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Title: THE DEERHORN CASE STUDY: A Production and Cost Analysis of a Single-Grip Harvester and Small Cable Yarder Performing a Thinning/Salvage Operation in Eastern Oregon.

Abstract approved: Loren D. Kellogg

Loren D. Kellogg

Land managers in the Blue Mountains of eastern Oregon are currently faced with large areas of forest with health problems and extreme levels of fuel loading in the stand and on the forest floor. 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 economic analysis of a harvesting system aimed at treating these stands while minimizing soil impacts.

A combined thinning of the dense stands 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 small cable yarder to transport the logs to landings. The terrain on the site was flat and therefore presented logistical challenges for yarding. This unique combination of equipment was chosen to minimize machine traffic on the site in an attempt to reduce ground impacts on areas with sensitive soils or critical habitat concerns.

The harvester was to fall and process all non-marked standing trees and process any solid stems on the forest floor into logs. A Koller K501 yarder

(33ft tower), using a standing skyline, slackline system rigged with a tail tree and occasionally an intermediate support, was used to transport the logs to the landing. Production estimates obtained for the harvester and yarder were 7.33 cunits/PMH (20.74 m^3/PMH[1]) and 5.41 cunits/PMH (15.31 m^3/PMH) respectively. Actual system production was approximately three to four truck loads removed off the site on an average day, with some days as low as two loads and some as high as six loads. An average truck load contained 5 Mbf (28.3 m^3) or 24 tons (21.7 tonnes) of wood.

Total logging cost for the system (stump to mill) was $78,809 which equated to $97/cunit ($34.24/m³) or $42.44/ton ($46.78/tonne) of material removed. On a per acre basis, the cost was $1,970/acre ($4869/ha). The presence of sawlogs in the unit allowed the landowner to make a profit from revenues of $103,258. Sawlogs made up 28% of the volume or 34% of the weight removed from the site but contributed 57% of the revenue generated. At the time of the study, pulpwood prices were approximately $36/ton and sawlog prices were approximately $515/Mbf. The logging cost of $42.44/ton was greater than the value of the pulpwood and thus logging was made profitable by the presence of sawlogs.

The thinning and salvage logging of a flat eastern Oregon stand with the combination of a single-grip harvester and small cable yarder proved to be reasonably cost efficient. The costs determined in this case study appear to be higher than traditional ground based methods of logging in similar terrain, but the cable system appears to have resulted in less soil impacts. Thus, in areas were soil protection is the most important consideration, this logging system may be a viable alternative to traditional ground based logging systems. Further research is recommended to evaluate potential improvements in the harvester - skyline system and to more fully compare this system with conventional skidding and forwarding systems, under the context of minimizing soil impacts.

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[1] PMH = Productive machine hour

THE DEERHORN CASE STUDY:
A Production and Cost Analysis of a Single-Grip Harvester and Small Cable Yarder Performing a Thinning/Salvage Operation in Eastern Oregon.

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1.0 Introduction

Almost every pioneer journal from the 1850's that describes the Blue Mountains portion of the Oregon Trail noted and marvelled at the tall, "magnificent" pines, large grassy openings, and the lack of underbrush [Evans 1990]. The current state of much of these forests bears little resemblance to these earlier descriptions, due in part to a combination of management practices and natural occurrences. Wickman (1992) characterized these present day stands as "thickets of sapling and pole-sized fir severely defoliated by western spruce budworm, scattered Douglas-fir (Pseudotsuga menziesii) and grand fir (Abies grandis) being killed by bark beetles, pockets of root disease killing fir, and scattered second growth stands of ponderosa pine that often are infected with dwarf mistletoe".

This transition had begun by the early 1900's as the fire dependant ecosystems of the area were altered by the attempt to exclude fire [Agee 1990]. As fire suppression became more efficient, fuels - including forest floor duff, dead woody material, and dense conifer thickets - were building to an alarming level in many stands [Hall 1976]. Also contributing to the decline in forest health were such factors as the extensive harvesting of the western larch and ponderosa pine overstory during the 1900's, the continued drought, and epidemic levels of insect infestations and disease found in the replacement stands of shade tolerant fir [Mutch 1993].

The suppression of fire and the high levels of mortality occurring in these stands created massive fuel stockpiles and the threat of intense, highly destructive fires. Arno and Brown (1991) observed that, since the late 1970's, there has been an abundance of large, severe wildfires that have occurred in the Blue Mountains and elsewhere in the inland West. They suggest that attempts to eliminate fire in these areas have simply led to a different fire regime; one where frequent low intensity fires are replaced by severe, uncontrollable fires burning in heavy fuels.

Land Managers in eastern Oregon are now faced with the challenge of restoring many acres of dilapidated forests. They are faced with stands that are overstocked and have medium to heavy surface slash as a result of several factors. Where the occurrence of frequent, low intensity fires would have reduced the amount of successful regeneration and eliminated woody debris on the forest floor, fire suppression has allowed the stand to become dense and contain excessive amounts of down woody debris. Frequent insect infestations and coniferous tree pathologies have also contributed to the deterioration of the health of the stands. Most suggested management activities that have been proposed to attempt to restore the area to its previous state include the reintroduction of fire into the ecosystem. But, because many stands are now excessively dense and contain high fuel loads it is not possible to simply reinstate fire into the ecology of the area as it would be far too destructive. Mutch et al. (1993) suggest that " where large quantities of standing dead trees are present, salvage logging should be encouraged to remove unnatural accumulations of fuel and to obtain wood products". This concept is the guiding principle behind the project described in this paper.

Operational technology and economics have limited the options available to land managers to accomplish this goal because of environmental standards that must be maintained and the low economic value of current stands. For example, government land managers must select logging systems that are cost effective and have a minimal negative impact on the growing site and timber stand. Traditional logging systems employed on gentle terrain have utilized skidders and crawler tractors for primary log transport, and more recently forwarders have been used to accomplish this task. These systems all involve machinery making repetitive passes over some portion of a given unit and thus there is potential for negative impacts on the soil (compaction and disturbance) to occur if the logging is not properly planned and managed. These negative impacts can be minimized or eliminated through measures such as logging on snow or surface slash, designating trails that the machines cannot leave, and using special low ground pressure vehicles.

The Deerhorn project is an attempt to utilize an alternative to ground based harvesting systems to salvage downed material and thin standing volume while minimizing soil impacts. Managers working for the US Forest Service in La Grande, Oregon, proposed the combination of a single-grip harvester to process the material being removed and a small cable yarder using a standing skyline system to transport logs over the flat terrain to landings. This pilot project was a test of this system's ability to meet certain environmental constraints necessary to manage fuel conditions in the Upper Grande Ronde and Beaver Creek watersheds. Management of fuel conditions is made difficult in these areas because of the presence of critical habitat for endangered and old growth dependant fish and wildlife species, as well as the "roadless" designation for the areas and the presence of the La Grande municipal watershed in the Beaver Creek drainage. The study site would not normally have the same level of management restrictions as mentioned above but it is being treated as such in order to explore the feasibility of applying this system to the intended operational areas.

Government land managers are striving to eliminate negative soil impacts in areas of sensitive soils or critical habitat and thus are searching for logging systems that are able to meet this requirement within reasonable economic limits. Private land managers are likely to have their own idea of what constitutes "acceptable" soil impacts for their land and may not find it cost effective to try and totally eliminate these impacts. It is the situation faced by the Forest Service in La Grande, Oregon that is driving this study.

A harvester was selected to process the timber because it generally makes only one pass over a given spot and is usually supported on a mat of branches and slash that serves to protect the soils underneath. Hand cutting, the least compactive of tree felling and processing methods, would not be economically feasible on this study site due to the large numbers of stems/acre (1000+) that exist, the jack-strawed nature of the dead and down timber, and the timber's relatively low market value. A cable yarder was selected for primary log transport because the USFS land managers in La Grande felt that by replacing ground based systems with a cable system, the exposure of forest soils to heavy machinery is minimized and thus, soil impacts could be reduced.

While the use of a single grip harvester is quite common with the dense stands and flat ground found in eastern Oregon, cable yarders are not commonly used on this flat terrain as it is difficult to obtain the necessary lift to keep the cables suspended in the air for a reasonable yarding distance. The system being used in this trial used residual trees in the stand to lift the cable at the end of the yarding road (tailtree) and at points along the span (intermediate support trees).

The project aimed to track the cost and productivity of the harvesting system operating on flat ground, while also assessing the treatment's affect on fuel loading, soil compaction, and soil disturbance. The silvicultural prescription was to salvage most of the downed material and thin the stand to 80-90 trees per acre in order to reduce fuel loading and move the stand toward its pre-fire suppression form. Ponderosa Pine and Western Larch were to make up as much of the residual stand as possible.

The project was conceived by Dave Wyland of the USFS in the La Grande Ranger District. It is a cooperative research project between the US Forest Service, Louisiana Pacific Corporation, Oregon State University, and the PNW Research Station. Each group is responsible for a different aspect of the study.

US Forest Service -	Stand layout, project preparation and coordination.
Louisiana Pacific -	Project site and logging coordination.
Oregon State University -	Soil compaction study,
	Logging system productivity and cost study,
	Extension and information transfer services,
	Video documentation.
PNW Research Station -	Fuel loading assessment.

This paper summarizes the logging system productivity and cost assessment conducted by OSU and briefly touches on the other study issues in order to provide a summary of project results.

If the combination of a harvester and cable yarder is going to be judged as a successful management tool for harvesting on flat terrain, then it needs to be proven to be economically and operationally feasible while meeting specific management objectives. The feasibility of using this system to salvage log in other areas with flat terrain and sensitive soils will ultimately depend on the cost and production capabilities of the system. If it is not economically feasible for the system to perform the intended task then it is unlikely that it will be utilized on any large scale. It is possible that reduction in fuel loading and improvement in stand health can be considered an investment in the future of the stand and a reduction in fire hazard benefiting the public, but this goal needs to be accomplished at the lowest cost that still protects the environment. Thus, it is crucial that the productivity and cost of this harvesting system is determined along with its ability to meet land management objectives.

It is important to point out that this is only a ***pilot case study*** and results cannot be generalized for other conditions. Additional replications need to be conducted in the future and other logging systems should also be compared with this one.

2.0 Literature Review

Currently, little research exists that assesses the costs or production of combining a single grip harvester and a small skyline yarder on gentle terrain to handle small wood in a thinning operation. This is not surprising as past harvesting has strived to minimize costs when choosing equipment, and skyline systems have long been regraded as more costly than ground based systems when used on gentle terrain [Kellogg, FE 370 notes]. Gentle terrain is well suited for the less expensive ground based systems of log transport (ie. skidders and forwarders) and mechanized methods of harvesting (ie harvesters, feller-bunchers).

However, as land managers strive to minimize soil degradation in areas of sensitive soils, one option they may choose is to reduce the amount of vehicle traffic that occurs in a harvest unit. Recent compaction studies have found that:

> "A by-product of mechanized harvesting is the energy transmitted from machine to soil. Pressure and vibration combine to produce an undesirable impact on forest soils." [Froehlich, 1993]

Thus, minimizing vehicle traffic on the soil will reduce soil compaction, but at what cost? Obviously some impacts on forest soils can be considered "acceptable" if they do not adversely affect water quality or future land productivity. In addition, soil compaction impacts can be lessened over time by natural processes such as freezing and thawing or mitigated with mechanical processes such as tillage after harvest. Each land manager uses their own definition for "acceptable" impacts for a specific site when selecting an appropriate, cost effective harvesting system. This study's purpose was to provide information on soil impacts and associated costs of just one of the harvesting options available to land mangers today.

2.1 SINGLE GRIP HARVESTERS

Single grip harvesters have been used extensively in Norwegian countries for the falling 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 (rubber tired or tracked), a boom, a computer, and a hydraulic harvesting head. The operator is able to sit in a protected, comfortable cab and manoeuvre the machine throughout the stand while operating the harvesting head in conjunction with the computer. The machine is able to fall, delimb, buck and top a tree without ever releasing it. The harvester head contains a chainsaw 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 falling, delimbing, and bucking small trees less than 22 inches in diameter. They also produce end products of higher quality and more consistent dimension than do conventional systems [Anderson, 1991] The productivity of a Harvester can vary widely depending on the individual tree size, operator skill and motivation, branch size, merchantable trees/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] summarizes several studies showing that harvester production is closely related to tree size. As tree size increases, there is a rapid decrease in the harvesting cost per volume. 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]

Kellogg and Bettinger [1994] found that thinning a 47 year old Douglas Fir / Western Hemlock stand with a single grip harvester resulted in a cost of

$11.81/cunit. The study area had slopes ranging from 0-49%, an average dbh of approximately 13.5 inches, and a before thinning stocking of approximately 385 trees/acre. Production for the harvester exceeded 1087 ft^3/PMH† or 750 ft^3/SMH† (approx. 70 trees/PMH). The forwarder used in this study for primary log transport (AYD=900 ft) had a cost of $19.26/cunit, and the stump to truck logging cost was $35.37/cunit (excluding truck hauling and profit and risk). On a per acre basis, the logging cost was $1140/acre.

Other studies of forwarding for the primary transport of logs found production to be 13.97 tons/PMH with a average haul distance of 2100 ft [Raymond and Moore, 1989] and 338.98 ft^3/SMH with an average haul distance of 560 ft [Sirén, 1984]. These values can be compared to the yarding production figures derived in this study to give an indication of the trade off of using a skyline system in place of a forwarding system.

2.2 SMALL CABLE YARDERS

The other half of the production system being analyzed in this study is a small cable yarder (Koller K501). Small cable yarders have been used successfully in thinning operations on steep slopes in the Pacific Northwest for many years because their small crew sizes 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

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† PMH=Productive machine hours. Refers to an hour of work where the machine is always productive (ie. no delays) SMH = Scheduled machine Hours. Refers to all hours that a machine is scheduled to be working.

yarders have generally been limited to areas of small timber and where cable spans are relatively short (less than 1000 ft). 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 but few have been on similar slopes (essentially flat) to this study. These past studies can act as a baseline for conventional skyline thinning operations.

Hochrien and Kellogg (1988) studied a Koller K300 yarder and a Madill 071 yarder performing thinnings at two intensities in a Douglas Fir stand (350 TPA[†]). The timber stand had an average dbh of 12" and was on moderate slopes. Light and heavy thinning intensities were performed where 80 TPA and 124 TPA were removed respectively. The Koller was rigged as a standing skyline system with a hand slack-pulling carriage and the Madill was rigged as a standing skyline , slackline system with a mechanical slack-pulling carriage. They found that the light thinning cost 20-22% more than the heavy thinning, due to smaller turn sizes and less volume being yarded per skyline road. The yarding, loading and total logging(stump to dump) costs are shown below:

	Heavy Thinning		Light Thinning	
Cost Component	Koller K300	Madill 071	Koller K300	Madill 071
Yarding+Loading($/cunit)	$60.05	$68.33	$73.23	$82.21
Total cost ($/cunit)	$97.06	$105.32	$110.23	$119.21

** Note: Logging prices were originally in 1988 dollars and have been changed to 1994 dollars at a 4% rate of inflation.

In two other studies of thinning with small to midsize yarders on moderate to steep terrain, the following results were obtained:

[Kellogg and Olsen, 1984] A Koller K300 yarder was used with a manual slack-pulling carriage to thin slopes ranging from 9-38%. The stand was

† TPA = trees per acre

thinned to 160 TPA(avg dbh = 11"). Yarding only costs ranged from $53.88/cunit (cold decking) to $65.88/cunit while using a skidder to clear the deck. These figures have been converted from 1984 to 1994 dollars at 4%.

[Kellogg, Olsen, Hargrave, 1986] A Madill 071 yarder was used with a mechanical slack-pulling carriage to thin slopes ranging from 0-90%. The stand was thinned to 63 or 83 TPA (avg dbh = 13") depending on the treatment unit. Yarding and loading costs ranged from $76.94/cunit to $87.96/cunit for 63 TPA and 83 TPA respectively. These figures have been converted from 1986 to 1994 dollars at 4%.

The above studies can be used to represent skyline thinning costs in typical cable yarding ground in the Pacific Northwest. These values can later be used as a base for a limited comparison with skyline thinning on flat ground. The comparisons are limited due to the many differing factors between each of the above studies and this case study.

One 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] A relatively less expensive yarder or sled mounted winch, with lower production capabilities, has typically been used to prebunch or extract the logs to the skyline corridor and then a more costly yarder, capable of larger payloads, has been used to swing the prebunched logs to the landing. The larger yarder would be under utilized in a conventional yarding scenario as it would not be able to get large enough payloads during the lateral yarding phase to maximize its potential. Several studies have shown that yarding costs are reduced with prebunching and swing yarding [Kellogg,1976 and Zielinsky, 1980] and others have shown no improvement or higher yarding costs [Hochrein & Kellogg, 1988 and Keller, 1979] depending on stand conditions and logging techniques.

Prebunching has also been shown to improve production and reduce extraction costs for ground based systems such as feller bunching and grapple skidding. The harvesting system utilized in this case study is somewhat similar to this as the harvester piles logs on either side of its 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.

2.3 SIMILAR STUDIES

The only past study that evaluated the combination of a harvester and cable yarder on similar terrain as this study was completed in South Africa by Howe Logging, Limited [Howe, 1994]. A small Bell TH120 harvester with a single grip harvester head was used to fall, process and stack 19 ft Eucalyptus grandis logs into bunches of approximately 30 logs. This represented a single turn at maximum payload(2 tons) for the 33 ft 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 (max slope = 25%) so single tree intermediate supports were rigged such that the jacks hung at 25 feet above the ground and were spaced at 260 ft along the corridor in order to maintain lift. There were as many as five intermediate support jacks per skyline road. 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 road was approximately 1600 ft long and 250 feet wide. Average lateral yarding was approximately 50 feet.

The harvester felled and processed four rows of trees in a pass and created bundles 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 because the larger trees would be capable of handling larger payloads.

The Bell TH120 harvester produced 8.4 tons/hour including the debarking and piling of the 19' logs. This rate of production was a quarter of that 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.

This case study was driven by a goal of minimizing soil compaction and was successful at achieving that goal. Howe states that, "Soil disturbance in the trial areas was so minimal that Mondi Forests (private timber company) deemed it unnecessary to quantify." Some of the factors that contributed to the success were: the light weight of the small harvester (4.1 lbs/in^2) and its ability to walk on the brush mat that it created, the judicious use of intermediate supports that allowed the load to be fully suspended in some areas of the cable yarding corridors, and the minimal amount of machine traffic on soils within the unit.

