Cable Thinning in Young Forests with Average DBH of 5-8 Inches: A Case Study

by

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This paper describes the results of a time-study conducted near Grand Ronde, Oregon, to determine the production rates and total harvesting costs of a cable thinning in a young stand. The stand had a species mix of 48 percent western hemlock (Tsuga heterophylla (Raf.) Sarg.), 45 percent Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), and 7 percent white fir (Abies concolor (Gord. & Flend.) Lindl.). The stand had an average age of 33 years, with a mean dbh of the total stand (over 1.5 inches (3.81 cm) dbh) of 5.7 inches (14.48 cm). The mean dbh of the merchantable stems (over 6 inches (15.84 cm) dbh) was 8.3 inches.

The yarder belonged to the small size class of yarders, and was rigged with a live skyline system using a self-clamping, manual slack-pulling carriage. Three hooking techniques consisting of three chokers with sliders, presetting three ring chokers and using a toggle hook, and flying six ring chokers per turn were compared on a production basis.
Regression equations were developed for the individual elements of the yarding cycles and for total cycle times for each hooking technique. Results indicate that there is no significant difference between the production rates of three chokers and sliders compared with three preset ring chokers and a toggle hook. There was a significant difference between the production rates when using the three chokers and sliders compared with using six ring chokers and a toggle hook. The six ring chokers and toggle hook was about 13 percent faster per MBF.

The total harvesting cost was compared with the mill value of the timber. The total harvesting cost included felling, limbing, and bucking cost, equipment move-in and move-out cost, yarding cost, loading cost, and hauling cost. Not included in the harvesting cost was road costs, engineering and layout costs, timber tax costs, or any profit and risk costs. The total harvesting cost came to $227.90 per MBF. The weighted average mill price for the logs was $250.24 per MBF.
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SYMBOLS AND ABBREVIATIONS USED IN THE PAPER

\[
\begin{align*}
\text{cm} & = \text{Centimeter} \\
\text{CU. FT.} & = \text{Cubic Foot} \\
\text{dba} & = \text{Diameter at Breast Height} \\
\text{EIPS} & = \text{Extra Improved Plow Steel} \\
\text{ft} & = \text{Foot} \\
\text{ft}^3 & = \text{Cubic Feet} \\
\text{ha} & = \text{Hectare} \\
\text{hr} & = \text{Hour} \\
\text{lbs} & = \text{Pounds} \\
\text{m} & = \text{Meter} \\
\text{m}^3 & = \text{Cubic Meter} \\
\text{MBF} & = \text{Thousand Board Feet} \\
\text{P} & = \text{Probability} \\
\ast & = \text{The significance level of a statistical test}
\end{align*}
\]
Young-growth stands are becoming an increasingly important source of timber in the Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) region. As old growth stands are replaced by vigorous young stands, the harvest volume percentage of these young stands will increase significantly (Tedder, 1979). Pressure for intensive management of these young stands is pushing commercial thinning into even younger age classes. The harvesting activities in these young stands on steep terrain can be difficult and expensive. Past research by Oregon State University has looked at several systems for thinning young stands that averaged 10-14 inches (25.4-35.6 cm) dbh. One of the things this work suggested is that a major cost in yarding small timber with cable systems is the fixed cost of the equipment.

As commercial thinning move into the 5-8 inch (12.7-20.32 cm) diameter classes, the cost and profitability of thinning such stands needs to be evaluated in light of techniques to increase production and to use systems having less costly machines. At present there are no quantitative or comparative data published to indicate the cost and profitability of thinning in such stands with cable systems in the Pacific Northwest.

There are many small yarders in the logging industry that are old, used, and have small resale value. Small
yarders have been defined by Aulerich (1975) as machines under 100 horsepower and include the Skagit SJ Series, the Schield-Bantam T350, and small European systems. Some of these yarders are currently in use in smallwood logging operations. Since these lower-cost machines are available, a logical first step is to define the production potential and yarding costs with these small, used yarders.

Based on the results of previous yarding studies (Mann, 1979 and Keller, 1979), a major component of the time required for a yarding cycle is the activity referred to as hooking or setting of the chokers. This activity required between 12.8 to 27.3 percent of the total time of a yarding cycle. Utilizing techniques that decrease the hooking time over standard yarding procedures is a possible method of increasing the production rate. An example of this is presetting of the chokers before each turn.

