	$	0.00	
Estimated life of rigging (hours)	#	0.00	
Cost of tires or tracks	$	0.00	
estimated life of tires or tracks (hours)	#	0.00	
Summary			
Ownership			
Depreciable value:	$	800.00	
Equipment depreciation:	$	400.00	/ Year
Interest expense:	$	80.00	/ Year
Taxes, license, insurance and storage:	$	24.00	/ Year
annual ownership cost:	$	504.00	/ Year
Ownership cost (subtotal):	$	0.32	/ Hour
Machine operating cost			
Repairs and maintenance:	$	0.19	/ Hour
Fuel and oil:	$	0.47	/ Hour
Lines and rigging:	$	0.25	/ Hour
Tires or tracks:	$	0.00	/ Hour
Equipment operating cost (subtotal):	$	0.91	/ Hour
Labor			
Direst labor cost:	$	0.00	/ Hour
supervision and overhead:	$	0.00	/ Hour
Labor cost (Subtotal):	$	0.00	/ Hour
OWNERSHIP COST	$	0.32	/ Hour
OPERATION COST	$	0.91	/ Hour
LABOR COST	$	0.00	/ Hour
Machine rate (Ownership + Operating + Labor)	$	1.23	/ Hour

Pick-up #2

Equipment Ownership Cost Inputs			
Delivered equipment cost	$	22,032.00	
Minus line and rigging cost	$	0.00	
minus tire or track replacement cost	$	400.00	
minus residual (salvage) value	$	1,500.00	
Life of equipment	#	6.00	
number of days worked per year	#	300.00	
Number of hours worked per day	#	8.00	
Interest Expense	%	10.00	
Percent of average annual investment for:			
taxes, license, insurance, and storage	%	3.00	
Equipment Operating Cost Inputs			
Percent of equipment depreciation for repairs	%	50.00	
Fuel amount (gallons per hour)	#	0.75	
Fuel cost (per gallon)	$	1.10	
Percent of fuel consumption for lubricants	%	1.75	
Cost of oil and lubricants (per gallon)	$	4.00	
cost of lines	$	0.00	
Estimated life of lines (hours)	#	0.00	
Cost of rigging	$	0.00	
Estimated life of rigging (hours)	#	0.00	
Cost of tires or tracks	$	400.00	
estimated life of tires or tracks (hours)	#	1,800.00	
Summary			
Ownership			
Depreciable value:	$	20,132.00	/ Year
Equipment depreciation:	$	3,355.33	/ Year
Interest expense:	$	1,347.70	/ Year
Taxes, license, insurance and storage:	$	404.31	/ Year
annual ownership cost:	$	5,107.34	/ Year
Ownership cost (subtotal):	$	2.13	/ Hour
Machine operating cost			
Repairs and maintenance:	$	0.70	/ Hour
Fuel and oil:	$	0.88	/ Hour
Lines and rigging:	$	0.00	/ Hour
Tires or tracks:	$	0.22	/ Hour
Equipment operating cost (subtotal):	$	1.80	/ Hour
Labor			
Direst labor cost:	$	0.00	/ Hour
supervision and overhead:	$	0.00	/ Hour
Labor cost (Subtotal):	$	0.00	/ Hour
OWNERSHIP COST	$	2.13	/ Hour
OPERATION COST	$	1.80	/ Hour
LABOR COST	$	0.00	/ Hour
Machine rate (Ownership + Operating + Labor)	$	3.93	/ Hour