The first few studies in this literature review provide examples of logging costs and production for both the single-grip harvester and the small cable yarder in thinning situations. These values can be used as a reference point so that the production and cost values obtained in this case study can be assessed relative to past experience. The South African case study [Howe 1994] has many similarities to the case study presented in this paper, but it also has several important differences. The main items being that Howe's case study utilized the harvester/yarder combination in a clearcut situation and the harvesters went to a great deal of effort to make yarding as efficient as possible. In the case study presented here, a thinning was being performed and the harvester made minimal efforts to position the logs for yarding. The two case studies provide comparisons of two different logging techniques but conclusions are limited because of the different silvicultural treatments.

3.0 Study Objectives

1. Determine logging planning/layout time and cost for a harvester-skyline system in a fuel management case study.

2. Determine gross (shift level) production rates for the harvester and skyline yarding system.

3. Determine logging cost per unit volume produced.

4. Quantify the amount of pulp and sawlog material obtained from salvage logging and thinning the study site.

5. Determine work cycle times for the single grip harvester and skyline system.

4.0 Field Study Description

This section of the paper provides detailed information on the study site, silvicultural treatment, logging equipment specifications, logging techniques, and data collection methods.

4.1 STUDY SITE

The study site was 50 acres of Louisiana Pacific Corporation's land located on Deerhorn ridge, south of Ukiah, Oregon (T 6 S, R 30 E W.M.). Figure 4.1 shows the site location within Oregon and the USA. The area has a history of ground based selective timber harvest and was purchased recently by Louisiana Pacific with the intent to manage it for timber production. The site was made available to the Forest Service for this project as though it were managed by the Forest Service but with Louisiana Pacific accepting any profit or loss resulting from the logging.

The study site was very flat with undulating terrain at a maximum slope of approximately 10 percent. The soils were deep volcanic ash, and the plant association for the area was Grand fir/Big Huckleberry [USFS La Grande, OR]. Road access already existed to the unit, and a fence line ran down the middle that showed obvious signs of cattle grazing. The overstory was composed of Douglas-fir (Pseudotsuga menziseii var glauca), Grand fir (Abies grandis), Western larch (Larix occidentalis), Ponderosa pine (Pinus ponderosa), and Lodgepole Pine (Pinus contorta). Lodgepole regeneration was clumped into some of the stand openings that also included a few scattered overstory trees. Most of the mature lodgepole pine in the stand was severely damaged by the mountain pine beetle (Dendroctonus ponderosae) attack in the 1970's and was defoliation of the fir by western spruce budworm dead and laying on the forest floor. Other stand health concerns included of the fir by western spruce

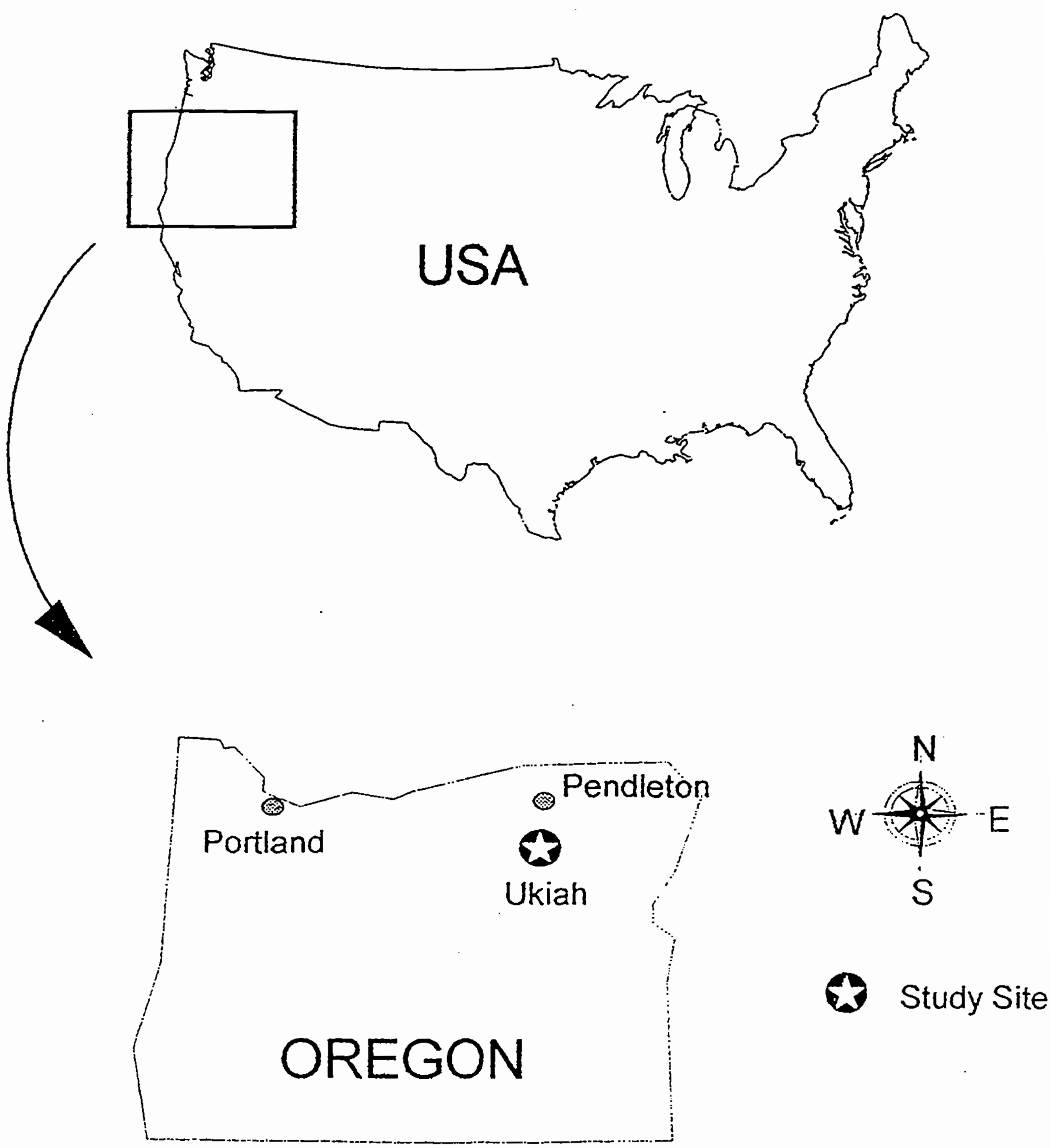


Figure 4.1 Study Site Location Map

budworm (Choristoneura occidentalis), the presence of dwarf mistletoe in Douglas-fir, lodgepole pine with needlecast (L. concolor), and scattered Grand fir with dead tops.

The stand structure varied over the entire unit. Some areas were open with patches of pine trees and grass, while other areas were moderately stocked with dense lodgepole regeneration, and other areas had a very dense overstory with no understory at all. In general, the stand was incredibly varied with patches of trees of various heights and an immense amount of dead material laying on the forest floor (Figure 4.2). The Forest Service did not complete a cruise of the area but the author of this paper estimates that there were 1000+ stems/acre and the average dbh was approximately 7-9 inches.

A fuel loading assessment was completed by the US Forest Service's Pacific Northwest Research Station prior to logging and the results are as follows:

	Unit #1	Unit #2	Control
Downed woody fuel loading (tons/acre)	32.6	31.5	35
Litter and duff loading (tons/acre)	16.1	14.3	13.1
Total loading (tons/acre)	48.7	45.8	48.1

Much of the pre-treatment fuel was larger than 3 inches in diameter and consisted of lodgepole pine stems laying jack-strawed on the ground.

The study area was divided into two treatment units and a control unit. (Figure 4.3). Sixteen foot log lengths were cut in treatment unit # 1 and 32 foot log lengths were cut in treatment unit # 2. This treatment variation was completed in an attempt to observe logging production differences and possible site impact differences between the two log lengths. The control unit was not logged. Because no roads were constructed inside the unit boundaries, the yarder was forced to set up at various locations around the perimeter of the unit. Several small spur roads were constructed to gain access to the unit boundary when the existing road was not a feasible landing choice (Figure 4.3).

Figure 4.2 Example of Fuel Loading Before Treatment

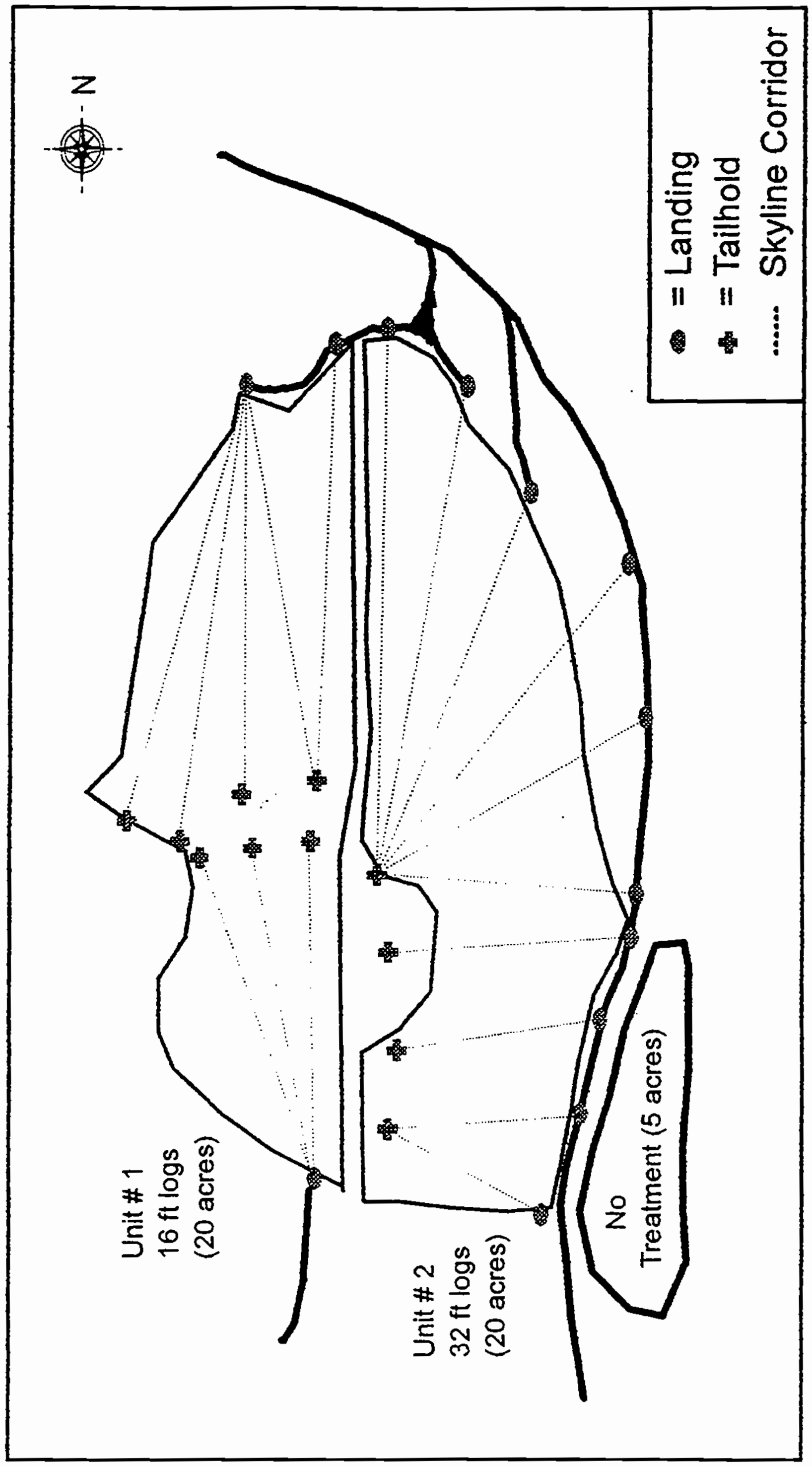


Figure 4.3 Map of Study Unit and Treatment Boundaries

4.2 LOGGING LAYOUT AND PLANNING

Skyline roads were flagged before any logging began and potential intermediate support trees and tailtrees were marked to ensure that they did not get harvested. The layout was done by Northwest Timberland Consulting Inc. of Eugene, Oregon with direction from the yarder operator and Louisiana Pacific. Minimal road building was allowed and no roads were permitted inside the harvest unit. Thus, the skyline system reached into the unit from the boundary with a variety of radial and parallel skyline patterns(Figure 4.3). Each of these skyline roads was less than 1000 ft long and had a specific landing and tailtree designated for use. At least one potential intermediate support was identified on each skyline road. Preference was given to double tree intermediate supports but both single tree and double tree supports were identified depending on the availability of suitable trees. An attempt was made to place the intermediate supports where they would provide the most benefit (ie. midspan or at terrain breaks) but the patchy nature of the stand usually didn't allow for many options. Intermediate supports were located so that there was never more than 450 feet in a single span on flat terrain.

Generally, the tailtree was selected first and then a straight line was flagged to the chosen landing using a staff compass and previously hung ribbons as a guide. Once this was completed, the skyline road was assessed for potential intermediate supports and the trees that provided the best options were marked with paint. Occasionally, no suitable supports were found and the location of the skyline road was reassessed.

4.3 TREATMENT GOALS AND SILVICULTURAL PRESCRIPTION

The USFS in La Grande, Oregon was responsible for determining the desired future condition of the stand and developing the silvicultural and operational prescription. The general stand objectives were to reduce the fuel loading in the area, increase stand health by eliminating diseased trees, and provide some late seral structure in a landscape dominated by younger pine stands. The desired future condition of the stand was determined to be "uneven aged and composed of 2-5 distinct size classes: the overstory consisting of Ponderosa pine, Western Larch, Douglas fir, Englemann Spruce and Grand fir; the scattered, smaller overstory in more open areas; the small saw timber of the same species; and the poles, saplings and established seedlings"[USFS La Grande, OR].

The silviculture prescription designed to accomplish this goal was to thin the stand to 80-90 trees per acre where needed and sanitation/salvage log most of the dead, dying, or diseased timber. A precommercial thinning of the dense clumps of lodgepole pine would follow the first entry and natural regeneration is being counted on for restocking the site. Woody debris (50 pieces/acre) was to be left on site to provide habitat for ant populations and other small mammals.

4.4 LOGGING EQUIPMENT SPECIFICATIONS AND OPERATIONS

The logging that occurred in this study was performed by contractors using their own equipment. Forest Recovery Systems of Baker City, Oregon was contracted to fall and process the wood with their single grip harvester. This contractor was local to the area and had worked with Louisiana Pacific many times in the past. The operator was accustomed to logging under the conditions present in the study and had more than 4 years of experience running harvesters. However, this study was the first time the operator had used the harvester to cut timber for a cable yarding operation.

McCaulley Inc. of Port Angeles, Washington was contracted to yard, load, and truck the logs to Pilot Rock, Oregon, which was approximately a 75 mile round trip from the study site. The contractor owned yarding equipment but subcontracted locally for a loader and trucking. The hook tender with McCaulley Inc. had 20+ years of cable logging experience, the rigging slinger had 10+ years of cable logging experience, and the choker setter and yarding engineer were recently converted fallers. Both fallers were very productive at their new tasks. The crew was very skilled at climbing and rigging tailtrees but was new to logging on flat ground with intermediate supports. They had owned the yarding system used in the study for only two months prior to the study but were reasonably well accustomed to logging with it due to previous experience with a similar yarder.

4.4.1 HARVESTING EQUIPMENT AND OPERATION

Equipment Specifications:

1992 Single Grip Harvester (Package assembled by Triad Equipment)

- Link Belt 'C' Series II tracked carrier (LS 2800).
- Pierce modified feller buncher boom.
- Waratah 20" single grip, hydraulic processing head.
    - 3 feed rollers
    - chainsaw bar for bucking
    - computerized length measurements and piece counts
- Machine weight = 53,000 lbs
- Ground pressure = 6.3 PSI
- Purchase price new = $345,000.

Equipment Operation

The harvester was responsible for falling and processing any non-marked standing trees and the processing of any merchantable dead and down stems. Processing involved delimbing, topping and bucking the stems into specified log lengths - preferably 16' or 32' depending on the treatment unit. The harvester worked strips of approximately 50 feet in width that were usually parallel to the marked skyline corridors. Parallel passes were made through the stand until the harvester had reached the opposite side of the unit (Figure 4.4). When 16' logs were cut , the processed logs were placed in rows on either side of the harvester's path and when 32' logs were cut, logs were usually only placed on the side which had already been thinned. This difference occurred because the harvester's boom was not long enough to allow it to process a 32' log toward itself and still maintain a clear path ahead, thus each of the long logs had to be processed across the front of the machine. Few long logs were processed into the untouched stand as they would lay on top of dead and down logs that would have to be handled on the next pass. The 16' logs could be processed inside the reach of the boom and thus could be placed on either side of the harvesters path.

The harvester produced logs in rows that were parallel to its direction of travel and these rows usually corresponded to the orientation of the skyline corridors. The orientation of logs within the rows was dependant on the harvester's direction of travel along these rows. Trees were felled to the side or ahead of the machine and when the stems were forced through the harvesting head for processing; the resultant logs were placed anywhere from perpendicular to the row to angled back toward where the machine came from (Figure 4.5). Thus, if the harvester was travelling toward the landing where the yarder was to sit, the log orientations would range from perpendicular to the corridor to a perfect herringbone pattern. If the harvester was travelling in the opposite direction, logs were not as well oriented.

The harvester was operated by a single person throughout the study and he was asked to process the wood so that it would facilitate yarding. The operator was free to select a technique for harvesting the stand so that this objective was met. He did not have to select which standing trees to remove as they were previously marked by the Forest Service.