In harvesting these young stands, it is possible that the average payload will be smaller than the payload capacities of even the smaller class of yarders. An increase in production could be realized by increasing the number of logs per turn. Prebunching has been studied as a method of increasing production (Kellogg, 1976, Keller, 1979, and Zielinsky, 1980). In these past studies, a smaller yarder was used to bunch and a larger yarder was used to swing the logs. In the younger stands there are more stems per acre and less volume per stem. It's possible that a larger turn can be yarded by increasing
the number of chokers flown per turn, thus hooking a turn closer to payload capacity without the need of prebunching.

LITERATURE REVIEW

Since 1972 the Forest Engineering Department at Oregon State University has conducted a research program aimed at improving harvesting operations in young timber stands on steep slopes. Of the 18 completed projects, four have dealt specifically with skyline thinning. Aulerich, et al., (1974) looked at the differences in random thinnings between tractors and skylines. His stand of 35-year-old Douglas-fir, with an average dbh of 10 inches, closely approaches the size of the stand in this present study. He found that of the total turn time, (7.7 minutes), the hooking activity accounted for 19 percent—the largest of all activities. Aulerich (1975) then looked into strip thinning stands by four herringbone patterns. The timber stand was similar to the previous study in the random thinned stand, and a 17 percent reduction in the average turn time was found. Neilson (1977) studied the production of the Inglend-Jones Trailer Alp in uphill thinning. His average stand dbh was 14.1 inches. His average total turn time (including delays) was 4.5 minutes. The last completed project was done by Kellogg (1978). He looked at the same machine as Neilson, but did a downhill thinning study. Kellogg's average stand dbh of 12 inches is comparable with
Neilson's study and his total turn time of 6.55 minutes shows an increase in total turn time of downhill versus uphill thinning.

This previous work has analyzed thinning in young Douglas-fir stands down to 10 inches average dbh. In these past studies, even though more than one corridor was logged for a data base, the entire data base was used to develop the predictive production equations. Keller (1979) was the first to use replicated treatments to attach statistical significance to reported differences in yarding production rates. This project used the same idea in the replication of treatments in order to validate the developed regression equations.

OBJECTIVES

The specific objectives of this project were:

1. To develop predictive production rates for yarding in young stands of 5-8 inch average dbh utilizing a Skagit SJ-2 yarder.

2. To determine the total harvesting cost for cable thinning in a young stand with a SJ-2 yarder.

   Total cost includes felling and bucking, equipment move in and out, yarding, loading, and hauling.

3. To determine how yarding production rates are affected by three different hooking techniques:

   (1) three chokers with sliders, (2) three preset
ring chokers and a toggle, (3) six chokers flown per turn.

SCOPE

This project was concerned with developing production rates for the Skagit SJ-2. This is a two-drum yarder with a 50-foot tower and fits the smaller yarder class definition. The choice of this machine was based on the expectation that it is a fair representative for the size of the used, smaller yarders currently in use or available to the forest industry. Any use of the predictive production rates should be used with the knowledge that other machines will differ in payload capabilities (due to line sizes and tower heights), line speeds, and other factors. Adjustment may be necessary to estimate production rates for different machines. Also the chordslope of the skyline, the yarding crew, the stand parameters, and the thinning regime were held constant throughout the study. This helped when comparing the differences between treatments within the stand, but relinquishes any analysis of how these characteristics affect production. The time study took place in the summer of 1979. The corridors ranged up to 750 feet in slope yarding distance and no intermediate supports were used. No landings were built because the SJ-2 had swing capabilities and the decks were built on the road. Gross times for felling and
bucking, and of loading were measured to get an estimate of
their production to derive the total cost. The analysis of
these activities was not part of this paper. Detailed time
studies were taken of the yarding cycle elements so that
besides production rates, factors that effect the pro-
duction could be analyzed.

EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS PROCEDURES

Six corridors were logged for this study. These cor-
ridors were divided into two units of three corridors
each (Figure 1). Three different hooking techniques were
used. The three treatments per unit were:
1. A control corridor used three chokers and sliders
   (Figure 2).
2. A second corridor used three preset ring chokers
   and a toggle hook (Figure 3).
3. A third corridor used six ring chokers per turn with
   the toggle hook.

The three treatments were randomly assigned to the
three corridors in the first unit. The first unit of
corridors was used to generate multiple regression equations
for the yarding cycle. The treatments were repeated in the
same order in the second block. The second unit of cor-
ridors was used to validate the generated equations. This
replication of treatment has not usually been done in past
production studies. Production equations that have never
Figure 1. Study area contour map
Figure 1. Three chokers and sliders.