John Deere 690 Loader

Equipment Ownership Cost Inputs			
Delivered equipment cost	$	250,000.00	
Minus line and rigging cost	$	0.00	
minus tire or track replacement cost	$	13,000.00	
minus residual (salvage) value	$	75,000.00	
Life of equipment	#	7.00	
number of days worked per year	#	200.00	
Number of hours worked per day	#	8.00	
Interest Expense	%	10.00	
Percent of average annual investment for:			
taxes, license, insurance, and storage	%	3.00	
Equipment Operating Cost Inputs			
Percent of equipment depreciation for repairs	%	70.00	
Fuel amount (gallons per hour)	#	4.00	
Fuel cost (per gallon)	$	1.20	
Percent of fuel consumption for lubricants	%	7.00	
Cost of oil and lubricants (per gallon)	$	4.00	
cost of lines	$	0.00	
Estimated life of lines (hours)	#	0.00	
Cost of rigging	$	0.00	
Estimated life of rigging (hours)	#	0.00	
Cost of tires or tracks	$	13,000.00	
estimated life of tires or tracks (hours)	#	6,000.00	
Summary			
Ownership			
Depreciable value:	$	162,000.00	/ Year
Equipment depreciation:	$	23,142.86	/ Year
Interest expense:	$	17,500.00	/ Year
Taxes, license, insurance and storage:	$	5,250.00	/ Year
annual ownership cost:	$	45,892.86	/ Year
Ownership cost (subtotal):	$	28.68	/ Hour
Machine operating cost			
Repairs and maintenance:	$	10.13	/ Hour
Fuel and oil:	$	5.92	/ Hour
Lines and rigging:	$	0.00	/ Hour
Tires or tracks:	$	2.17	/ Hour
Equipment operating cost (subtotal):	$	18.21	/ Hour
Labor			
Direst labor cost:	$	21.80	/ Hour
supervision and overhead:	$	3.27	/ Hour
Labor cost (Subtotal):	$	25.07	/ Hour
OWNERSHIP COST	$	28.68	/ Hour
OPERATION COST	$	18.21	/ Hour
LABOR COST	$	25.07	/ Hour
Machine rate (Ownership + Operating + Labor)	$	71.96	/ Hour

Fire Equipement

Equipment Ownership Cost Inputs			
Delivered equipment cost	$	1,200.00	
Minus line and rigging cost	$	0.00	
minus tire or track replacement cost	$	0.00	
minus residual (salvage) value	$	200.00	
Life of equipment	#	10.00	
number of days worked per year	#	200.00	
Number of hours worked per day	#	8.00	
Interest Expense	%	10.00	
Percent of average annual investment for:			
taxes, license, insurance, and storage	%	3.00	
Equipment Operating Cost Inputs			
Percent of equipment depreciation for repairs	%	10.00	
Fuel amount (gallons per hour)	#	0.00	
Fuel cost (per gallon)	$	0.00	
Percent of fuel consumption for lubricants	%	1.00	
Cost of oil and lubricants (per gallon)	$	4.00	
cost of lines	$	0.00	
Estimated life of lines (hours)	#	0.00	
Cost of rigging	$	0.00	
Estimated life of rigging (hours)	#	0.00	
Cost of tires or tracks	$	0.00	
estimated life of tires or tracks (hours)	#	0.00	
Summary			
Ownership			
Depreciable value:	$	1,000.00	/ Year
Equipment depreciation:	$	100.00	/ Year
Interest expense:	$	75.00	/ Year
Taxes, license, insurance and storage:	$	22.50	/ Year
annual ownership cost:	$	197.50	/ Year
Ownership cost (subtotal):	$	0.12	/ Hour
Machine operating cost			
Repairs and maintenance:	$	0.01	/ Hour
Fuel and oil:	$	0.00	/ Hour
Lines and rigging:	$	0.00	/ Hour
Tires or tracks:	$	0.00	/ Hour
Equipment operating cost (subtotal):	$	0.01	/ Hour
Labor			
Direst labor cost:	$	0.00	/ Hour
supervision and overhead:	$	0.00	/ Hour
Labor cost (Subtotal):	$	0.00	/ Hour
OWNERSHIP COST	$	0.12	/ Hour
OPERATION COST	$	0.01	/ Hour
LABOR COST	$	0.00	/ Hour
Machine rate (Ownership + Operating + Labor)	$	0.13	/ Hour