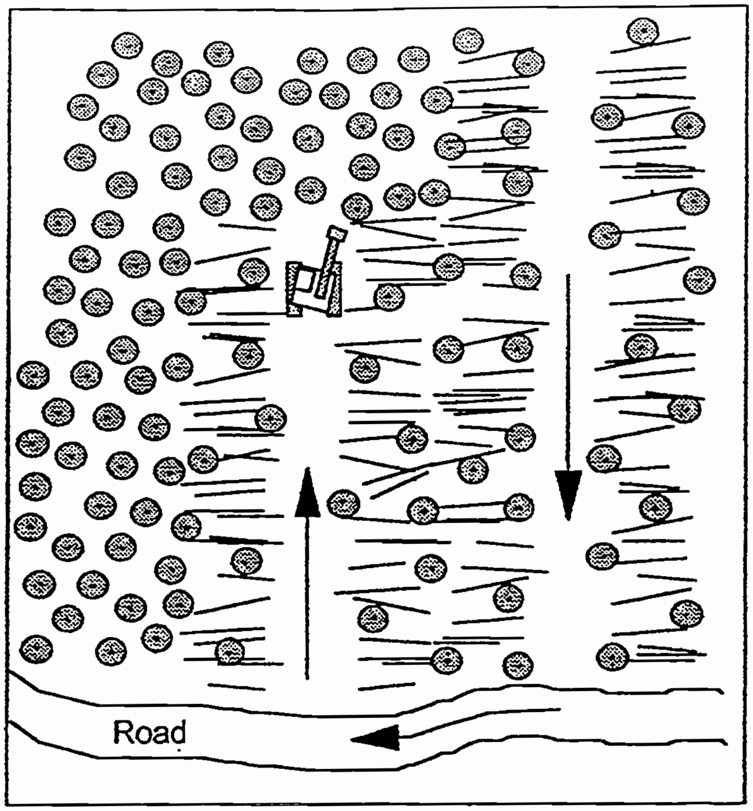


Figure 4.4 Harvester's pattern for processing the stand.

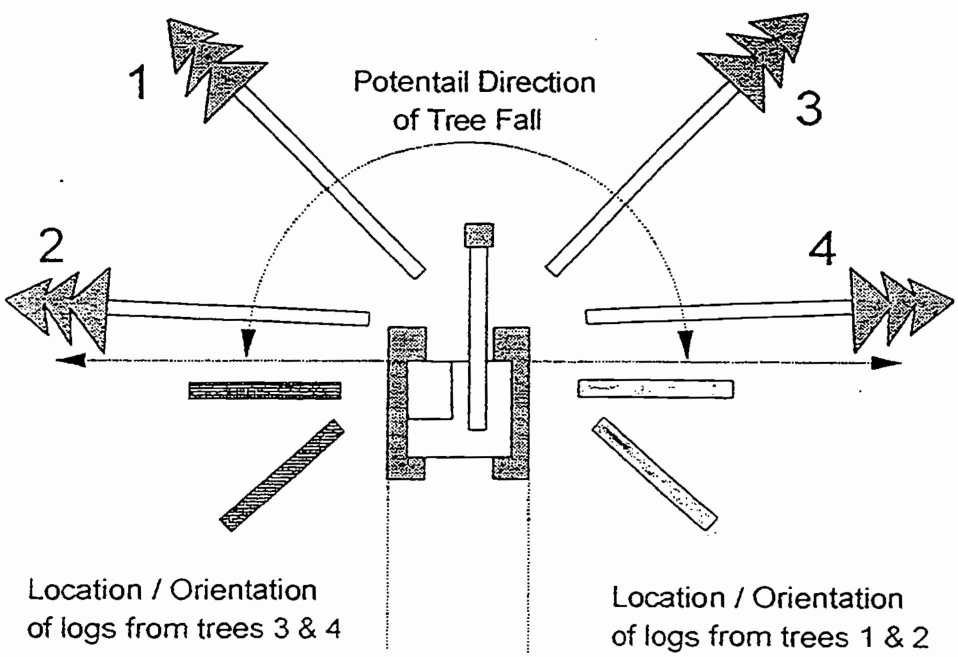


Figure 4.5 Typical Orientation of Harvested Logs

4.4.2 YARDING/LOADING EQUIPMENT AND OPERATION

Equipment Specifications:

1994 Koller K501 trailer mounted yarder

- 33 foot tower supported by three guylines behind the yarder.
- 3 drums, skyline, mainline, and haulback.
- 1965 feet of 3/4" swaged skyline.
- 2600 feet of 1/2" mainline.
- 4000 feet of 3/8" haulback line.
- 2 sets of 4 plastic coated ring chokers (9 ft long).
- purchase price new (with lines and rigging) = $134,500.

1993 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.
- weighs 1200 pounds
- one Eagle intermediate support jack.
- purchase price new = $32,000.

1994 John Deere 690 ELC Loader

- Track mounted.
- Uses hydraulic grapple combined with a heel boom.
- Purchase price new = $250,000.

Miscellaneous Equipment Used with Yarding Operation

- 1992 Ford F250 pickup truck
- 1978 Ford 10 tons, dual axle flatbed truck
- Miscellaneous fire equipment(shovels, water backpacks, polaski's etc.)
- 2 Stihl 064 chainsaws
- climbing gear
- intermediate support rigging (jack, blocks, straps, 3/8" wire rope)

Yarding Equipment Operation

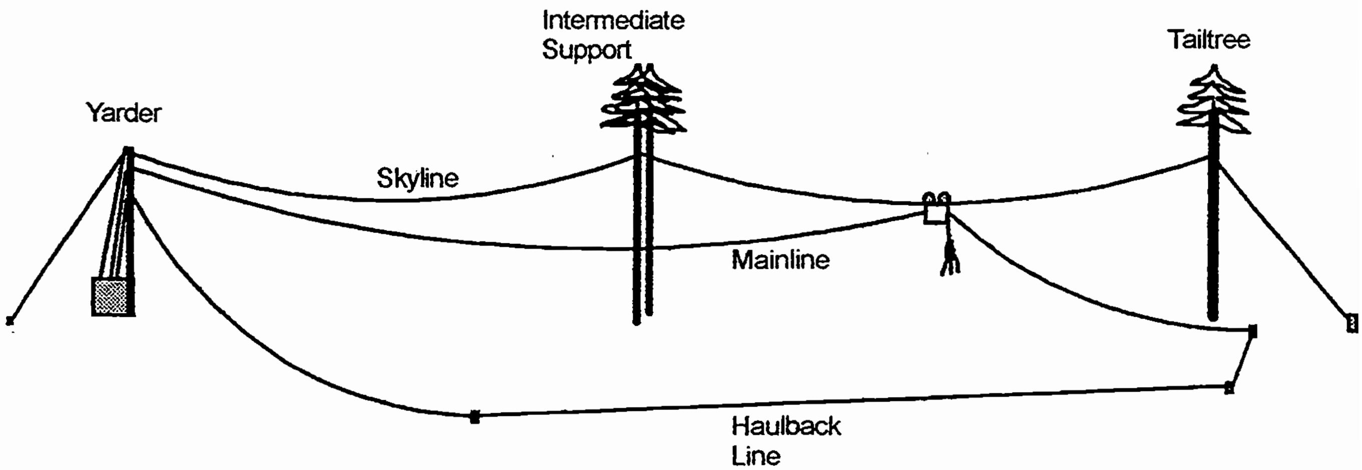
The yarding/loading phase of this operation was responsible for moving processed logs to the landing and then loading them onto trucks. The loader worked in conjunction with the yarding to clear decked logs into two sorts (pulp and sawlogs) or directly onto waiting log trucks. However, the first three skyline roads did not function this way as no loader was available when logging began. For these skyline roads, all of the wood from each corridor was cold decked into very large piles at their respective landings.

The cable system was rigged as a standing skyline, slackline system that utilized tailtrees and occasionally double tree intermediate supports to create multiple spans(Figure 4.6). 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 located in the setting.

A typical yarding cycle started with the engineer sending the carriage out into the setting 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 chokerman 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 signalled 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 yarding engineer was responsible for unhooking the turn.

There were five 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, only three people were needed to operate the yarding system and the hook tender was used to pre-rig future skyline corridors.

Multispan Standing Skyline, Slackline System



Double Tree Intermediate Support Detail

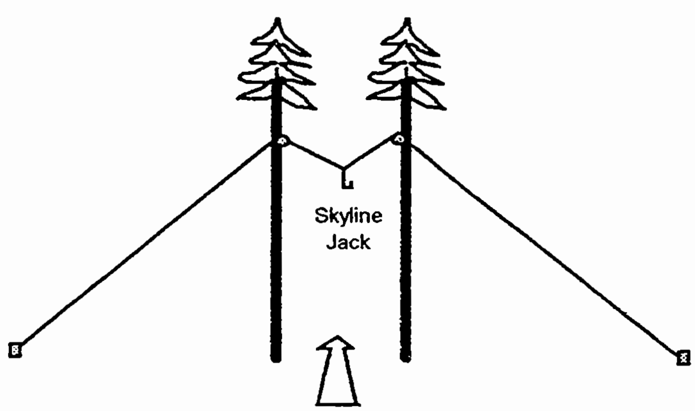


Figure 4.6 Standing Skyline System with a Tailtree and Intermediate Support

4.5 DATA COLLECTION METHODS

Data collection was undertaken with the goal of gathering information that would be needed to satisfy the stated study objectives. Production and cost information was obtained on different components of the logging operation through several different types of studies. These studies can be grouped into two types: shift level studies and intensive sampling studies. Shift level studies served to provide a description of each days logging operations in terms of production and hours worked. These studies also captured information on logging delays and equipment down time that occurred during each shift. The intensive, short term, sampling studies served to supplement the shift level studies by providing details that could not be captured in the shift level approach. In some cases the two study types overlapped to collect similar information. In cases where this occurred and different results were obtained by both studies, the author selected the one that he felt more confident in, based on how the particular studies were carried out. Data collection was broken down into the following areas of concentration:

1. Layout and logging planning
2. Yarding operations
3. Harvesting operations
4. Loading operations
5. Harvested timber / Products produced

Each of these areas of concentration 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 filled out daily by the layout crew. An example of this form can be found in Appendix A. The form collected person hours spent doing layout or logging planning each day and the type of activity that was performed. 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.

For this study, logging layout included the design and field work associated with identifying road locations, landings, and skyline corridors. The location of boundaries and the marking of the standing trees to be removed was not included in the study as this work had already been completed by the US Forest Service prior to the start of this study.

4.5.2 HARVESTER OPERATIONS

Two types of studies were employed to collect information on the harvester. A shift level form was used to collect daily production and a description of the shifts activities. Activity sampling studies were completed on the harvester in each of the treatment units to define the proportion of time spent on specific activities and to provide more detailed information on production and the type of products created.

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. Treatment unit # being felled and processed,
2. Shift date, start, end, and break times,

3. Name of operator,
4. Production (number of logs 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 not as useful because the number of logs produced each shift, provided by the on board computer, was somewhat questionable. The figures seemed too high when compared with the figures from the rest of the study or the harvester's activity sampling study. After the study was complete, the operator was uncertain whether the computer had been counting saw cuts or logs produced. Thus, the production information gathered through the shift level form was not used.

The activity sampling study performed on the harvester proved to be very valuable for describing the proportion of time spent on specific production related activities, providing production information, and describing the type of wood products produced. The activity sampling study consisted of two parts. The first quantified time the harvester spent on different activities during the falling and/or processing of 20 stems. The second quantified log production based on the same 20 stems and also described the logs produced as dead or live.

The harvester's activities were grouped into the following elements for the activity sampling study:

1. Position/Clear - time spent positioning the harvesting head for tree felling or clearing brush.
2. Felling - time from when the head first grabs the tree until the tree hits the ground.

3. Processing Dead - time for delimbing and/or bucking of dead stems.
4. Processing Live - time for delimbing and/or bucking of live stems.
5. Swing to Bunch - time spent positioning logs beyond what was completed during the falling or processing of the stem.
6. Travelling - any time where the harvester's tracks were moving.
7. Repair and Maintenance - time spent on mechanical delays.
8. Other delays - any delays other than mechanical.

The harvester's actions were recorded into one of these eight categories every 12 seconds until 20 stems had been processed. A total time was recorded for the twenty stems and the quantity of logs yielded was also tallied. Thus, a representative proportion of time spent on each activity was captured and the associated production for the sampling time was also obtained. This procedure required two researchers and each study(20 stems processed) took approximately 15 minutes to complete. Twenty five studies were done in each treatment unit at randomly selected locations. The forms used in the activity sampling study can be found in Appendix A.

4.5.3 YARDER OPERATIONS

Two types of studies were used to collect the information necessary 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. An example of this form can be found in Appendix A; the following information was collected:

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 production.

Production information entered on the form was obtained by using two mechanical counters attached to the yarder that were operated by the yarding engineer. One counter kept a daily tally on turns(yarding cycles) and the other on logs brought to the landing. The piece counts(logs) were later converted to volumes using the average piece size determined for the unit. 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 allow researchers to allocate a day's production to a particular skyline corridor in the setting.

The second type of study used was a detailed time study on the yarding production cycle. This was done to quantify the time spent on each segment of the production cycle and collect more detailed information on the yarding operation. There was no intent to develop a predictive regression equation from the detailed time study data as it was only meant to supplement the shift level study with more detailed information on the yarding cycle. The following information was collected:

A) Yarding cycle times consisting of:

Outhaul - Begins when carriage leaves landing, ends when carriage is stopped at location of turn.

Drop - Begins when Outhaul ends, ends when rigging slinger has the load hook and the chokers have been taken off.

Lateral Out - Begins when Drop ends, ends when the mainline toggle was placed through the choker ring on the first preset log.

Hook - Begins when Lateral Out ends, ends when the rigging slinger blows the go ahead whistle to the yarding engineer.

Lateral In - Begins when Hook ends, ends when the load reaches the carriage and the whistle is blown to release the skyline brake.

Inhaul - Begins when Lateral In ends, ends when the carriage reaches the landing and the whistle is blown to drop the logs.

Unhook - Begins when Inhaul ends, ends when carriage leaves the landing for another turn.

B) Independent variables consisting of:

1. Number of logs in each turn.
2. Number of chokers used in each turn.
3. 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.
4. 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).

C) Delay time - when normal yarding operations 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.

The detailed time study data was collected by two field personnel in radio communication using a handheld Husky Hunter 2 computer running SIWORKS software. One researcher remained at or near the landing to observe the carriage reaching the landing, the unhooking of the logs, and the beginning of the new turn. The other researcher was located in the field where the turns originated. This person recorded all the information gathered for a given turn into the computer. Approximately 250 samples (yarding cycles) were obtained in each of the two treatment units.

Seven skyline road/landing change times were also obtained. Time for a skyline road/landing change was defined to begin when the skyline was lowered to the ground and end when it was up and ready to go 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 give a loading 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. Truck ticket numbers and their associated landings were also recorded by the loader operator in order to keep track of where specific volumes came from in the setting. For the purposes of this study, volumes associated with truck tickets were simply allotted to the treatment unit(16' logs or 32' logs) where the load originated.

To obtain an estimate of truck loading times (study descriptive use only), researchers randomly recorded truck loading times when it was convenient. This tended to occur when the detailed time study was going on or when the researchers were working close enough to the landing to be able to see the trucks being loaded. Time for loading a truck began when the first log was placed into its bunks and ended when the truck drove away to secure the load with binders. Twenty two truck loading times were obtained.

4.5.5 HARVESTED TIMBER

Volume and other descriptive measures of the timber removed from the site were obtained with the use of two types of scaling and the harvester's activity sampling study. Every truck load that left the site was weight scaled in order to determine the tons of material removed off the site. Roll out scaling by Southern

Oregon Log Scaling and Grading Bureau was also done on every sawlog load and one out of every three pulplog loads that left the study site. The scale tickets for these loads provided detailed information on each log and summary statistics for the entire load. Selected information such as the number of pieces / load, Bdft / load, ft^3/ load, and an average diameter and length /load were utilized to produce average piece sizes for each treatment unit and the entire setting. Species and grade information was also available and allowed a summary description of the wood material that was removed from the site.

Because every truck load that left the site was weight scaled, information on the pulplog loads that did not get scaled could be constructed from simple linear regressions based on load weight. Regression equations were created to estimate the board foot volume and cubic foot volume of these loads and they can be found Appendix B.

4.6 EQUIPMENT OWNING, OPERATING AND LABOR COSTS

Hourly costs for the harvesting, yarding, and loading equipment were produced 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,licences 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 1993/94 Oregon Loggers Association statistics. The other inputs used to determine the equipment costs can be found with a summary of the owning and operating 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 C.

5.0 Results

This section of the paper presents cost and production figures determined for the logging system used in this study and also describes the wood material produced by logging. Results presented are those that the author felt best described the logging operation and best fulfilled study objectives.

5.1 DESCRIPTION OF WOOD MATERIAL OBTAINED FROM HARVESTING

The amount and type of wood material produced from logging was determined from the scale tickets associated with each truck load. Only two products were produced from the variety of species and wood quality that was found on the site: sawlogs and pulpwood. These two sorts were identified by the diameter of the log and by whether it was dead or alive.

The forty acre treated area produced a total of 20,920 logs: 14,460 of which were pulplogs and the remaining 6,461 were sawlogs. Sawlogs made up 28% of total volume and 34% of total weight removed off the site. This difference occurred because pulpwood was generally dead and dry, while sawlogs were generally from heavier, live stems. Table 5.1 provides a breakdown of total volumes removed and Table 5.2 provides a description of the average logs removed.

Table 5.1 Gross Volumes Removed (based on truck loads before scaling)

	Pieces	Ft^3	Mbf	Tons	m^3
Sawlogs	6461 (31%)	22578 (28%)	115.12 (29%)	635 (34%)	639.3 (28%)
Pulplogs	14460 (69%)	58697 (72%)	287.73 (71%)	1222 (66%)	1662.1 (72%)
TOTALS	20920	81275	402.85	1857	2301.4

Table 5.2 Average Log Descriptions

	Avg Dia (small end)	Avg Length	Avg Ft^3/log	Avg Bdft/log	Avg Tons/log	Avg m^3/log
Sawlogs	6.9 in	19.3 ft	7.00	35.73	0.194	0.198
Pulplogs	4.3 in	18.3 ft	3.41	16.73	0.069	0.097
All logs	4.7 in	18.5 ft	3.89	19.26	0.089	0.110

The harvester's activity sampling studies provided an estimate of the proportion of dead material vs live material that was removed from the site. Figure 5.1 depicts this information in a graph. 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.