Figure 3. Three ring chokers and a toggle hook.
been tested have no indication of their validity. In this study, if any valid equations were found, they were used to determine if any significant differences existed between treatments. If an equation was not validated, then the mean of the yarding cycle time for that treatment was used in the comparison. In either case, the dependent variables for the treatments were estimated over the same range of variables in the comparison of production rates.

An experimental corridor was logged before the study to acquaint the researchers and the logging crew with the different treatments and procedures of this study.
SITE, STAND, AND SILVICULTURAL DESCRIPTION

SITE

The research project was conducted on International Paper Company's land southwest of Grande Ronde, Oregon (Figure 4). The study area was located in the NE, SE, & SE, Sec.25, T6S, R9W, Willamette Meridian (Figure 5). The land is classified as Site III (medium site productivity), has an average elevation of 2000 feet (609.6 meters) above mean sea level, and has an east aspect. The slope averages 40 percent (Appendix A) and the soil is from the Tyee sandstone formation.

STAND

The stand was a naturally regenerated, uneven aged stand with the dominant trees having an average age of 33 years. The species mix was 48 percent western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), 45 percent Douglas-fir, and 7 percent white fir (*Abies concolor* (Gord. & Glend.) Lindl.). The total number of trees (over 1.5 inches (3.81 cm) dbh) per acre was 1091. The number of merchantable stems (over six inches (15.84 cm) dbh and 17 feet (5.18 m) in length) was 483 stems per acre. The dbh distribution of the stand is shown in Figure 6. The mean dbh of the total stand (over 1.5 inches dbh) was 5.7 inches (14.48 cm). The mean dbh of the merchantable stems (over six inches dbh) was 8.3
Figure 4. Project location.

Figure 5. Location relative to Grand Ronde.
Figure 6. Diameter distribution.
inches (21.08 cm). The estimated cubic foot volume was 5250 cubic feet (387.4 m³ per ha). A conversion of 3.42 board feet per cubic foot was found based on the comparison of cubic volumes and board foot volumes from the experimental corridor. This gave an estimate of 17,850 board feet per acre.

**HARVESTING**

Thinning intensity and residual tree spacing guidelines utilized by International Paper were used for this study. The desired residual stand was 200 trees per acre, which is a residual tree spacing of 15 feet by 15 feet. The leave trees were marked before the cutters started. The dominant trees were left. Where there was a choice between leaving a western hemlock or Douglas-fir, the Douglas-fir was preferred. The trees were directionally felled in a herringbone pattern at approximately a 45 degree angle from the corridor with the tops falling away from the corridor. The trees were limbed and bucked to a five-inch top diameter. The trees in the corridor were kept as long as possible (up to 40 feet), while the trees in the thinning were bucked at a 32-foot length maximum to help lower the hangups and residual tree damage. The logs were sent to a local stud mill to be used as sawlogs. The merchantability specifications for the logs were set by the mill. The minimum log size was a five-inch top diameter and a 15-foot plus trim length.
The yarding system was a live skyline with a self-clamping Christy carriage (Figures 7, 8, & 9). The chokers were hooked to the mainline by either the toggle or by sliders. The toggle is in the shape of a "T" with the top part movable to allow the rings to go on (Figure 3). The use of the ring and toggle approach has two advantages. First is the ease of attaching and unattaching the chokers from the mainline. The second is that the inside diameter of the rings are larger than the diameter of the mainline ball that is used with the Christy carriage. This allows the chokers to be spread along the mainline and gives a larger area for locating logs to be hooked in a single turn (Figure 10).

The yarder operator and the rigging slinger were the same throughout the study. They were both part owners in the company. They had about ten years logging experience, with the last couple of years yarding experience using the SJ-2. A third crew member was the same throughout the study, either working as the chokersetter or the chaser. During the study, three different people worked as the forth member of the crew. All of these three people and the third crew member have had a few years of logging experience. The yarding contractor was paid on an hourly basis during the study.

The logs were cold decked for all the corridors and loading occurred after the yarder was moved out. A joint decision between the researchers and International Paper
Figure 7. Live Skyline.
Figure 8. Christy carriage—schematic.

Figure 9. Christy carriage (note toggle).
Figure 10. Spreading ring chokers along mainline.