Hitachi EX200 LC

Equipment Ownership Cost Inputs			
Delivered equipment cost	$	235,000.00	
Minus line and rigging cost	$	0.00	
minus tire or track replacement cost	$	13,000.00	
minus residual (salvage) value	$	75,000.00	
Life of equipment	#	5.00	
number of days worked per year	#	200.00	
Number of hours worked per day	#	8.00	
Interest Expense	%	12.00	
Percent of average annual investment for:			
taxes, license, insurance, and storage	%	5.00	
Equipment Operating Cost Inputs			
Percent of equipment depreciation for repairs	%	70.00	
Fuel amount (gallons per hour)	#	5.00	
Fuel cost (per gallon)	$	1.20	
Percent of fuel consumption for lubricants	%	30.00	
Cost of oil and lubricants (per gallon)	$	4.00	
cost of lines	$	0.00	
Estimated life of lines (hours)	#	0.00	
Cost of rigging	$	0.00	
Estimated life of rigging (hours)	#	0.00	
Cost of tires or tracks	$	13,000.00	
estimated life of tires or tracks (hours)	#	4,000.00	
Summary			
Ownership			
Depreciable value:	$	147,000.00	/ Year
Equipment depreciation:	$	29,400.00	/ Year
Interest expense:	$	20,520.00	/ Year
Taxes, license, insurance and storage:	$	8,550.00	/ Year
annual ownership cost:	$	58,470.00	/ Year
Ownership cost (subtotal):	$	36.54	/ Hour
Machine operating cost			
Repairs and maintenance:	$	12.86	/ Hour
Fuel and oil:	$	12.00	/ Hour
Lines and rigging:	$	0.00	/ Hour
Tires or tracks:	$	3.25	/ Hour
Equipment operating cost (subtotal):	$	28.11	/ Hour
Labor			
Direst labor cost:	$	26.96	/ Hour
supervision and overhead:	$	4.04	/ Hour
Labor cost (Subtotal):	$	31.01	/ Hour
OWNERSHIP COST	$	36.54	/ Hour
OPERATION COST	$	28.11	/ Hour
LABOR COST	$	31.01	/ Hour
Machine rate (Ownership + Operating + Labor)	$	95.66	/ Hour

Shop Truck for Harvester

Equipment Ownership Cost Inputs			
Delivered equipment cost	$	10,000.00	
Minus line and rigging cost	$	0.00	
minus tire or track replacement cost	$	600.00	
minus residual (salvage) value	$	3,000.00	
Life of equipment	#	10.00	
number of days worked per year	#	200.00	
Number of hours worked per day	#	8.00	
Interest Expense	%	10.00	
Percent of average annual investment for:			
taxes, license, insurance, and storage	%	3.00	
Equipment Operating Cost Inputs			
Percent of equipment depreciation for repairs	%	50.00	
Fuel amount (gallons per hour)	#	0.75	
Fuel cost (per gallon)	$	1.35	
Percent of fuel consumption for lubricants	%	10.00	
Cost of oil and lubricants (per gallon)	$	4.00	
cost of lines	$	0.00	
Estimated life of lines (hours)	#	0.00	
Cost of rigging	$	0.00	
Estimated life of rigging (hours)	#	0.00	
Cost of tires or tracks	$	600.00	
estimated life of tires or tracks (hours)	#	8,000.00	
Summary			
Ownership			
Depreciable value:	$	6,400.00	/ Year
Equipment depreciation:	$	640.00	/ Year
Interest expense:	$	685.00	/ Year
Taxes, license, insurance and storage:	$	205.50	/ Year
annual ownership cost:	$	1,530.50	/ Year
Ownership cost (subtotal):	$	0.96	/ Hour
Machine operating cost			
Repairs and maintenance:	$	0.20	/ Hour
Fuel and oil:	$	1.31	/ Hour
Lines and rigging:	$	0.00	/ Hour
Tires or tracks:	$	0.08	/ Hour
Equipment operating cost (subtotal):	$	1.59	/ Hour
Labor			
Direst labor cost:	$	0.00	/ Hour
supervision and overhead:	$	0.00	/ Hour
Labor cost (Subtotal):	$	0.00	/ Hour
OWNERSHIP COST	$	0.96	/ Hour
OPERATION COST	$	1.59	/ Hour
LABOR COST	$	0.00	/ Hour
Machine rate (Ownership + Operating + Labor)	$	2.54	/ Hour