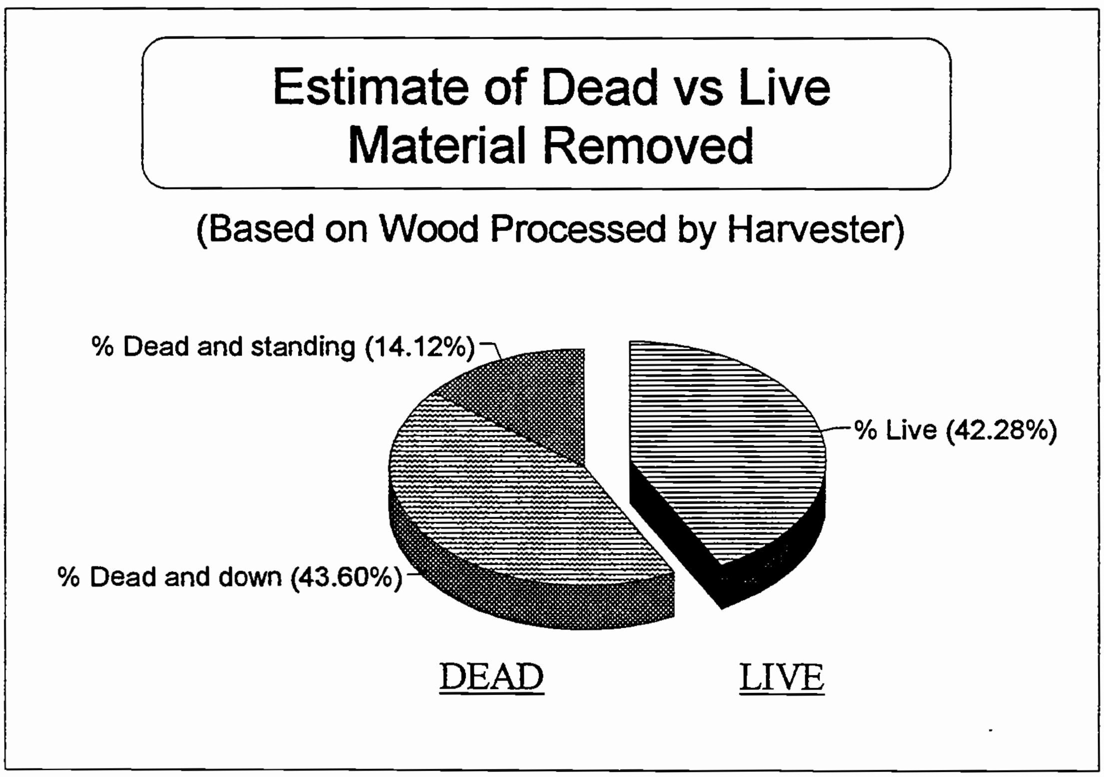
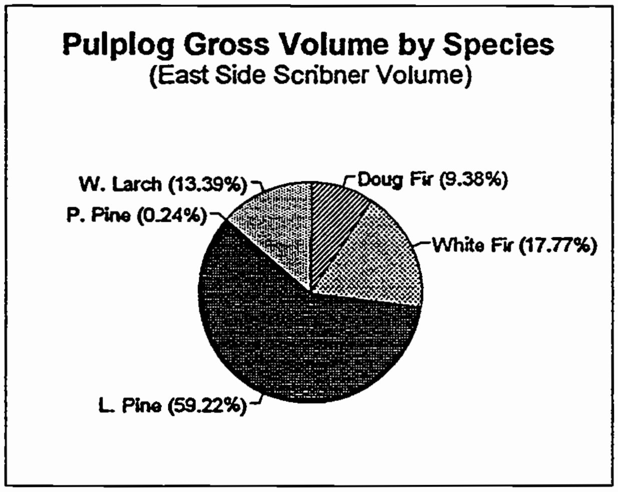
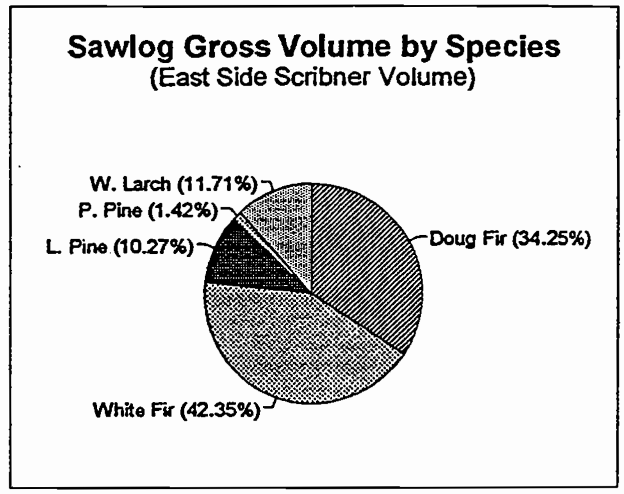


Figure 5.1 Estimate of Proportions of Dead and Live Material Removed

The following graphs illustrate the breakdown of gross volume removed by species and log grades(sawlog, pulpwood, and cull).

Gross Volume Removed By Species





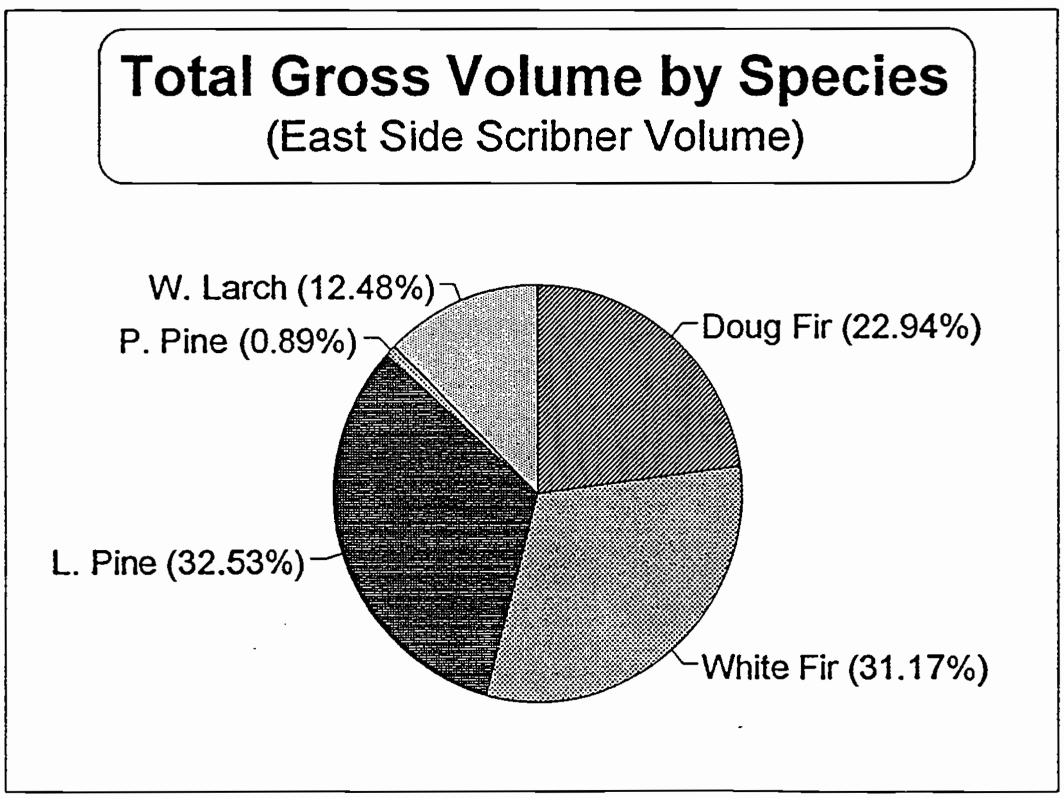
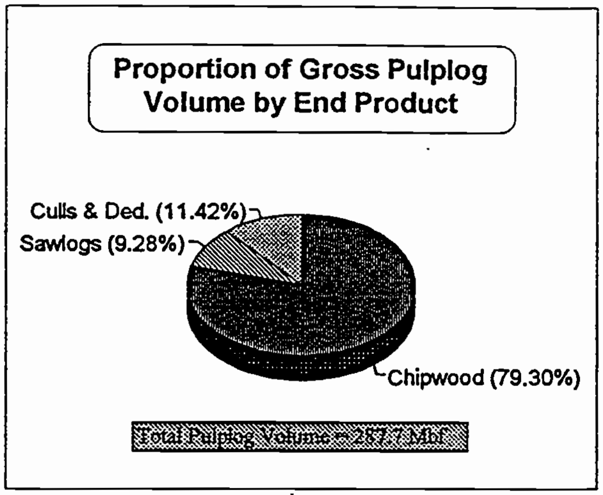


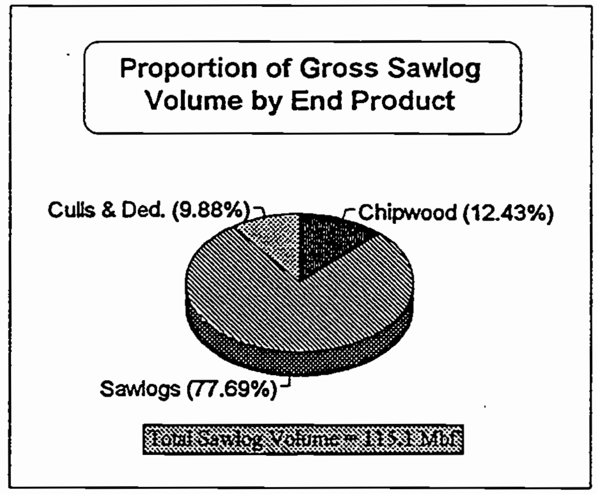
Figure 5.2 Gross Volume Removed by Species

Scaled Truckloads: A Mill's Point of View

Actual Scale of Pulplog Loads



Actual Scale of Sawlog Loads



Actual Scale of All Truck Loads

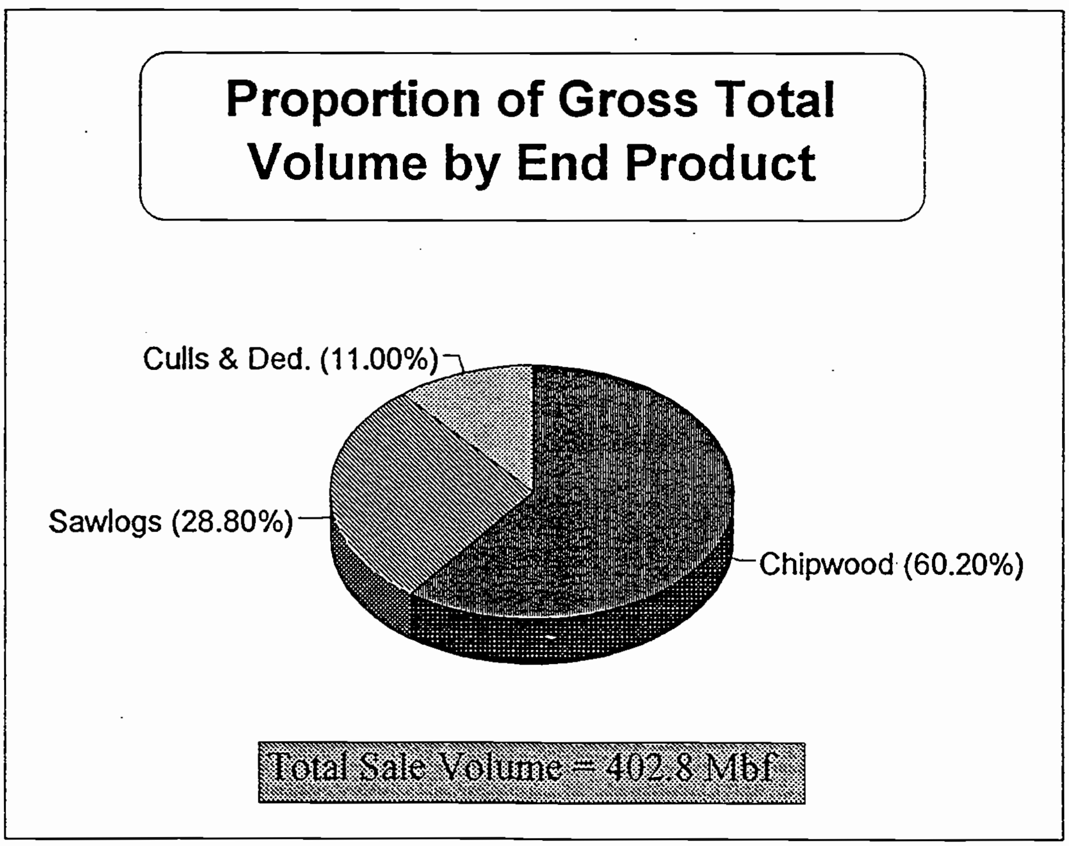


Figure 5.3 Gross Volume Removed by Scaled End Product

5.2 EQUIPMENT PRODUCTION RATES

One of the objectives of this paper was to produce production estimates for the harvesting and yarding operations. This section of the paper provides the results to satisfy that objective and also provides some descriptive statistics on the loading operation. The production rates reported below represent a weighted average for logging the entire setting (both treatment units). The production realized on each of the different treatment units can be found in Appendix E but should not be used to draw conclusions on the effects of different log lengths due to the number of confounding variables present (ie. different volume/acre on each unit).

Production rates for the equipment are provided per scheduled machine hour (SMH) and productive machine hour (PMH). Scheduled machine hours are defined as hours within a given shift, irrelevant of what the machine is doing. Productive machine hours are a subset of the schedule hours and are defined as the time when the machine is operating (ie. PMH's = SMH's - delay time). Thus, it is a measure of what the machine is capable of producing if it was operated continuously without delays.

5.2.1 HARVESTER PRODUCTION RATES

As stated in the data collection section of this paper, the activity sampling studies were used to estimate the production rate of the harvester. Data obtained from these studies provided a very accurate estimate of production per PMH but did not adequately reflect production per SMH. Because of the nature of the activity sampling studies, daily maintenance time and major breakdowns were not captured as part of the SMH estimate and thus, the production / SMH and utilization rate would have been overestimated. However, from the shift level study of the harvester, a more accurate estimate of the utilization rate was determined to be 80.4% and this was used to determine a production rate per SMH. Table 5.3 shows the production rates calculated for the harvester.

Table 5.3 Harvester Production Rates

	Logs / hr	Ft^3 / hr	Bdft / hr	Tons/hr	m^3 / hr
Scheduled Hours	151.5	589.4	2917.8	13.5	19.7
Productive Hours	188.5	733.3	3630.5	16.8	20.8

5.2.2 HARVESTER OPERATION: DESCRIPTIVE STATISTICS

The activity sampling study provided an estimate of the amount of time the harvester spent on specific activities in this case study. Figure 5.4 displays these results.

5.2.3 YARDING PRODUCTION RATES

Yarding production rates per SMH and PMH were obtained from two different types of studies on the yarding operation. The shift level study was able to capture all delays, down time, and road changes and thus was an excellent estimate of production per SMH. The same study was able to provide an estimate of productive time based on the delay time the loggers wrote on the shift level forms, but a more accurate estimate of production per PMH was determined from the detailed time study data. For this study, PMH's for the yarding operation were considered to be when the crew was actively logging. This time included such things as resetting chokers, repositioning the carriage and any other activities that occurred during active yarding. The PMH's did not include time spent on mechanical breakdowns, rigging changes, road changes, or personal delays. Table 5.4 shows the production rates determined for the yarding operation.

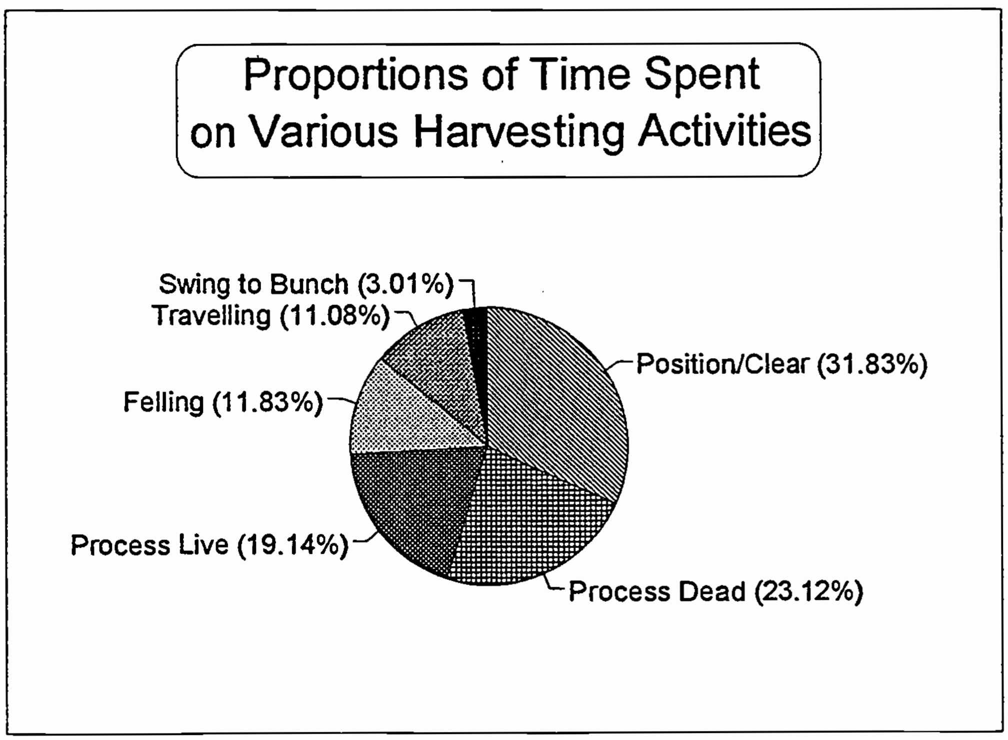


Figure 5.4 Harvester Operation in Deerhorn Case Study

Table 5.4 Yarding Production Rates

	Logs / hr	Ft^3 / hr	Bdft / hr	Tons / hr	m^3 / hr
Scheduled Hours	78.5	305.4	1511.9	7.0	8.7
Productive Hours	139.0	540.7	2677.1	12.4	15.3

The utilization rate determined for the yarding operation was significantly lower than that of the harvester due to large amounts of time spent on nonproductive activities such as road changes. Based on the difference between productive and scheduled hours, the utilization rate for the yarding operation was approximately 57 percent (Figure 5.5).