Figure 11. Typical log deck.
estimated that the production of the yarding crew would not be high enough to justify hot loading. Using the Skagit's capability of swinging, a deck was first built on the road behind the yarder. When there were more logs than a deck on the road could hold, the remaining logs were decked in front of the yarder (Figure 11). The logs were in the corridor, but brought to up within five feet of the yarder.

The loader moved in after all the corridors were logged and the yarder moved out. Long log trucks were used to transport the logs.
Skagit SJ2-R Mobile Thinning Yarder

- 453 GMC diesel, Allison torque and transmission
- Main drum: 700' - 5/8"/500' - 3/4"
- Haulback drum: 1200' - 1/2"/2000' - 3/8"
- Skyline drum optional
- Two powered guylines drums
- Strawline drum
- Continuous 360° swing
- Four hydraulic outriggers
- Rubber tire undercarriage, 18 x 22.5 tires
- Three speeds forward and reverse
- 50,000-pound weight with lines
- 40-foot yarding tower

Figure 12. Skagit SJ-2
DICO 166 Hydraulic Log Loader

- Elevated cab
- Two hydraulic outriggers
- Hydraulic grapple
- Mounted on International truck

Figure 13. Dico 166.
SKYLINE PAYLOAD ANALYSIS

Each of the six skyline corridors were analyzed prior to logging. This was done to obtain the maximum number of logs per turn that could be yarded safely for any corridor. The analysis was done with the aid of the Skyline Analysis Program (SAP) (Sessions, 1978) for the Hewlett Packard 9830 desk-top computer. The assumptions used in the analysis were:

1. A safety factor of 3.0 was used for the safe working load.
2. A 3/4-inch skyline and a 5/8-inch mainline was used.
3. A heelboom tower with a height of 35 feet was used.
4. The weight of Douglas-fir is 53.7 lbs/ft$^3$ and the weight of western hemlock is 59.9 lbs/ft$^3$ (Hartman et al., 1974). This gives an average of 56.8 lbs/ft$^3$.
5. The carriage weight was 300 lbs.
6. The loaded carriage clearance was 10 feet.
7. The block in the tailtree was rigged at a height of 35 feet.
8. The average volume per log was 6.97 cubic feet, based on a random sample of tagged log dimensions.

Table 1 summarizes the analysis results. The ground profiles are found in Appendix A.
TABLE 1. SKYLINE PAYLOAD ANALYSIS PRIOR TO LOGGING

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Maximum Payload</th>
<th>Maximum Volume</th>
<th>Maximum Logs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5321 lbs.</td>
<td>93.68 ft³</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>4683</td>
<td>82.45</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>2272</td>
<td>40.00</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>2733</td>
<td>48.12</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>4233</td>
<td>75.12</td>
<td>11</td>
</tr>
<tr>
<td>6</td>
<td>2200</td>
<td>38.73</td>
<td>6</td>
</tr>
</tbody>
</table>

ASSIGNMENT OF TREATMENTS

The corridors were divided into two units. The first three corridors (numbers 1, 2, & 3) were very similar in maximum yarding distance and ground slopes. These were used as the unit on which the production equations were developed. The last three corridors, which had different maximum yarding distances, were used as the unit for validating the production equations. The treatments were randomly assigned to the first unit, and then repeated in the same sequence in the second unit. The first corridor in each unit was assigned the control treatment of using three chokers and sliders. The second corridor in each unit was assigned the treatment of using three preset ring chokers and the toggle hook. The third corridor in each unit was assigned the treatment of using six ring chokers and the toggle hook.

1. Number of average size logs rounded to a whole number.
STUDY PROCEDURE AND MEASUREMENTS

FELLING, LIMBING, AND BUCKING

A gross production time study was conducted for the felling and bucking operation. Each cutter had a researcher working with him. The researcher recorded the time the cutter started and finished each day, along with any personal breaks such as lunch. The researcher put a numbered tag on each log and recorded in a field book the diameters of both ends, the length, the species, and if it was a second log from a tree. By knowing the hours worked each day and the number of logs cut, an estimate of gross production was made. Since this data was also recorded each day, a learning curve was made to see if the cutters increased their production with time. The cutters had experience thinning, but not in the eight-inch average dbh and high density stands as in this study.