Keto Harvester Head

Equipment Ownership Cost Inputs			
Delivered equipment cost	$	35,000.00	
Minus line and rigging cost	$	0.00	
minus tire or track replacement cost	$	0.00	
minus residual (salvage) value	$	7,000.00	
Life of equipment	#	5.00	
number of days worked per year	#	200.00	
Number of hours worked per day	#	8.00	
Interest Expense	%	12.00	
Percent of average annual investment for:			
taxes, license, insurance, and storage	%	3.00	
Equipment Operating Cost Inputs			
Percent of equipment depreciation for repairs	%	70.00	
Fuel amount (gallons per hour)	#	0.50	
Fuel cost (per gallon)	$	0.00	
Percent of fuel consumption for lubricants	%	100.00	
Cost of oil and lubricants (per gallon)	$	4.00	
cost of lines	$	0.00	
Estimated life of lines (hours)	#	0.00	
Cost of rigging	$	500.00	
Estimated life of rigging (hours)	#	200.00	
Cost of tires or tracks	$	0.00	
estimated life of tires or tracks (hours)	#	0.00	
Summary			
Ownership			
Depreciable value:	$	28,000.00	/ Year
Equipment depreciation:	$	5,600.00	/ Year
Interest expense:	$	2,856.00	/ Year
Taxes, license, insurance and storage:	$	714.00	/ Year
annual ownership cost:	$	9,170.00	/ Year
Ownership cost (subtotal):	$	5.73	/ Hour
Machine operating cost			
Repairs and maintenance:	$	2.45	/ Hour
Fuel and oil:	$	2.00	/ Hour
Lines and rigging:	$	2.50	/ Hour
Tires or tracks:	$	0.00	/ Hour
Equipment operating cost (subtotal):	$	6.95	/ Hour
Labor			
Direst labor cost:	$	0.00	/ Hour
supervision and overhead:	$	0.00	/ Hour
Labor cost (Subtotal):	$	0.00	/ Hour
OWNERSHIP COST	$	5.73	/ Hour
OPERATION COST	$	6.95	/ Hour
LABOR COST	$	0.00	/ Hour
Machine rate (Ownership + Operating + Labor)	$	12.68	/ Hour

27" Morbark Chipper

Equipment Ownership Cost Inputs			
Delivered equipment cost	$	135,000.00	
Minus line and rigging cost	$	500.00	
minus tire or track replacement cost	$	2,000.00	
minus residual (salvage) value	$	27,000.00	
Life of equipment	#	6.00	
number of days worked per year	#	200.00	
Number of hours worked per day	#	8.00	
Interest Expense	%	10.00	
Percent of average annual investment for:			
taxes, license, insurance, and storage	%	3.00	
Equipment Operating Cost Inputs			
Percent of equipment depreciation for repairs	%	50.00	
Fuel amount (gallons per hour)	#	4.00	
Fuel cost (per gallon)	$	1.10	
Percent of fuel consumption for lubricants	%	7.00	
Cost of oil and lubricants (per gallon)	$	3.50	
cost of lines	$	0.00	
Estimated life of lines (hours)	#	0.00	
Cost of rigging	$	500.00	
Estimated life of rigging (hours)	#	800.00	
Cost of tires or tracks	$	2,000.00	
estimated life of tires or tracks (hours)	#	4,800.00	
Summary			
Ownership			
Depreciable value:	$	105,500.00	/ Year
Equipment depreciation:	$	17,583.33	/ Year
Interest expense:	$	9,000.00	/ Year
Taxes, license, insurance and storage:	$	2,700.00	/ Year
annual ownership cost:	$	29,283.33	/ Year
Ownership cost (subtotal):	$	18.30	/ Hour
Machine operating cost			
Repairs and maintenance:	$	5.49	/ Hour
Fuel and oil:	$	5.38	/ Hour
Lines and rigging:	$	0.63	/ Hour
Tires or tracks:	$	0.42	/ Hour
Equipment operating cost (subtotal):	$	11.92	/ Hour
Labor			
Direst labor cost:	$	19.95	/ Hour
supervision and overhead:	$	2.00	/ Hour
Labor cost (Subtotal):	$	21.95	/ Hour
OWNERSHIP COST	$	18.30	/ Hour
OPERATION COST	$	11.92	/ Hour
LABOR COST	$	21.95	/ Hour
Machine rate (Ownership + Operating + Labor)	$	52.16	/ Hour