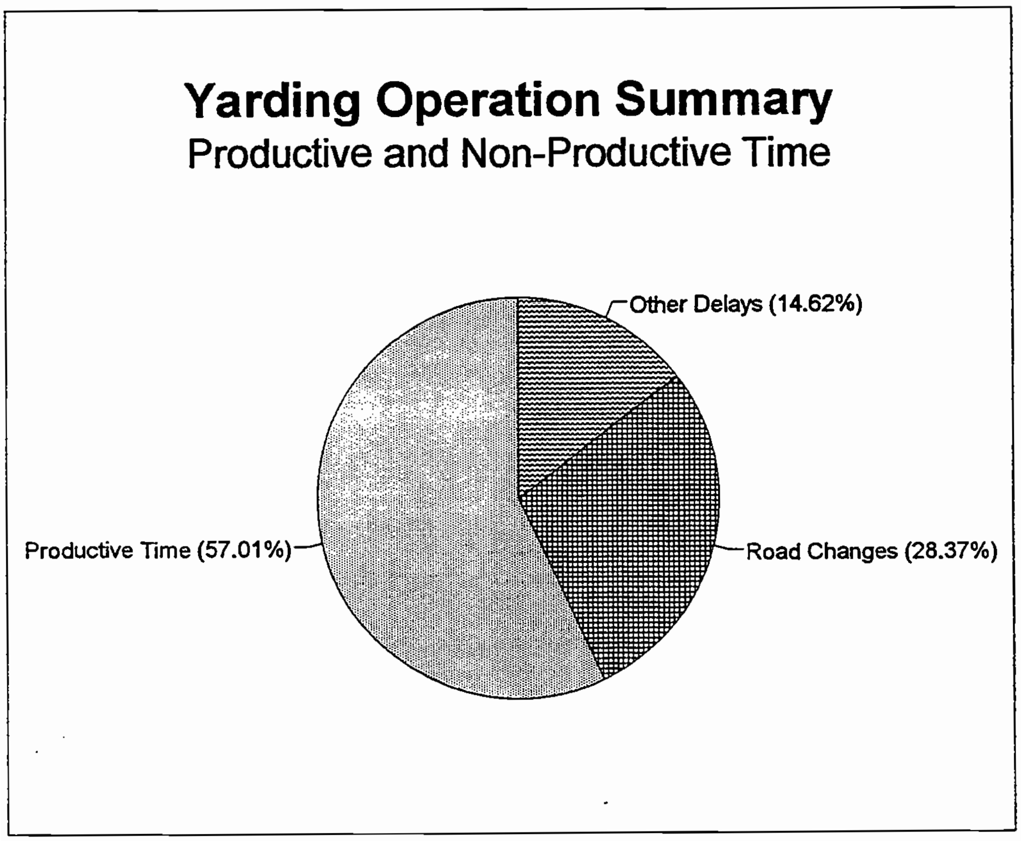


Figure 5.5 Summary of Yarding Operation Hours

5.2.4 YARDING OPERATION: DESCRIPTIVE STATISTICS

The detailed time study provided a description of the average yarding production cycle and other descriptive statistics of the yarding operation. The yarding production cycle breakdown is based on 518 samples(turns) and can be found in Figure 5.6 and the other yarding statistics can be found in Table 5.5.

There were 19 skyline roads used during logging. Only 3 of the 19 skyline roads used intermediate supports (double tree) to gain lift, while all skyline roads used tailtrees. The typical rigging height of a tail tree was 45 feet with some rigged as high as 65 feet. Three tailtrees were broken during yarding.

Table 5.5 Descriptive Yarding Statistics

	Average	Maximum	Minimum	Std. Dev.
Turn Time (min)	3.81	11.29	1.84	1.23
Logs / turn	10.3	30.0	1.0	4.34
Chokers/turn	3.8	6.0	10.0	0.52
Logs/choker	2.7	9.33	1.0	1.10
Yarding Distance	329.0 (100.3 m)	800.0 ft (243.8 m)	10.0 ft (3.05 m)	202.12 ft (61.6 m)
Lateral Yarding Distance	39.1ft (11.92 m)	165.0 ft (50.29)	0.0 ft (0.0 m)	31.33 ft (9.55 m)
Skyline Road Lengths	658.0 ft (200.6 m)	912.0 ft (278.0 m)	380.0 ft (115.8 m)	-
Road Change Times	2.1 (hours)	3.2 (hours)	1.22 (hours)	-

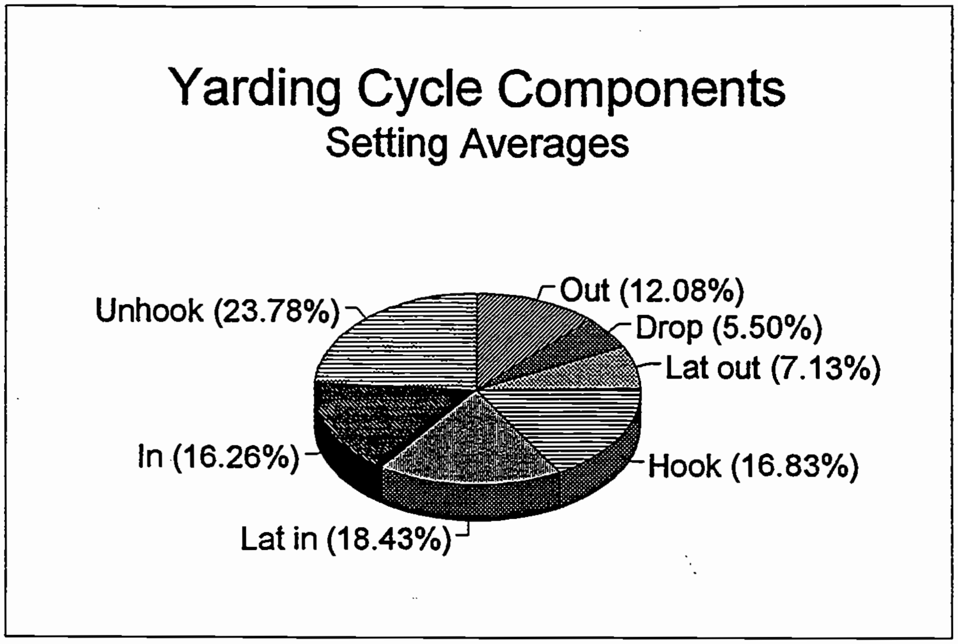


Figure 5.6 Yarding Production Cycle Breakdown

5.3 LOADING STATISTICS

Although there is no objective in this study that deals with the loading portion of the logging system, it is useful to provide some statistics that describe the loader operation. Refer to Table 5.6.

Table 5.6 Truck Loading Times and Descriptions

	Stingers		Mule Trains	
	Sawlogs	Pulp	Sawlogs	Pulp
Typical Truck Loading Time	30 min	60 min	75 min (truck=sawlogs, trailer=pulp)	
Max Pcs/load	194	213	238	668
Min Pcs/load	67	160	94	288
Avg Pcs/load	95	188	297 (truck=sawlogs, trailer=pulp)	

The large number of pieces that had to be handled had a significant impact on the loader's production. These figures reflect production of the John Deere loader working in conjunction with the yarding crew. Loading times were significantly higher for the first four days of the study when an old Barko loader was used. This is because it was forced to sort large cold decks of wood and its grapple was not able to handle small wood efficiently. The Barko loader took five and a half hours to load a single mule train with pulpwood.

5.4 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. For comparison, these costs are similar to the contract rates paid for this logging operation (refer to Appendix D). 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 from Appendix C were used in conjunction with the scheduled hours for each component of the logging operation to calculate a total cost for 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 cost summary table (Table 5.7).

Insufficient data were 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 were used to provide a total trucking cost.

Logging costs per unit volume can be found in Table 5.7 and were determined by dividing total cost by total units of timber removed from the site. No conversion factors were used as the weight scales and roll out scales provided all three volume measures (ft^3, Bdft, Tons).

Total revenue generated by logging was determined by multiplying the total sawlog and pulpwood volumes by their market prices at the time of the study ($515/Mbf and $36/ton). Total revenue was calculated to be $103,258 and total owning, operating and labor cost was found to be $78,808 (no profit or risk allowance) which left an net profit of $24,450. Total revenue and total cost are shown in Figure 5.7 as a sum of their parts. In summary, this case study demonstrated that logging with a harvester and cable yarder, under the circumstances present in this case study, was economically feasible. This result is due in part to the number of sawlogs that were removed from the unit as the pulpwood was being logged at a loss. This is discussed further in the Discussion section of this paper.

Table 5.7 Stump to Mill Logging Costs (Owning, Operating and Labor)

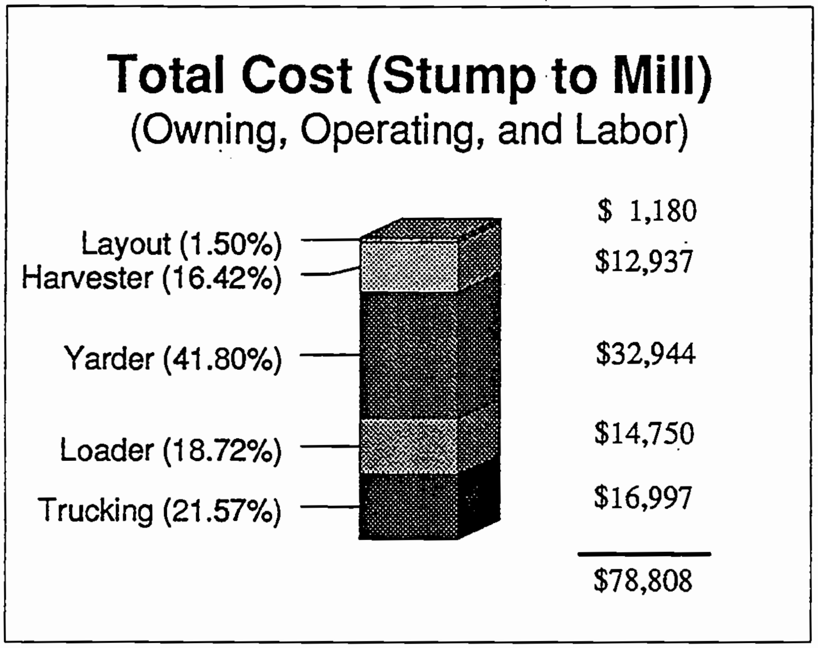
Stump to Mill Logging Costs

(Owning, Operating, and Labor Costs)

	Cost/hour	SHM's	Total Cost	$ / Cunit	$ / Mbf	$ / Ton	$ / m^3	$ / acre (40 ac)	$ / hectare (16.2 ha)
Layout (w pickup)	$21.27	55.5	$1,180.49	$1.45	$2.93	$0.64	$0.51	$29.51	$72.93
Harvester	$89.41	144.7	$12,937.20	$15.92	$32.11	$6.97	$5.62	$323.43	$799.21
Yarder	$132.79	248.1	$32,944.49	$40.53	$81.78	$17.74	$14.31	$823.61	$2,035.19
Loader	$67.64	218.1	$14,750.16	$18.15	$36.61	$7.94	$6.41	$368.75	$911.21
Trucking			$16,997.38	$20.91	$42.19	$9.15	$7.39	$424.93	$1,050.04
TOTALS	$311.10	666.38	$78,809.71	$96.97	$195.63	$42.44	$34.24	$1,970.24	$4,868.57

* Layout hourly cost includes a pickup and 40% for wage fringe benefits

** Trucking rates are based on Louisiana Pacific's contract rates.



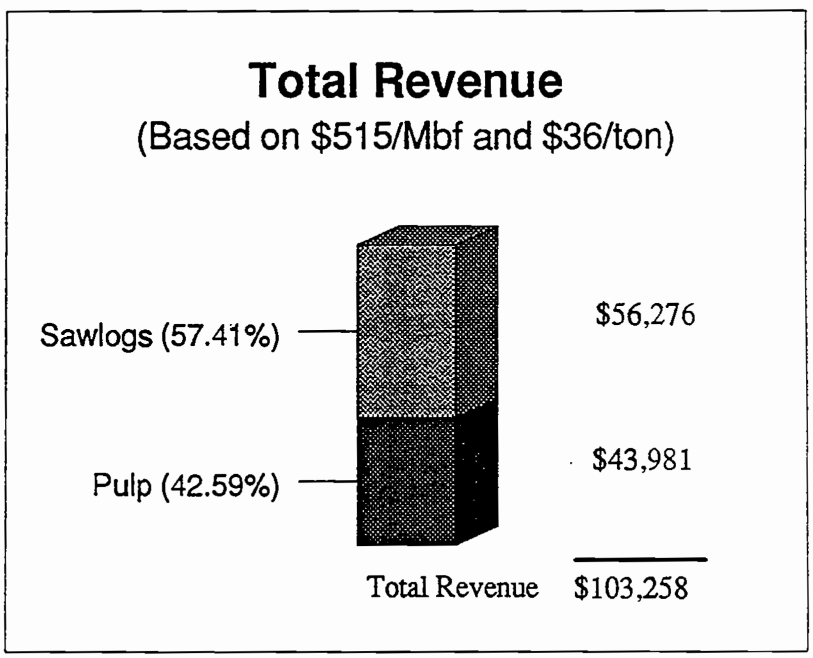


Figure 5.7 Logging Cost vs Logging Revenue

6.0 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.

These six areas serve to summarize the knowledge gained by the author from this pilot project and provides a forum for suggestions relative to future use of this logging system.

6.1 INTERPRETATION OF RESULTS / COMPARISONS TO PAST STUDIES

This section discusses the results presented in this paper and compares these results to studies presented in the literature review.

6.1.1 LOGGING LAYOUT AND PLANNING

The layout work that was done prior to logging had a cost of $1,180 ($29.5/acre) which represented 1.5% of the total logging cost. This small investment was instrumental 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.

This vision allowed the harvester operator to better position the logs that he produced because the locations of the skyline roads were known and marked on the ground. 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 dependant on these trees for 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 sequence the yarding of the corridors with respect to minimizing move distances and maintaining truck access to log decks. Thus, the preplanning of the yarding corridors made the operation much more efficient than if preplanning was not performed.

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

6.1.2 HARVESTER OPERATION

The harvester operation in this case study had a cost of $12,937 (owning, operating and labor) which represented 16.4% of 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 synchronization with the yarder resulted from using the marked skyline corridors as guides for the processing pattern of the stand (refer to Figure 4.5). The harvester travelled parallel to the skyline road and created rows of logs that were roughly perpendicular to the corridors. The activity sample studies estimated that only 3% of the harvester's time was spent actively positioning or bunching logs beyond the normal processing activity. During the falling and processing activities, the harvester was able to do almost all of the positioning of logs that was completed and very little extra effort was spent to orient or reposition logs once they were processed. When this technique was followed, the logs were reasonably well oriented for the yarding operation. 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. Thus, in most cases, the processed logs were reasonably well oriented for cable yarding with minimal extra effort from the harvester.

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. 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 very fast, much faster than the live stems. 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 case study showed a lower production rate and a higher cost. This is likely due to the small average piece size on the Deerhorn site. For instance, when thinning a second growth Douglas-fir stand (avg dbh=13.5") in the westside mountains of Oregon, the single grip harvester cost was \$11.81/cunit, while the single grip harvester on the Deerhorn site (avg dbh=7-9") cost \$16/cunit. Production in the Douglas fir stand was 1087 ft^3/PMH and 750 ft^3/SMH, while the harvester's production on the Deerhorn site was 733 ft^3/PMH and 589 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.

The harvester contractor was paid \$8/ton of wood removed from the site. The independent cost analysis that was done for this study showed that the cost of owning, operating, and labor for the harvester was \$89.41/SMH or \$6.97/ton. This analysis did not include profit or risk so the contract rate of \$8/ton was a reasonable one that allowed the contractor a 15% allowance for profit and risk.

6.1.3 YARDING AND LOADING OPERATIONS

The yarding and loading operations had an owning, operating and labor cost of \$47,694 which represented 60.5% of total logging cost. Yarding made up the majority of this cost (\$32,944), with loading costing less than half of the yarding cost (\$14,750). 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 heavy, remote controlled carriage between skyline roads when road changes occurred. The cost assigned to the loader is based on the use of the John Deere 640 ELC loader for all of the days that a loader was present on the Deerhorn site.

There was a large difference in the production rates per SMH and PMH for the yarder. This reflects the large amount of time spent on nonproductive activities such as skyline road changes and rigging delay times. The utilization rate is a measure of the percent of the scheduled hours that are productive. The utilization rate for the Koller was approximately 57%. Therefore, only 57% of the scheduled hours were used to yard logs and the remaining 43% 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%. 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].

When the yarder was in operation, the crew was very hard working and efficient at producing logs, but the following factors contributed to reducing the percent of productive hours in a shift below a reasonable level:

1. Organizational Difficulties

    All components of the logging system were not owned by the same contractor and cooperation between contractors was mediocre. The harvester component ran smoothly because all associated equipment was owned by Forest Recovery Systems Incorporated. However, the yarding operation was not self contained and was dependant on subcontractors to operate. MaCaulley Inc. owned the yarding system but did not own a loader or trucks and thus, was at the mercy of the operators of this equipment. There were difficulties coordinating the contractors to make the operation run smoothly, and day to day yarding production suffered because of it.

2. Long Road Changes

Skyline road changes averaged 2.1 hours in length due to the lack of an efficient method of moving the carriage, sporadic levels of prerigging, hand cranks on guylines and stabilizer pads, and likely, the crew's inexperience at moving the yarder. The lack of a drum on the yarder to pull strawline was also a factor in the time for road changes as the contractor was forced to use his pickup truck to pull strawline. Other contractors using the same yarder claimed to be able to move in 30-40 minutes without having to rig a haulback line or intermediate supports, so 60-90 minutes is probably a reasonable time frame for a road change in this situation. 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 K501 yarder. On the rare occasions when intermediate supports were used in the Deerhorn study, the road changes took much longer (3.5 hours) due to the logger's inexperience at rigging supports.

The skyline road pattern at the Deerhorn site made road changes relatively easy because of common tailtrees, few intermediate supports, short yarding roads, and easy terrain, but the times were still quite long. The length of time for road changes had a substantial effect on the productive hours spent yarding.

3. Rigging Failures

Three tailtrees were broken during yarding which resulted in rigging failures. This was likely due to excessive rigging heights in tail trees in order to try and avoid rigging intermediate supports. In most cases, one or both of the guylines in the tailtree broke which then resulted in the tree breaking at the halfway point from the ground to the skyline rigging. The loggers were inexperienced at rigging intermediate supports and therefore always pushed the limits of a tailtree instead of rigging a support. These failures resulted in delays of over an hour and therefore influenced the amount of productive time spent yarding. In addition, the lack of intermediate supports on some key corridors likely caused production to suffer due to a lack of suspension.

In summary, several factors combined to reduce the number of hours in a shift that could be considered productive below a reasonable level. Yarding could potentially be more productive and cost efficient if one or all of the above problems were addressed.

There were also a few factors beyond the control of the yarding crew that made for a lower utilization rate. The layout was driven by minimizing the amount of new road construction and the end result had several short yarding roads with little volume on them. The small amount of volume on these skyline roads and the long road change times combined to create a lot of down time relative to the amount of time spent yarding. Another delay beyond the control of the yarding crew was the public relations work that was part of this pilot project. There was a great deal of public interest in this pilot project and groups occasionally interrupted the yarding operation.