LOADING

A gross production time study was conducted for the loading operation. The number of pieces per load and the time required to load the truck were recorded. The average was used as a reliable estimate of the time required to load log trucks for the size timber in this study.
ROAD CHANGES

A gross time study was conducted on the road change operations. One researcher timed the activities on the landing and another the activities of the rigging crew. Times were measured with wristwatches and recorded to the nearest five seconds. The elements studied were determined by the first road change. Subsequent road changes were measuring the same elements plus any activity not occurring in the first road change. The average road change time was used in production estimates involving yarding with delays and road changing times.

YARDING

A detailed time study was done during the yarding operation. The time required to complete each yarding element of the yarding cycle was measured to the nearest 1/100 minute. A stopwatch was used with the "snap back" method, in which times are recorded continuously for each activity by resetting the stopwatch to zero when a new activity begins. A time study form (Appendix B) was used to aid in the data collecting and to insure that all variables were measured for each turn.

DEPENDENT VARIABLES

In this study, the dependent variable measured was time. The following were the yarding elements studied in
the thinning operation.

OUTHAUL - This is the time required for the carriage to move from the landing to the carriage-stop. The activity starts when yarder operator begins raising the skyline after the unhook element stops. The activity ends when the carriage locks onto the carriage-stop on the skyline.

LATERAL OUTHAUL - This is the time required to pull the mainline (or mainline and toggle in a preset corridor) from the skyline corridor to the logs to be hooked. The activity begins when a choker setter grabs the chokers and begins to pull the mainline laterally away from the corridor. In the preset corridor, this time also includes the time to drop off the chokers from the toggle. The activity ends when the choker setter reaches the logs to be set. When the logs are scattered and cannot be reached from one location, the time ends when the choker setter reaches the furthest log to be set.

HOOK - This is the time required to hook a turn of logs or to put the rings of the preset chokers onto the toggle. The activity begins when the choker setter reaches the furthest log to be set. The activity ends when the whistle is blown that indicates the start of the lateral inhaul element.
LATERAL INHAUL - This is the time required to yard a turn of logs from where they are set, to the skyline corridor. The activity begins when the whistle is blown that indicates the lateral inhaul element. The activity ends when the carriage is released from the carriage-stop.

INHAUL - This is the time to move a turn of logs from a position at the carriage-stop up to the landing. The activity begins when the carriage is released from the carriage-stop. The activity ends when the skyline is dropped so the turn can be swung onto the deck.

SWING - The time required to swing a turn of logs from the top of the corridor onto a log deck. The activity begins when the skyline is dropped after inhaul. The activity ends when the logs are on the log deck and the chaser begins to unhook the turn.

UNHOOK - The time required to unhook a turn of logs. The activity starts when the turn of logs is positioned on the log deck and the chaser begins to unhook the logs. The activity ends when the chaser is clear of the deck and the skyline is starting to be raised.

The yarder always started to raise the skyline as it swung back to the corridor to start outhaul.

DELA YS

Delays were noted and recorded whenever they occurred.
Delays were categorized as either operational or experimental. Experimental delays are unique to the study of a new technique and include such things as methodology consultation, time study delays, and group tours. The experimental delays were not included in the final production analysis. The operational delays are common to an operation. The following are the categories the delays were recorded as:

- **RESET** - This is the time required to reposition the choker or lines, rehook a log, or unhook a log so that turn of logs is free to pass an obstacle. The activity starts when the whistle is blown to stop the movement of yarding lines. The activity ends when the turn passes the obstacle and resumes the normal activity (usually lateral inhaul).

- **CARRIAGE-STOP MOVE** - This is the time required to move the carriage-stop from one position to another on the skyline. The activity starts when a whistle to stop any other activity is blown. This time would include any lowering or raising of the skyline that was necessary to move the stop.

- **SORT RIGGING** - This is the time required for the choker setter to untangle the chokers after the outhaul activity. The time starts when the choker setter grabs the chokers. The activity ends when the choker setter is finished untangling the chokers and starts out laterally to turn of logs.
TRANSIT - This is the time required when a choker setter is out of position to perform an activity, to move to the correct position. The activity starts when an activity that normally should start doesn't. The activity ends when the choker setter has moved to the proper position and the normal activity starts.

LANDING - Any extra time required on the landing that cannot be classified into another delay category was classified as a landing delay.

REPOSITION - Any time required to relocate logs on the log deck in order to facilitate the swing, the unhook, or to maintain a neat and workable log deck was classified as repositioning.

MECHANICAL (CARRIAGE) - Any time required to repair, replace, or readjust either the carriage, the carriage-stop, or the "trip" ball on the mainline was classified as mechanical (carriage).