APPENDIX G

Assumptions

Limber Jim Assumptions

I. Site characteristics

1. *Slope* - Slope was not significant for the skyline units
2. *Average yarding distance* - Yarding distances are looked at over a range of distances as they are not linear
3. *Uphill vs. downhill yarding* - There is no significant difference between downhill and uphill yarding
4. *Trees per acre removed* - all pre and post stand data comes from the USFS
5. *Down material per acre removed* - The best information for this data is from the USFS
6. *Average tree size* - Average tree size is from plot data where each standing tree in the plot was measured for diameter at breast height and tree height to a 2 inch top

II. Production rates

1. *Production relationships* – Because the chipping and harvesting operations were common to both the skyline and forwarder units, this information was pooled
2. *Loading* - There were no loading activities observed
3. *Hauling* - Hauling times were not available
4. *Productive time* - Productive time includes normal operating delays less than 10 minutes
5. *Utilization rates* - Utilization rates are calculated per scheduled machine hour
6. *Log sizes* - Log sizes differed between the skyline units and the forwarder units, therefore, volume per log was converted to volume per linear foot and the data was combined
7. *Production units* - Cubic foot volume was the basic unit and all conversions were converted from this. Chips were converted to bone dry units
8. *Chip van weights* - All chip van data was combined and an average was used

III. Equipment costs

1. *Replacement costs* - New replacement costs were used for calculating equipment rates (see Appendix F)

IV. Move-in costs

1. Move-in and move-out - These costs were calculated from Pendleton, OR and were used on a per SMH basis

V. Management costs

1. Supervision and overhead - 15% was used for supervision and overhead

VI. Final output

1. Output units - data from the mill was in tons, therefore, $/ton is the basic unit

APPENDIX H

Conversions

Note: Information provided by the purchaser was in tons for pulpwood with tons and mbf for sawlogs. Therefore, it was necessary to convert from these quantities to m^3, ft^3, and mbf (for pulpwood). Prices were given in dollars per mbf for sawlogs, and dollars per bone dry unit for pulpwood.

CONVERSION FACTORS:

0.0283 m^3 per ft^3

0.23 ft^3 per linear foot of log

5536.5 linear feet per chip van

192 ft^3 per mbf

5.29 ft^3 per log

2400 lbs per bone dry unit

Equation for Fuel Loading

Fuel Loading = $(11.64 * \Sigma dia^2 * s * a * c) / n * l$

where:

a = non-horizontal angle correction	a = 1
s = specific gravity	s = 1
c = slope correction factor	c = 1
n = number of sample plots	n = 1
l = length of sample plane	l = 74.47 feet

Conversion from $/bdu to $/green ton

($/bdu)*(1 bdu/2400 lbs)*(2000 lbs/ton)*(1/((%mc/100) + 1)

mc = 73.14%