The description of the yarding production cycle found in the results section of this paper illustrates the percentage of time spent on each portion of the cycle.

The only unusual result in this production cycle breakdown was the large proportion of time spent unhooking the load at the landing (23.8%). Watching this occur in the field showed that the large number of logs coming in on a single turn made it difficult for the yarder operator to unhook all chokers at once. He would often have to go back to the yarder and raise and lower the load to expose the chokers still unhooked. This process was time consuming and lead to the unhook portion of the production cycle being the most time consuming of all other components.

It is also important to point out that the small wood found in this project required a loader that was designed to handle small pieces. An old Barko loader was initially used in the project and it demonstrated how much performance can suffer when a loader's grapple is not able to handle small diameter logs efficiently. This loader took over five hours to load a single truck (mule train) with pulpwood. Any loader that is to be successful in this type of logging must be able to handle large numbers of small diameter logs efficiently. The number of pieces that the loader must handle to load a truck is a major factor in how fast it can load trucks. Trucks carrying pulp took longer to load than trucks carrying sawlogs due to the increased number of pieces. Some mule trains carrying pulpwood had 400-500 logs on a single load, thus it was crucial that the loader could handle logs efficiently.

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 in the Deerhorn study. The studies presented in the literature review on small cable yarders, showed yarding and loading costs to be between \$60-\$75/cunit when thinning second growth stands in western Oregon on moderate to steep slopes. The yarding and loading cost for this project was \$59/ cunit. Therefore, in this case study, an unconventional use of a small cable yarder resulted in costs slightly less than that of typical skyline thinning with larger timber and steeper slopes. 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 Deerhorn project had better production(5.41 cunits/PMH) than the best Koller K300 thinning results(3.57 cunits/PMH) and lower production than the best Madill 071 thinning results (7.15 cunits/PMH). This makes intuitive sense as the K501 is larger than the K300 and smaller than the Madill 071. This illustrates that equipment cannot be selected solely on production rates as it may not be the most cost effective. In this case study the K501 had a much lower cost per cunit logged than the Madill 071 had in its study, even with its higher production rates. This is due to the lower owning, operating, and labor costs found with the smaller K501 yarder.

The yarding contractor was paid $24 / ton for yarding and loading. The cost determined by this study, based on an independent calculation of owning, operating, and labor costs, for yarding and loading was $200.43/ SMH or $25.68 / ton. This analysis did not include any allowance for profit or risk. The contract rate of $24/ton was below cost for this case study and therefore it is likely that MaCaulley Inc. lost money on the yarding and loading. This may be due in part to the low utilization during yarding or it may be that the contract price was simply too low . The yarding and loading operation could potentially break-even (cost=$24/ton) if the contractor was able to reduce the amount of non productive time by 10% (utilization rate increased from 57% to 67%). This could potentially be done with faster road changes, less rigging delays(failures), and better coordination between logging contractors (or a single contractor).

The cost and production of yarding equipment used in the Deerhorn study can also be compared with other primary log transport systems that have traditionally been used in areas similar to the Deerhorn site. Grapple skidding or forwarding are both alternative methods of accomplishing the same task as Deerhorn'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 ($41.00/cunit) experienced in the Deerhorn study. If only pulpwood production rates and cost are considered from the same study [Kellogg, 1994], the difference is slightly less spectacular. Yarding production in the Deerhorn study was 305 ft^3/SMH or 540 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 only of $25.60/cunit can be determined. Thus, Deerhorn's yarding operation had higher production than the forwarder but its hourly rate ($132.79/SMH) is almost double that of the forwarder's ($70.41/SMH), which results in considerably higher yarding costs/cunit. The harvester contractor employed in the Deerhorn study estimated that his forwarder could fulfil the same contract obligations as the yarding/loading operation($24/ton) for a contract rate of $16-$18/ton. He felt that his company could do the entire logging operation (stump to truck) using harvesters and forwarders for $26/ton.

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 is thinned with a feller buncher and the logs are skidded with a Franklin 105 grapple skidder to the landing, average skidder production is 28.3 tons /PMH. This can be compared to the Deerhorn yarding operations production of 12.4 tons/PMH. These figures are slightly misleading because the large component of dead and dry wood that was yarded in the Deerhorn 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. Future research is necessary to quantify reductions in cost and the related change in ground impacts for skidding and forwarding so that the most cost effective method of achieving acceptable ground impacts can be determined.

6.1.4 TRUCKING

Trucking had a cost of $16,997, which represented 21.6% of the total logging cost. No data was collected in this study to do an independent evaluation of owning, operating and labor costs associated with the trucking, and therefore the costs shown here reflect contract values paid out by Louisiana Pacific. The contracts were separated by truck type as follows: Stingers received $7.10/ton and Mule trains received $10.00/ton.

6.1.5 THE LOGGING SYSTEM AS A WHOLE

The total cost of logging (stump to dump) for this project was $78,808 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 limited by the yarding operation as it had the lowest production rate of all segments. Once the harvester's work on the first skyline road had been completed, the yarder was able to start working and not be held up by the harvester. The production of the entire system can be expressed best as the number of truckloads that were removed off the site per day. Typically, four loads were hauled off the site per day with some days reaching a high of six loads or a low of two loads. Truck loads averaged 5 Mbf or 24 tons of wood.

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 Deerhorn study is 61% higher than that of the Howe study, while the yarding production rate in the Deerhorn study is 80% 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 Deerhorn study, the harvester in the Howe study was less productive and the yarder in the Howe study was 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. Optimizing equipment operation for minimum total logging cost is discussed in Appendix J.

6.2 SENSITIVE VARIABLES IN THE SOLUTION

The Deerhorn project was only a pilot case study of a small cable yarder working in conjunction with a single grip harvester. Because the results are limited to the specific site and operating conditions, it is difficult to extrapolate the results and predict outcomes for different circumstances. This section of the paper discusses how the results might be affected by variations in certain key variables. The author felt that the following variables were ones that were subject to change from site to site and would also impact the production and cost of the system.

6.2.1 AVERAGE PIECE SIZE

Average piece size dictates the number of pieces that must be handled to produce a unit volume of certain wood types(ie. Mbf or tons). Piece size can also define the log grade assigned to a given log. As average piece size decreases(defined by diameter and/or length), more pieces must be handled to obtain a unit volume and the log grades of these pieces will likely be lower. 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 production drop from 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 them 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. In isolation, this suggests that log length 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 different in each of the two treatment units so that this variable could be explored. Thirty two foot logs were the preferred length in unit two and sixteen foot logs were preferred in unit one. The results found in Appendix E show that production rates/PMH were similar in the two units. Productive hours is used for comparison because it eliminates the variation of delay time in each treatment unit. The production rate for 32 foot logs was slightly higher for the yarding operation and slightly lower for the harvester operation when compared with 16 foot logs. This agrees with the statement made earlier that the harvester operator found long logs slightly harder to handle and the yarder could more easily maximize its payload each turn with long logs. However, conclusions from this comparison are limited because of variations in stand variables (ie. vol/acre) between the two units that could not be standardized.

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. The impacts of variations in log length on the entire system are less understood but the indications from this study suggest that longer lengths are more cost effective. Future research should attempt to better define the differences in production and stand damage associated with logging long vs short logs.

6.2.2 PROPORTION OF SAWLOGS VS PULPWOOD

In this case study, the price of pulpwood was $36/ton and the price of sawlog material was $515/Mbf. The profitability of the entire operation depended on the proportion of sawlog material that was removed because stump to mill logging costs ($42/ton) were higher than pulpwood revenues ($36/ton). Thus, the pulp was being logged at a loss but the revenue from the sawlogs made up the difference to yield a total net profit of $24,450 for the site. This result was obtained with sawlogs generating 57% of the revenue from 34% (635 tons) of the weight removed and 28% of the volume removed.

At the market prices stated above, the proportion of total weight represented by sawlogs required to just meet logging costs is 11%. If the gross weight of the sawlogs is less that than 11% of the total weight removed then the logging operation would be unprofitable. In the break-even scenario (11% of the weight is sawlogs), the sawlogs contribute 25% of the total revenue. In summary, if all other variables remain the same, the logging at the Deerhorn project would have been profitable as long as no more than 89% of the weight 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 would 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.

6.2.3 GROUND SLOPES

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(ie. 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-levelling 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 dead stem was almost always less than that of a similar size live 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. Because of the lighter log weights, more logs could be included in a yarded turn before the payload of the system was exceeded and thus dead logs allowed more volume to be yarded per turn. The handling of dead material was generally more efficient than the handling of live material. The amount of dead material did not have any affect on the loading system accept that it was prone to breakage.

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 Deerhorn project that looked at several resource issues, namely soil impacts, the effect on fuel loading, and the effect on stand health. The soil impact information presented here are the opinions of this researcher and Mr. Bryan Hogervorst (Forest Engineering Graduate Research Assistant) of Oregon State University. The fuel loading information represents the preliminary results obtained by the USFS Pacific Northwest Research Station. 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.

6.3.1 SOIL IMPACTS

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. Because of the limited contact with the forest soils, compaction can be assumed to be minimal. More detailed information can be found in the report dealing specifically with this issue that will be prepared by Dr. Paul Adams 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 under the skyline corridor and two isolated areas that were more severely disturbed due to lack of front end log clearance, which resulted from a failure to rig an intermediate support. These areas looked like trenches and were approximately a foot deep with earth piled on either side. This disturbance could easily have been avoided with the proper use of intermediate supports. Because of the lack of vehicle traffic on the soil in this phase of the operation, compaction was not an issue.

6.3.2 FUEL LOADING

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. The end result was a small reduction(20%) in total fuel load and a change in fuel loading structure from larger debris to fine fuels. 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.

6.3.3 STAND HEALTH / SILVICULTURAL PRESCRIPTION

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. In the opinion of the author, the treatment unit in which 32 foot logs were cut and yarded appeared to have slightly more damage that the 16 foot log unit.

The silvicultural prescription appeared to have been well executed. The damaged and dying trees were removed and the healthiest trees were left as residuals. The prescription also stated that ponderosa pine and western larch were to be left whenever possible (ie. healthy specimens were present). Figure 5.2 shows that these two species make up only a small portion of the material removed from the site and the western larch that was removed was mostly dead or dying. This suggests that the prescription was well carried out.

6.4 SUGGESTIONS FOR FUTURE LOGGING OPERATIONS

Future applications of a single-grip harvester and skyline yarding system can learn from this initial trial 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 a small portion 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 as can be done efficiently. 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. Make better use of intermediate supports.

During skyline yarding, the use of intermediate supports may be necessary to mitigate soil disturbance in areas where logs would not be at least partially suspended off the ground. The logging layout performed for this project provided the yarding contractor with an intermediate support on each skyline road, yet he chose not to use many of them - sometimes a poor decision. The use of profile analysis in the layout stage could help predict which corridors will ***require*** intermediate supports and their associated rigging heights. 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 dependant 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 fulfil his contract and may not make the extra effort needed to improve yarding efficiency. If different contractors must be hired for each phase, as in this project, it is important that the contracts are written to require a high level of coordination and cooperation between them.

Another problem experienced in this project was the lack of availability of equipment at inopportune moments. Contractors that need to subcontract for additional equipment could be at the mercy of subcontractor's, and their working practices and equipment. If it is possible to hire a contractor that owns all of the required equipment, do so.

4. Improve the utilization rate for the yarding operation.

The percentage of scheduled hours that were actually productive for yarding was low when compared with similar operations. Almost all of the above suggestions will help in raising the utilization rate of the yarder, but the biggest gains can potentially come with improved road change times. Road changes for the Koller K501 made up a significant portion of the non-productive time that occurred. Higher levels of prerigging and a more efficient method of moving the carriage will help to shorten the down time associated with changing skyline roads. The crew was often forced to wait for the loader to bring the heavy carriage to them before they could begin yarding. Sporadic levels of prerigging made road change time longer than it had to be. Other improvements that may speed up road changes would be to keep the truck attached to the trailer(yarder) whenever possible to eliminate hookup time, and to develop a better system of moving the strawline. Using a pickup truck to pull the strawline around the blocks was not efficient and took additional time to clean up when the process was finished. Utilizing a drum on the yarder may be a better alternative.

5. 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 $67.64. This size of loader was not really necessary for the size of wood being handled and was quite expensive. If possible, a less expensive, smaller loader would likely do the same job for less cost and not have a negative effect on production.

6.5 OPPORTUNITIES FOR FUTURE RESEARCH

There are several opportunities for future research in areas related to the Deerhorn case study. 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 case 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. Assuming that the Deerhorn case study is an example of low harvester effort, future trials to explore higher levels of effort could be as follows:

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.

A Comprehensive Study with Replications and Alternative Systems

Additional replications of this system are needed to verify the preliminary results obtained in this case study and explore the effects of differing stand and terrain variables. The results presented in this paper reflect a single trial of a new system and may not necessarily reflect the outcome of future uses. Additional replications will provide results under different circumstances that can then be used to predict results of future applications.

More detailed studies of this logging system would also be useful in order to determine which log length (16' or 32') results in better production. The data collection format used in this study did not allow all of the variables influencing production on the two treatment units(16' logs and 32' logs) to be standardized. Detailed time studies are necessary to do make comparisons of production between different log lengths.

Trials of other ground based systems should also be done for comparison with this system. Ground impacts, stand damage, and logging costs need to be assessed for each system in order to make an informed decision about which logging system is best able to meet management objectives in the most cost effective way. Specifically, combining the harvester with either grapple skidders or forwarders should be explored.

7.0 Conclusion

This paper evaluated the production and costs resulting from a single grip harvester and small cable yarder used to thin and salvage log an eastern Oregon stand on essentially flat ground. Production of the harvester and yarder were found to be 7.33 cunits/PMH (20.74 m^3/PMH) and 5.41 cunits/PMH (15.31 m^3/PMH) respectively. For the circumstances found in this case study, the cost of logging from stump to mill was $97/cunit ($34.24/m^3) or $42.44/ton ($46.78/tonne) which represented a per acre cost of $1,970 ($4869/ha). The landowner was able to make a profit from logging because of the presence of sawlogs in the unit. Pulpwood prices at the time of the study were $36/ton and thus a loss of $10/ton of pulplogs removed was incurred. Conversely, the sawlogs removed received $515/Mbf which was approximately $93/ton and thus a profit of $50.56 was made on every ton of sawlogs removed. The percentage of sawlogs was high enough to cover losses from logging pulpwood and make a profit for the landowner. Total logging cost was $78,809 and total revenue generated was $103,258.

Future management implications from this study are that a harvester and small cable yarder can be combined to successfully thin and salvage-log flat terrain in a reasonably cost effective manner. In areas where soil impacts are of critical importance, this harvesting system may provide a viable 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

Examples of Shift Level Forms and Activity Sampling Forms

Unit Layout Information

Project: ______________________ **Unit** __________

Treatment: ______________________

Avg daily travel time __________ **(hrs)**

Layout Crew Daily Work Log
(Hours Worked by Task)

Date (dd/mm/yy)	**Person hours spent by crew on each activity (1/4 hr increments)**							**Total Crew Hours**
	General Recon	Roads & Landings	Locating Skyline Rds	Locating Boundary	Office Analysis	Other**	Breaks	

** NOTES: Please provide a brief description of hours entered under "Other".

Date __________ Comment ____

Date __________ Comment ____

Date __________ Comment ____

Date __________ Comment ____

Date __________ Comment ____

Date __________ Comment ____

Date __________ Comment ____

Date __________ Comment ____

Date __________ Comment ____

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]: #1 (Long logs) OR #2 (Short logs)

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

16' ___________ Randoms _____________

32' ___________

COMMENTS

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

____

____

____

____

____

Daily Loader Production

GENERAL INFORMATION

Date ____________ Landing # ____________ 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 equip

Daily Yarding Production

GENERAL INFORMATION

Date ______________ Landing # ________

Start Time ________

End Time ________ Treatment Unit: Long logs (#1) ____ OR Short logs (#2) ____

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 way)

Deerhorn

Harvester Activity Sampling

Treatment unit # ______ Observer ____________________

Start Time _____________ Finish Time ______________

Interval ____________

Elapsed Time ___________

ACTIVITY	INTERVAL TALLY	TOTAL	%
Positioning Head			
Processing Dead			
Processing Live			
Felling			
Travelling			
Swing to Bunch			
Repair and Maintena			
Other Delays			

Number of trees processed ________________

Number of Live logs _________
Dead logs _________

Number of trees felled __________________

Harvester Production Tally Sheet

	Live	Dead
STEMS		
FELLED		
LOGS		

	Live	Dead
STEMS		
FELLED		
LOGS		

	Live	Dead
STEMS		
FELLED		
LOGS		

	Live	Dead
STEMS		
FELLED		
LOGS		

ROAD CHANGE TIME STUDY

Date:__________
Start:_________
Stop:__________

100 TPA_______
60 TPA_______
30 TPA_______

Unit #:__________
From Cable Road _____
To Cable Road ______
Tailhold Type:______

Component	Time	# People	Comments
Rig-Down			
Move Yarder			
Rig-Up			
Pre-Rigging			

Delays and Descriptions:

N

Appendix B

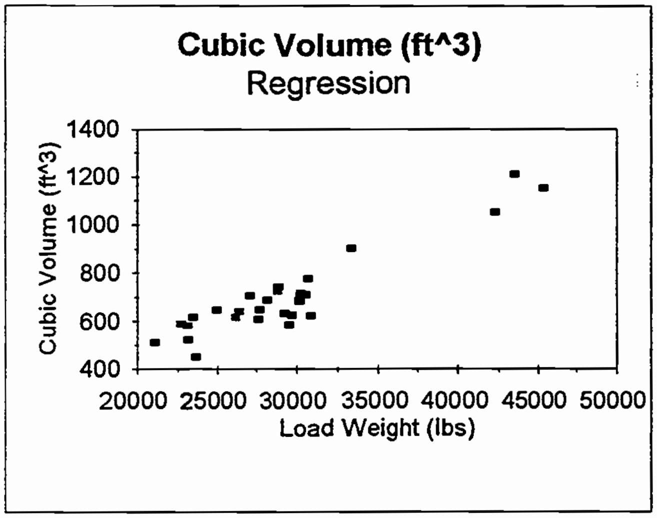
Regression Analysis for Non-scaled Loads

Appendix C

Owning, Operating, and Labor Costs as Calculated by *PACE*

PACE is software developed in OSU's Forest Engineering Department for calculating owning, operating, and labor costs of equipment.