MECHANICAL (YARDER - LINES) - Any time required to repair, replace, or readjust the lines or yarder (including splicing the lines) was classified as mechanical (yarder-lines).

PERSONAL - Any time required by any crew member for personal reasons was classified as personal delay. This includes sending down water to the choker setters but does not include sending lunches or the time required to eat lunch.
BUNCH - Any time required over and above one cycle of lateral outhaul, hook, and lateral inhaul to build up a turn of logs was classified as bunch delay. This activity occurred on the corridors where six chokers were flown at once.

EXPERIMENTAL - Any time required due to the researchers or the study that normally would not occur had not an experimental study been in progress, was classified as experimental delay.

OTHER - Any time required that could not be properly classified into preceding categories was classified as other delay.

INDEPENDENT VARIABLES

In previous similar production studies such as this, up to 18 independent variables were measured as influencing skyline logging (Curtis, 1978). For this study, only six independent variables were measured. The other independent variables were either unimportant to the study or held constant throughout the study. The following are the yarding variables measured in this study. Each variable is abbreviated by a mnemonic, which will be used in the remainder of this report.

NUMLOGS - The number of logs comprising the turn was recorded for each turn.

SCALE - The total cubic foot volume for each turn was used as an independent variable. The volume was found
by recording the tag numbers (put on the logs during felling), or recording the dimensions of the end diameters and the length of the log if the tag was missing. Then by having the end diameters and lengths, the volume per log was calculated by Smalian’s formula (Dilworth, 1976):

\[ V = \frac{b + t}{2} \times L \]

Where:
- \( V \) = log volume in cubic feet
- \( b \) = basal area in square feet at the large end of the log
- \( t \) = basal area in square feet at the small end of the log
- \( L \) = length of the log

The volumes for each log in a turn were added to arrive at the total turn volume.

ANGLE - The angle between the skyline and the path of the logs during the lateral inhaul (Figure 14), measured to the nearest 15 degrees, was recorded for each turn. A special device was used to measure these angles (Figure 15). The range of lead angles was expected to vary from zero to 90 degrees.
Figure 14. Diagram of "ANGLE".

Figure 15. Device used to measure "ANGLE".
CRHT - The vertical distance from the carriage to the ground at the end of the outhaul element was recorded for each turn. The distance was estimated to the nearest five feet by scaling the known height of a choker setter to the height of the carriage, as the choker setter grabbed the rigging.

SLOPEDIST - The distance in feet from the yarder to the carriage for each turn was recorded. Before yarding, corridor distances were measured and trees were painted with the distance for every 50 feet along the corridor. Distances during yarding were estimated to the nearest five feet using the painted trees as aids.

LINEDIST - The length of the line pulled from the carriage to the furthermost log to be hooked for a turn was used as a variable. This value was calculated by recording the lateral distance perpendicular to the corridor to the furthermost log, and dividing by the sine of the respective lead angle (ANGLE). Lines were painted in the timber stand at 25 and 50 feet perpendicular to the skyline corridor. This aided in estimating the lateral distances, which were estimated to the nearest five feet.
DATA ANALYSIS

POST THINNING ASSESSMENT

The thinning intensity desired by International Paper was a residual stand of 200 stems per acre. From the pre-thinning cruise, the stand averaged 483 merchantable stems per acre. A total of 2630 trees were felled during the study. Over the 13.58 acre study site, an average of 194 stems per acre were felled, or 40 percent of the merchantable stand. This left 289 merchantable trees per acre which is a 12.3 feet by 12.3 feet spacing. The unmerchantable trees were not cut. The difference between the desired spacing and the actual spacing was probably due to the tendency of the marking crew to undermark.

INDEPENDENT VARIABLES

Table 2 summarizes the independent variables measured for each corridor. When using three chokers per turn (corridors 1, 2, 4, & 5), three out of the four corridors averaged three or more logs per turn. When six chokers per turn were used (corridors 3 & 6), the average number of logs per turn was always less than the number of chokers. This indicates that the number of logs per turn that could be hooked was limited by something other than the number of chokers used.