Regression Analysis/Results

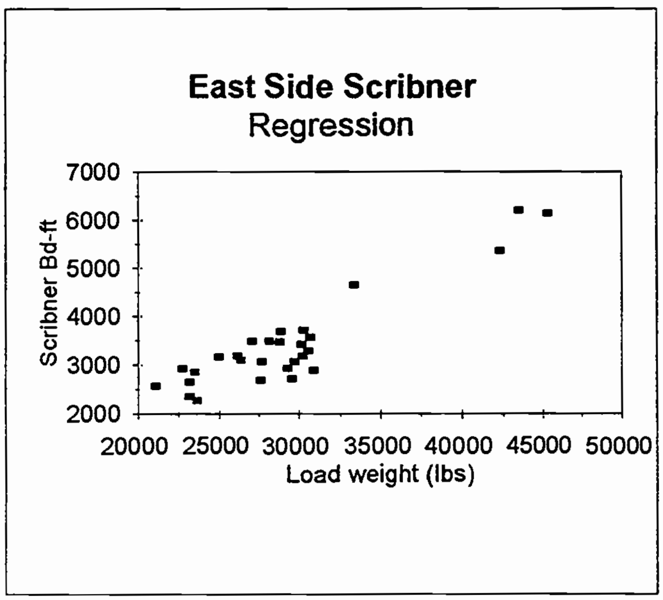


Cubic Volume Predictor

Regression Output		
Constant		-115.327
Std Err of Y Est		64.73056
R Squared		0.872377
No. of Observations		28
Degrees of Freedom		26
X Coefficient(s)	0.027925	
Std Err of Coef.	0.002095	

Cubic Vol = -115.327 + .027925(weight)

Cubic vol = volume (cubic feet) of wood in the truck load.
weight = weight of the load (lbs), not including truck weight.
** Note: Load weight range = 20000 - 45000



Scribner Predictor

Regression Output		
Constant		-1102.3
Std Err of Y Est		400.4906
R Squared		0.846047
No. of Observations		28
Degrees of Freedom		26
X Coefficient(s)	0.154912	
Std Err of Coef.	0.01296	

Scribner = -1102.3 + 0.154912(Weight)

Scribner = Bd-ft of timber on the truck load.
weight = weight of the load (lbs), not including truck weight.
** Note: Load weight range = 20000 - 45000

Equipment Owning and Operating Costs

	Owning Cost/hour	Operating Cost/hour	Labour Cost/hour	Move-in Cost/hour	Rate per Sched Hour	
Yarder	$13.54	$9.65	$94.22	$1.09	$118.50	
Carriage	$3.87	$2.58			$6.45	
Talkie Tooter	$0.70	$0.22			$0.92	
Chainsaw	$0.30	$0.88			$1.18	
Flatbed	$0.69	$1.65			$2.34	
Pickup Truck	$1.67	$1.49			$3.16	
Fire Equip	$0.22	$0.02			$0.24	$132.79
Harvester	$36.41	$23.55	$21.02	$4.73	$85.71	
Support Truck	$1.84	$1.86			$3.70	$89.41
Loader	$25.42	$18.20	$20.88	$3.14	$67.64	$67.64
Totals	71.12	50.45	41.9		171.33349	

Move in and Out Costs

	Labor Cost	Move Dist (Miles)	Trucking Cost	Move in Cost	Move Out Cost	Total $$ Move in
Yarder	$72	80	$62.86	$134.86	$134.86	$269.72
Harvester	$144	30	$342.00	$342.00	$342.00	$684.00
Loader	$144	30	$342.00	$342.00	$342.00	$684.00
Total for Project --->						1637.72

Yarder (Assumes move in from Pendleton)

Transport: 10 ton flat bed truck @ $2.34/hour * 4 hours
Feul: 8 Gallons/hour * 4 hours * $1.25/gallon * 1.07 lube and oil adj.
Labor: one person * 18/hr * 4 hours

Harvester and Loader (Assumes move in from another local job site)

Transport: Contract lowboy with pilot vehicles @ $100/hour * 3 hours
(Cost per hour are for loaded and unloaded time)
Permits: $30/permit + $0.40/loaded mile for loads in excess of 80,000 lbs

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)

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

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

$$I = \% \times AAI$$

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

Koller K501 Three Drum Yarder

Equipment Ownership Cost Inputs		
Delivered equipment cost	$	134,500.00
Minus line and rigging cost	$	5,000.00
Minus tire or track replacement cost	$	1,000.00
Minus residual (salvage) value	$	40,350.00
Life of equipment (Years)	#	6.00
Number of days worked per year	#	200.00
Number of hours worked per day	#	10.00
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)	#	3.00
Fuel cost (Per gallon)	$	0.95
Percent of fuel consumption for lubricants	%	7.00
Cost of oil and lubricants (Per gallon)	$	4.00
Cost of lines	$	3,500.00
Estimated life of lines (Hours)	#	2,000.00
Cost of rigging	$	1,500.00
Estimated life of rigging (Hours)	#	4,000.00
Cost of tires or tracks	$	1,000.00
Estimated life of tires or tracks (Hours)	#	6,000.00

Summary		
Ownership		
Depreciable value:	$	88,150.00
Equipment depreciation:	$	14,691.67 / Year
Interest expense:	$	9,527.08 / Year
Taxes, license, insurance and storage:	$	2,858.13 / Year
Annual ownership cost:	$	27,076.88 / Year
Ownership cost (Subtotal):	$	13.54 / Hour
Machine operating		
Repairs and maintenance:	$	3.67 / Hour
Fuel and oil:	$	3.69 / Hour
Lines and rigging:	$	2.13 / Hour
Tires or tracks:	$	0.17 / Hour
Equipment operating cost (Subtotal):	$	9.65 / Hour
Labor		
Direct labor cost:	$	81.93 / Hour (4 person crew)
Supervision and overhead:	$	12.29 / Hour
Labor cost (Subtotal):	$	94.22 / Hour
OWNERSHIP COST	$	13.54 / Hour
OPERATING COST	$	9.65 / Hour
LABOR COST	$	94.22 / Hour
Machine rate (Ownership + Operating + Labor)	$	117.42 / Hour

Eagle Eaglet Carriage

Equipment Ownership Cost Inputs		
Delivered equipment cost	$	32,000.00
Minus line and rigging cost	$	200.00
Minus tire or track replacement cost	$	0.00
Minus residual (salvage) value	$	7,500.00
Life of equipment (Years)	#	5.00
Number of days worked per year	#	200.00
Number of hours worked per day	#	10.00
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)	$	0.95
Percent of fuel consumption for lubricants	%	7.00
Cost of oil and lubricants (Per gallon)	$	4.00
Cost of lines	$	200.00
Estimated life of lines (Hours)	#	1,000.00
Cost of rigging	$	100.00
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:	$	24,300.00
Equipment depreciation:	$	4,860.00 / Year
Interest expense:	$	2,220.00 / Year
Taxes, license, insurance and storage:	$	666.00 / Year
Annual ownership cost:	$	7,746.00 / Year
Ownership cost (Subtotal):	$	3.87 / Hour
Machine operating		
Repairs and maintenance:	$	1.22 / Hour
Fuel and oil:	$	1.23 / Hour
Lines and rigging:	$	0.13 / Hour
Tires or tracks:	$	0.00 / Hour
Equipment operating cost (Subtotal):	$	2.58 / Hour
Labor		
Direct labor cost:	$	0.00 / Hour
Supervision and overhead:	$	0.00 / Hour
Labor cost (Subtotal):	$	0.00 / Hour

OWNERSHIP COST	$	3.87 / Hour
OPERATING COST	$	2.58 / Hour
LABOR COST	$	0.00 / Hour
Machine rate (Ownership + Operating + Labor)	$	6.45 / Hour

Talkie Tooter

Equipment Ownership Cost Inputs		
Delivered equipment cost	$	5,918.00
Minus line and rigging cost	$	0.00
Minus tire or track replacement cost	$	0.00
Minus residual (salvage) value	$	1,184.00
Life of equipment (Years)	#	7.00
Number of days worked per year	#	180.00
Number of hours worked per day	#	10.00
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	$	900.00
Estimated life of rigging (Hours)	#	7,200.00
Cost of tires or tracks	$	0.00
Estimated life of tires or tracks (Hours)	#	0.00

Summary		
Ownership		
Depreciable value:	$	4,734.00
Equipment depreciation:	$	676.29 / Year
Interest expense:	$	466.70 / Year
Taxes, license, insurance and storage:	$	116.67 / Year
Annual ownership cost:	$	1,259.66 / Year
Ownership cost (Subtotal):	$	0.70 / Hour
Machine operating		
Repairs and maintenance:	$	0.09 / Hour
Fuel and oil:	$	0.00 / Hour
Lines and rigging:	$	0.13 / Hour
Tires or tracks:	$	0.00 / Hour
Equipment operating cost (Subtotal):	$	0.22 / Hour
Labor		
Direct labor cost:	$	0.00 / Hour
Supervision and overhead:	$	0.00 / Hour
Labor cost (Subtotal):	$	0.00 / Hour

OWNERSHIP COST	$	0.70 / Hour
OPERATING COST	$	0.22 / Hour
LABOR COST	$	0.00 / Hour
Machine rate (Ownership + Operating + Labor)	$	0.92 / Hour

1992 Ford Pickup

Equipment Ownership Cost Inputs		
Delivered equipment cost	$	15,436.00
Minus line and rigging cost	$	0.00
Minus tire or track replacement cost	$	400.00
Minus residual (salvage) value	$	3,000.00
Life of equipment (Years)	#	6.00
Number of days worked per year	#	200.00
Number of hours worked per day	#	10.00
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)	$	0.95
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:	$	12,036.00
Equipment depreciation:	$	2,006.00 / Year
Interest expense:	$	1,025.00 / Year
Taxes, license, insurance and storage:	$	307.63 / Year
Annual ownership cost:	$	3,339.06 / Year
Ownership cost (Subtotal):	$	1.67 / Hour
Machine operating		
Repairs and maintenance:	$	0.50 / Hour
Fuel and oil:	$	0.76 / Hour
Lines and rigging:	$	0.00 / Hour
Tires or tracks:	$	0.22 / Hour
Equipment operating cost (Subtotal):	$	1.49 / Hour
Labor		
Direct labor cost:	$	0.00 / Hour
Supervision and overhead:	$	0.00 / Hour
Labor cost (Subtotal):	$	0.00 / Hour

OWNERSHIP COST	$	1.67 / Hour
OPERATING COST	$	1.49 / Hour
LABOR COST	$	0.00 / Hour
Machine rate (Ownership + Operating + Labor)	$	3.16 / Hour

1978 Ford- 10 ton Flatbed (Dual Axles)

Equipment Ownership Cost Inputs		
Delivered equipment cost	$	7,000.00
Minus line and rigging cost	$	0.00
Minus tire or track replacement cost	$	1,200.00
Minus residual (salvage) value	$	4,000.00
Life of equipment (Years)	#	3.00
Number of days worked per year	#	200.00
Number of hours worked per day	#	10.00
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	%	100.00
Fuel amount (Gallons per hour)	#	1.00
Fuel cost (Per gallon)	$	0.95
Percent of fuel consumption for lubricants	%	5.00
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	$	1,200.00
Estimated life of tires or tracks (Hours)	#	6,000.00

Summary		
Ownership		
Depreciable value:	$	1,800.00
Equipment depreciation:	$	600.00 / Year
Interest expense:	$	600.00 / Year
Taxes, license, insurance and storage:	$	180.00 / Year
Annual ownership cost:	$	1,380.00 / Year
Ownership cost (Subtotal):	$	0.69 / Hour
Machine operating		
Repairs and maintenance:	$	0.30 / Hour
Fuel and oil:	$	1.15 / Hour
Lines and rigging:	$	0.00 / Hour
Tires or tracks:	$	0.20 / Hour
Equipment operating cost (Subtotal):	$	1.65 / Hour
Labor		
Direct labor cost:	$	0.00 / Hour
Supervision and overhead:	$	0.00 / Hour
Labor cost (Subtotal):	$	0.00 / Hour
OWNERSHIP COST	$	0.69 / Hour
OPERATING COST	$	1.65 / Hour
LABOR COST	$	0.00 / Hour
Machine rate (Ownership + Operating + Labor)	$	2.34 / Hour

Chainsaw

Equipment Ownership Cost Inputs		
Delivered equipment cost	$	925.00
Minus line and rigging cost	$	0.00
Minus tire or track replacement cost	$	0.00
Minus residual (salvage) value	$	200.00
Life of equipment (Years)	#	2.00
Number of days worked per year	#	200.00
Number of hours worked per day	#	10.00
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)	$	1.25
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:	$	725.00
Equipment depreciation:	$	362.50 / Year
Interest expense:	$	89.25 / Year
Taxes, license, insurance and storage:	$	22.31 / Year
Annual ownership cost:	$	474.06 / Year
Ownership cost (Subtotal):	$	0.30 / Hour
Machine operating		
Repairs and maintenance:	$	0.17 / Hour
Fuel and oil:	$	0.46 / Hour
Lines and rigging:	$	0.25 / Hour
Tires or tracks:	$	0.00 / Hour
Equipment operating cost (Subtotal):	$	0.88 / Hour
Labor		
Direct labor cost:	$	0.00 / Hour
Supervision and overhead:	$	0.00 / Hour
Labor cost (Subtotal):	$	0.00 / Hour

OWNERSHIP COST	$	0.30 / Hour
OPERATING COST	$	0.88 / Hour
LABOR COST	$	0.00 / Hour
Machine rate (Ownership + Operating + Labor)	$	1.18 / Hour

Fire Equipment

Equipment Ownership Cost Inputs		
Delivered equipment cost	$	2,450.00
Minus line and rigging cost	$	0.00
Minus tire or track replacement cost	$	0.00
Minus residual (salvage) value	$	500.00
Life of equipment (Years)	#	10.00
Number of days worked per year	#	200.00
Number of hours worked per day	#	10.00
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	%	20.00
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:	$	1,950.00
Equipment depreciation:	$	195.00 / Year
Interest expense:	$	157.25 / Year
Taxes, license, insurance and storage:	$	47.17 / Year
Annual ownership cost:	$	399.42 / Year
Ownership cost (Subtotal):	$	0.20 / Hour
Machine operating		
Repairs and maintenance:	$	0.02 / Hour
Fuel and oil:	$	0.00 / Hour
Lines and rigging:	$	0.00 / Hour
Tires or tracks:	$	0.00 / Hour
Equipment operating cost (Subtotal):	$	0.02 / Hour
Labor		
Direct labor cost:	$	0.00 / Hour
Supervision and overhead:	$	0.00 / Hour
Labor cost (Subtotal):	$	0.00 / Hour
OWNERSHIP COST	$	0.20 / Hour
OPERATING COST	$	0.02 / Hour
LABOR COST	$	0.00 / Hour
Machine rate (Ownership + Operating + Labor)	$	0.22 / Hour

Link Belt Carrier with Waratah 22' Harvester Head

Equipment Ownership Cost Inputs		
Delivered equipment cost	$	345,000.00
Minus line and rigging cost	$	0.00
Minus tire or track replacement cost	$	9,718.00
Minus residual (salvage) value	$	69,000.00
Life of equipment (Years)	#	5.00
Number of days worked per year	#	230.00
Number of hours worked per day	#	10.00
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)	$	0.95
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	$	9,718.00
Estimated life of tires or tracks (Hours)	#	5,000.00

Summary		
Ownership		
Depreciable value:	$	266,282.00
Equipment depreciation:	$	53,256.40 / Year
Interest expense:	$	23,460.00 / Year
Taxes, license, insurance and storage:	$	7,038.00 / Year
Annual ownership cost:	$	83,754.40 / Year
Ownership cost (Subtotal):	$	36.41 / Hour
Machine operating		
Repairs and maintenance:	$	16.21 / Hour
Fuel and oil:	$	5.40 / Hour
Lines and rigging:	$	0.00 / Hour
Tires or tracks:	$	1.94 / Hour
Equipment operating cost (Subtotal):	$	23.55 / Hour
Labor		
Direct labor cost:	$	20.02 / Hour
Supervision and overhead:	$	1.00 / Hour
Labor cost (Subtotal):	$	21.02 / Hour
OWNERSHIP COST	$	36.41 / Hour
OPERATING COST	$	23.55 / Hour
LABOR COST	$	21.02 / Hour
Machine rate (Ownership + Operating + Labor)	$	80.99 / Hour

Support Truck for Harvester

Equipment Ownership Cost Inputs		
Delivered equipment cost	$	18,900.00
Minus line and rigging cost	$	3,000.00
Minus tire or track replacement cost	$	400.00
Minus residual (salvage) value	$	3,000.00
Life of equipment (Years)	#	6.00
Number of days worked per year	#	200.00
Number of hours worked per day	#	10.00
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)	$	0.95
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	$	3000.00
Estimated life of rigging (Hours)	#	8000.00
Cost of tires or tracks	$	400.00
Estimated life of tires or tracks (Hours)	#	2000.00

Summary		
Ownership		
Depreciable value:	$	12,500.00
Equipment depreciation:	$	2,083.33 / Year
Interest expense:	$	1,227.50 / Year
Taxes, license, insurance and storage:	$	368.25 / Year
Annual ownership cost:	$	3,679.08 / Year
Ownership cost (Subtotal):	$	1.84 / Hour
Machine operating		
Repairs and maintenance:	$	0.52 / Hour
Fuel and oil:	$	0.76 / Hour
Lines and rigging:	$	0.38 / Hour
Tires or tracks:	$	0.20 / Hour
Equipment operating cost (Subtotal):	$	1.86 / Hour
Labor		
Direct labor cost:	$	0.00 / Hour
Supervision and overhead:	$	0.00 / Hour
Labor cost (Subtotal):	$	0.00 / Hour

OWNERSHIP COST	$	1.84 / Hour
OPERATING COST	$	1.86 / Hour
LABOR COST	$	0.00 / Hour
Machine rate (Ownership + Operating + Labor)	$	3.70 / Hour

1994 John Deere 640 ELC Loader

Equipment Ownership Cost Inputs		
Delivered equipment cost	$	250,000.00
Minus line and rigging cost	$	0.00
Minus tire or track replacement cost	$	12,434.00
Minus residual (salvage) value	$	75,000.00
Life of equipment (Years)	#	5.00
Number of days worked per year	#	220.00
Number of hours worked per day	#	10.00
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)	$	0.95
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	$	12,434.00
Estimated life of tires or tracks (Hours)	#	6,000.00

Summary		
Ownership		
Depreciable value:	$	162,566.00
Equipment depreciation:	$	32,513.20 / Year
Interest expense:	$	18,000.00 / Year
Taxes, license, insurance and storage:	$	5,400.00 / Year
Annual ownership cost:	$	55,913.20 / Year
Ownership cost (Subtotal):	$	25.42 / Hour
Machine operating		
Repairs and maintenance:	$	10.35 / Hour
Fuel and oil:	$	5.78 / Hour
Lines and rigging:	$	0.00 / Hour
Tires or tracks:	$	2.07 / Hour
Equipment operating cost (Subtotal):	$	18.20 / Hour
Labor		
Direct labor cost:	$	19.88 / Hour
Supervision and overhead:	$	0.99 / Hour
Labor cost (Subtotal):	$	20.88 / Hour

OWNERSHIP COST	$	25.41 / Hour
OPERATING COST	$	18.20 / Hour
LABOR COST	$	20.88 / Hour
Machine rate (Ownership + Operating + Labor)	$	64.49 / Hour

Layout Crew and Pickup

Pickup	$ 3.16/hr	
Direct Labor	$18.11/hr	(12.95 /hr + 40% fringe benefits)

Total layout cost = $21.27/hr

Labor Rates for Equipment Operators

Employee	Base Wage	
Hook tender	$13.35	
Rigging slinger	$12.55	
Yarding Engineer	$12.02	(All wages are increased by 40% for fringe benefits)
Chokersetter	$10.85	
Loader operator	$12.91	
Harvester operator	$13.00	

Appendix D

Costs and Revenues from the Landowner's Point of View

Louisiana Pacific

LP Costs		Price/ton	Total Cost
	Harvester	$8.00	$14,855.20
	Yard/load	$24.00	$44,565.60
	Stingers	$7.10	$3,847.14
	Mule trains	$10.00	$13,150.25
		$49.10	$76,418.19

LP Revenues		Price	Value
	pulp	$36/ton	$43,981.20
	Sawlogs	$515/Mbf	$59,276.50
			$103,257.70

Profit	$26,839.51

Appendix E

Production and Volume Information by Treatment Unit (16' logs vs 32' logs)

Production Summary

(Combination of shift level and detailed study data)

Harvester Production

		Logs per hour	ft ^ 3 per hour	Bd-ft per hour	Tons per hour
Scheduled	16' logs	210.7	737.5	3621.9	17.28
Machine Hrs	32' logs	151.9	720.0	3625.9	15.80
Productive	16' logs	220	770.0	3781.8	18.04
Machine Hrs	32' logs	157	744.7	3750.0	16.34

SMH	TOTAL	181.3	705.3	3491.8	16.1
PMH	TOTAL	188.5	733.3	3630.5	16.8

Yarder Production

		Logs per hour	Ft^3 per hour	Bd-ft per hour	Tons per hour
Scheduled	16' logs	103	360.4	1770.2	8.45
Machine Hrs	32' logs	58	273.4	1376.6	6.03
Productive	16' logs	159	558.1	2741.1	13.08
Machine Hrs	32' logs	119	563.9	2839.6	12.37

SMH	Total	81.4	316.6	1567.8	7.2
PMH	Total	139.0	540.7	2677.1	12.4

Yarding Setting Statistics

16' logs (Unit 1)			32' logs (Unit 2)		
Road	Length (ft)	AYD(ft)	Road	Length (ft)	AYD(ft)
12	877	438.5	1	793	264.3
13D	623	311.5	2	735	245.0
13C	720	480.0	3	437	145.7
13B	684	456.0	4	465	155.0
13A	912	608.0	5	496	165.3
13AA	682	454.7	6	724	241.3
14A	827	551.3	7	380	190.0
14B	818	545.3	8	606	303.0
14C	771	514.0	9	446	178.4
			10	498	332.0
Averages	768	484.4	Averages	558	222.0
Max	912		Max	793	
Min	623		Min	380	

Setting Totals

	Length (ft)
Average	657.58
Max	912
Min	380

** Longest span without support = 912 ft (signifigant soil disturbance)

Harvest Volume Summary by Unit and Setting (Gross)

		Total Gross Volumes			Gross Log Averages				
		ft^3	Bd-ft	Tons	Diameter	Length	ft^3 / log	Bd-ft / log	Tons / log
(16' logs)	Pulplogs	37859.4	182885.5	801.3	4.48	16.44	3.07	14.82	0.065
	Sawlogs	12794.1	65718.0	384.6	7.24	15.89	6.05	31.06	0.182
	Unit total	50653.5	248603.5	1185.9	4.88	16.36	3.50	17.19	0.082
(32' logs)	Pulplogs	20837.6	104843.2	420.4	4.12	22.71	3.93	19.80	0.079
	Sawlogs	9783.8	49400.0	250.6	6.33	25.50	8.40	42.40	0.215
	Unit Total	30621.4	154243.2	671.0	4.52	23.21	4.74	23.87	0.104
Setting	Totals	81274.9	402846.7	1856.9					
	Averages				4.77	18.47	3.89	19.26	0.089

Unit 1 vs Unit 2

	Pulplogs	Sawlogs	Total logs
16' logs	12344	2116	14460
32' logs	5296	1165	6461
Total	17639	3281	20920

** Note: The number of pulplogs was estimated from the average number of logs on a truck.

Sawlogs vs Pulplogs

	Average ft^3 / log	Average Bd-ft/log	Average ton/log	TOTALS ft^3	Bd-ft	Tons
Sawlogs	7.00	35.73	0.194	22578	115118	635
Pulplogs	3.41	16.73	0.069	58697	287729	1222
All logs	3.89	19.26	0.089	81275	402847	1857

Percentage of Volume or weight

	Ft^3	%	Bd-ft	%	Tons	%
Sawlogs	22578	27.8%	115118.0	28.6%	635.2	34.2%
Pulplogs	58697	72.2%	287728.7	71.4%	1221.7	65.8%
All logs	81275	100.0%	402846.7	100.0%	1856.9	100.0%

Harvested Wood	Unit 1		Unit 2		Total Setting	
% Live		44.3%		40.2%		42.3%
% dead and down	40.2%		47.0%		43.6%	
% dead and standing	15.5%		12.8%		14.1%	
% Dead	------->	55.7%	------->	59.8%	------->	57.7%
Total		100.0%		100.0%		100.0%
% Felled		59.8%		53.0%		56.4%

Appendix F

Shift Level Study Results

Shift Level Data Summary

Segment	Unit	Days Worked	Sched Hrs Worked	Prod Hrs Worked	Delay Time (hrs)	Avg Pcs per turn	Pieces handled	Average Production					
								Logs per SMH	ft^3 per SMH	Bd-ft per SMH	Logs per Prod hrs	ft^3 per PMH	Bd-ft per PMH
Layout	Total	5	55.5	55.5	0		(Too High!)						
Harvester	16' logs	11	78.8	66.1	12.7		21977	278.90	976.14	4794.22	330.03	1155.11	5673.22
	32' logs	12	65.9	50.2	15.8		12675	192.28	911.40	4589.69	257.59	1220.98	6148.67
	Total	23	144.7	116.3	28.4		34652	233.23	907.28	4492.06	292.24	1136.80	5628.45
Yarding	16' logs	14	129.9	96.3	33.6	11.0	13139	101.15	354.01	1738.72	136.44	477.53	2345.37
	32' logs	15	118.2	72.35	45.9	7.8	6337	53.61	254.12	1279.73	87.59	415.17	2090.73
	Total	29	248.1	168.65	79.5	9.4	19476	78.50	305.37	1511.92	115.48	449.22	2224.18
Loading	16' logs	14	118.83	117.33	1.5								
	32' logs	11	99.25	95.05	4.2								
	Total	25	218.08	212.38	5.7								

Appendix G

Harvester Activity Sampling Results

Harvester Activity Sampling Summary

Activities	Time %'s		
	16' logs	32' logs	Setting
Position/Clear	31.9%	31.8%	32.0%
Processing Dead	26.0%	20.3%	23.0%
Processing Live	20.7%	17.6%	19.0%
Felling	8.7%	14.8%	12.0%
Traveling	9.9%	12.2%	11.0%
Swing to bunch	2.8%	3.2%	3.0%
TOTAL	100.0%	100.0%	100.0%

Appendix H

Yarding Detailed Time Study Results

Yarding Time Study Summary

	Averages		
	16' logs	32' logs	All
Out	57.91	31.49	45.86
Drop	21.39	20.30	20.89
Lat out	27.41	26.67	27.07
Hook (centimin)	64.17	63.62	63.92
Lat in	75.21	63.77	69.99
In	68.38	53.86	61.75
Unhook	96.97	82.36	90.31
Turn time (centimin)	409.22	342.60	379.07
(minutes)	4.09	3.43	3.79
Logs/turn	12.1	8.0	10.2
Chokers/turn	3.8	3.8	3.8
logs/choker	3.2	2.1	2.7
Yarding Distance	419	215	327
Lateral Distance	40	39	40

Associated Yarder Production (PMH's)

	UNIT 1 (16' logs)				UNIT 2 (32' logs)			
Study Number	logs per PMH	ft^3 per PMH	Bd-ft per PMH	Study Len (hrs)	Logs per PMH	ft^3 per PMH	Bd-ft per PMH	Study Len (hrs)
1	166.95	584.33	2869.87	4.75	70.58	334.55	1684.74	1.70
2	157.44	551.04	2706.39	4.17	117.68	557.80	2809.02	1.98
3	134.52	470.82	2312.40	4.04	106.88	506.61	2551.23	2.13
4	166.15	581.53	2856.12	1.52	189.29	897.24	4518.40	3.76
5	198.98	696.43	3420.47	4.58	81.18	384.79	1937.77	0.57
6	132.71	464.49	2281.28	2.83	162.20	768.83	3871.71	1.52
7					140.35	665.26	3350.15	1.92
8					83.52	395.88	1993.62	0.85
	Average			Total	Average			Total
	159.46	558.10	2741.09	21.89	118.96	563.87	2839.58	14.43

Appendix I

Other Study Results

Road Change Times (K501 using Haulback)

From Sky Rd	To Sky Rd	Rig down (min)	Move (min)	Rig up (Min)	Total Time (hours)	Prerigging (hrs)	Comments
8	9	24	6	85	1.92	3.0	Waited for loader, no strawline out
2	3	22	13	100	2.25	1.5	Common tailtree, no loader to move carraige
6	7	33	15	50	1.63	3.0	Lots of prerigging
9	10	30	12	85	2.12	1.0	Common tailtree
10	12	46	21	125	3.20	3.0	Change units, and I.S. used
12	13	30	16	95	2.35	1.0	Common tailtree
13D	13C	28	5	40	1.22	1.0	Common landing- move yarder 20 ft
AVERAGES		30.43	12.57	82.86	2.10		
		(min)	(min)	(min)	(hours)		

** NOTE: Average road change time from shift level data = 2.2 hrs, longest was 6 hrs(used I.S.)

Trucking Statistics

	Sawlogs		Pulpwood	
	1/2 Mule	Stinger	1/2 Mule	Stinger
Average Pcs/load	**65.7**	**116.3**	**215.8**	**188.3**
Std Deviation	13.6	45.5	39.5	21.8
Minimum Value	47	67	144	160
Maximum Value	119	194	284	213
Average ft^3/load	**399.5**	**999.3**	**640.9**	**1078.0**
Std Deviation	36.6	75.4	85.2	136.2
Minimum Value	345.1	925.1	449.7	900
Maximum Value	502.7	1145.1	775.4	1211.5
Average Bd-ft/load	**2051.4**	**5041.1**	**3090.3**	**5587.5**
Std Deviation	195.0	444.9	461.6	739.9
Minimum Value	1760	4560.0	2260.8	4640
Maximum Value	2610	5800.0	3710.0	6210
Average Tons/load	**12.0**	**25.2**	**13.6**	**20.6**
Std Deviation	1.0	2.5	1.6	2.7
Minimum Value	11.1	19.1	10.6	16.7
Maximum Value	15.6	27.0	15.5	22.7

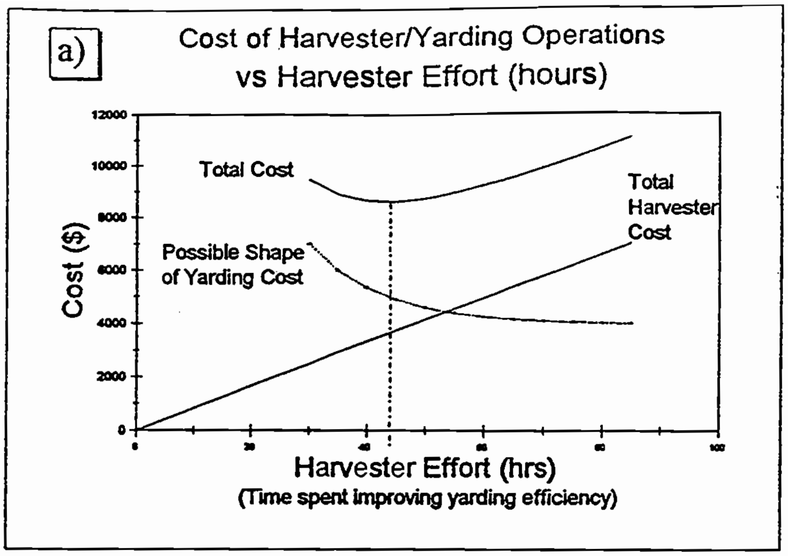
Appendix J

Optimization of System Resources (Coordinating Harvesting and Yarding)

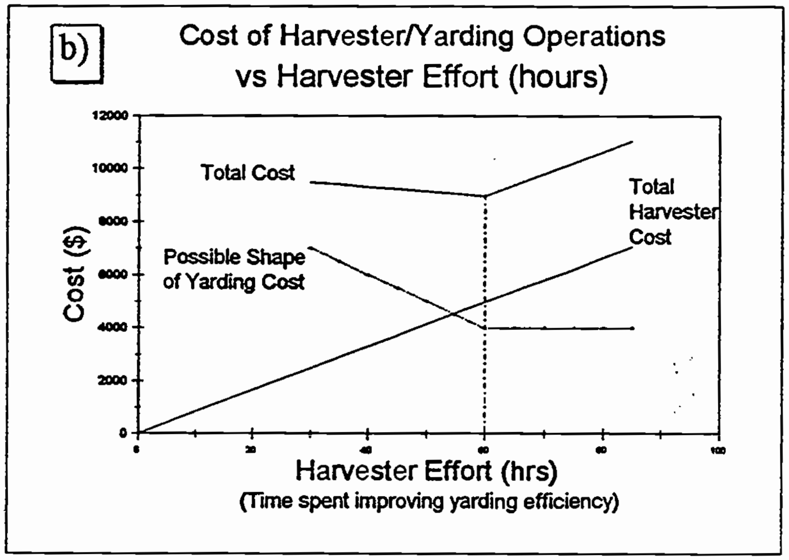
Optimization of System Resources

Total logging cost is the sum of harvesting, yarding, and loading cost. Each machine has its own hourly rate that represents the cost of owning and operating that machine for a given hour. In this study, the harvester operation's rate was $89.41/SMH and the yarding operation's rate was $132.79/SMH. The total cost of each segment of the operation depends on (1) the number of hours that the machine takes to accomplish its task, and (2) its hourly rate. To minimize total logging cost, the sum of all the segment costs must be minimized. This will result when system resources are optimized for maximum efficiency.

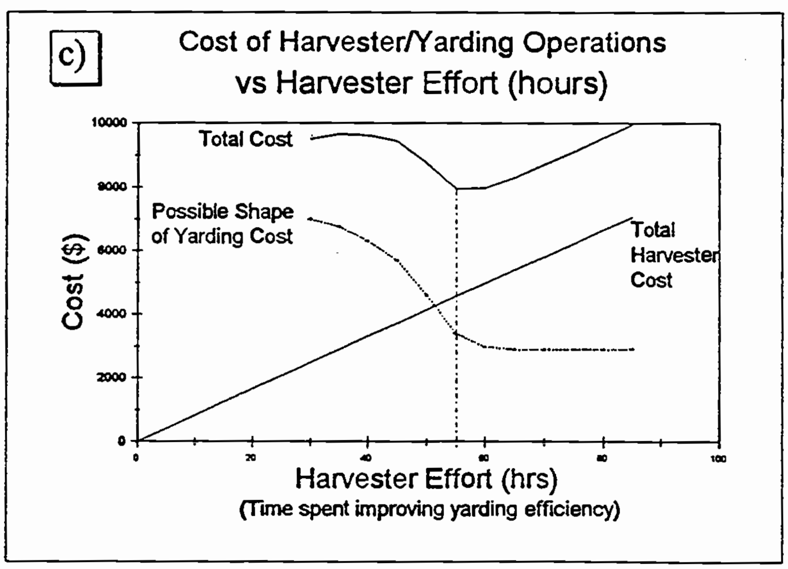
The hourly rates of the harvesting and yarding operations can help indicate the proportion of time that the harvester should spend making yarding more efficient. In general, as the harvester invests time in bunching and presenting logs in a unit so that yarding efficiency is improved, the harvester operation's total cost will rise while total yarding costs should be reduced. This means that the harvester should continue to invest effort in the bunching and presentation of logs until an additional hour of work in the unit no longer results in a decrease in yarding costs equal to the harvesters hourly rate. For example, in this study, the harvesters hourly rate is $89.41 and thus, the harvester should continue to invest an additional hour bunching and presenting logs in the unit as long as it lowers total yarding costs by at least $89.41. The same idea expressed in terms of time, says that the harvester should continue to invest another hour on the site to improve yarding efficiency as long as it is saving the yarding crew 40 minutes or more off its total operating time in the unit (due to the ratio of their hourly rates). Because it is currently impossible to accurately predict the increase in yarding efficiency relative to harvester effort, this optimization of system resources is very difficult to implement. Suggestions are made in the Opportunities for Future Research section of this paper that will help to define the relationship between harvester effort and yarding cost. Several possible relationships and their optimal combinations are shown in Figure J.



Possibility #1
Concave Yarding
Cost Curve



Possibility #1
Linear Yarding
Cost Curve



Possibility #1
Convex Yarding
Cost Curve

Figure J Total harvesting and yarding cost as a function of harvester effort.

Appendix K

Conversion Factors Used

Conversion Factors

Note: No conversion factors were used by the author to move between board feet, cubic feet, or tons as they were obtained directly from scale information.

1 hectare	x 2.4711	= acres
1 centimeter	x .3937	= inches
1 meter	x 3.2808	= feet
1 kilometer	x 0.6214	= miles

1 Cunit		= 100 feet
1 m^3	x 0.3531	= Cunits
1 tonne	x 1.1023	= tons
1 kilogram	x 2.2046	= pounds