2. A ratio of 1.14 logs to 1 tree was found in this study.
### TABLE 2. SUMMARY OF INDEPENDENT VARIABLES

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<tr>
<th>Variables</th>
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3. The treatment for this corridor was the control of three chokers and sliders

4. The treatment for this corridor was presetting three ring chokers

5. The treatment for this corridor was six ring chokers per turn.
Although this was a fairly dense stand with 220 merchantable logs per acre yarded, the logs had to lie on a fairly straight line from the carriage to make hooking in the same turn possible. This was due to the mainline being pulled in a straight line from the carriage. The ring chokers slid along the mainline, but only reaching out from the mainline the length of the choker. The ring chokers were 12 feet long and the regular chokers were 18 feet long. In this study, increasing the number of chokers beyond the six already used would not add much to the average number of logs per turn because the additional logs could not be reached per turn.

In the first unit of corridors (Numbers 1, 2, & 3), the mean scale for flying six chokers was about twice as large as the other corridors. In the second unit of corridors (Numbers 4, 5, & 6), the mean scales were not significantly different (probability at 95%). This is because the average log volume was less in corridor 6 than corridor 5 or 4 owing to the natural variation in the stand. The first unit of corridors had similar mean log volumes.

The means for the lead angle (ANGLE) are within 15 degrees of each other, which was the accuracy of the measurement. It is noted that the mean lead angle when presetting chokers was the largest value and the mean lead angle when flying six chokers was the smallest value in
both units. The amount of chokers attached to the mainline may influence the chokersetter when he determines the lead angle of the turn.

The differences in the means for carriage heights (CRHT) and slope distances (SLOPEDIST) was due to the topography and not the treatments. There was not a large difference in the means for the lateral yarding distance (LINEDIST).

DEPENDENT VARIABLES

Table 3 summarizes the yarding element times for each corridor. Most of the differences between mean values for a specific element can be explained by the variation in the independent variables. An example of this is the swing element where the ascending order of time required is the same as the ascending order of the average number of logs per turn. Of particular interest in this study is the hook times. Comparing the hook times indicates that preset chokers takes the least time and setting six chokers takes the most time. The magnitude of the differences between hooking three preset chokers and hooking three chokers is about .40 minutes. Setting six chokers takes just about twice as long as setting three chokers indicating a linear relationship between time and the number of chokers hooked.

Table 4 summarizes yarding element times as a percentage of productive time. By comparing the preset corridor
The treatment for this corridor was the control of three chokers and sliders.

The treatment for this corridor was presetting three ring chokers.

The treatment for this corridor was using six ring chokers per turn.

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</table>
(2 & 5), with the corridors where three chokers on sliders were used (1 & 4), the hook time percentage decreased by 8-9 percent, but the swing time and unhook time collectively increased about 7-10 percent. This ends up producing us total productive turn times that are very similar. In the corridors where six chokers were used the hook time requires between 26 to 28 percent of the total productive time. It was hook time, more than the other elements, that increased the total turn time of the corridors where six chokers were used. Therefore, the remaining elements in the corridors where six chokers were used tended to decrease in magnitude in comparison with the other corridors. Delay times must be added before comparing the production of the three treatments as they affect total turn time. There is the possibility that different treatments incur different delay times so that a decrease in production time could be offset by an increase in delay time. Also the production times must be evaluated under the same logging conditions before comparisons can be made.
REGRESSION ANALYSIS

The purpose of regression analysis is to quantify the relationships between the dependent variable (time) and the independent variables measured. The general linear regression model, with normal error term, is:

\[ Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_{p-1} X_{i,p-1} + \epsilon_i \]

where:

- \( \beta_0, \beta_1, \ldots, \beta_{p-1} \) are parameters
- \( X_{i1}, \ldots, X_{i,p-1} \) are known as constants
- \( \epsilon_i \) are independent \( N(0, \sigma^2) \)
- \( i = 1, \ldots, n \)

Regression equations were developed for the times of each yarding element along with one for the total yarding cycle times for each treatment. The equation for the yarding elements are useful in indicating what independent variables effect the elemental times and quantifying the effect. Differences in elemental times between treatments can then be explored and possibly explained. The equations for the total yarding cycle times are useful for predicting production rates for the treatments. If valid equations are generated, the production time of each of the treatments can then be estimated and compared over the same range of conditions.

The REGRESS subsystem of the Statistical Interactive Programming System (SIPS), (Rowe et al., 1978) was used to
generate the equations and analysis of variance tables. This system was run on the Oregon State University CDC 3300 Computer (Cyber Operating System). The selection criterion for the acceptance or rejection of the independent variables in each equation was based on: (1) The regression coefficient associated with an independent variable was significantly different from zero at the 0.10 probability level for elements and at the 0.05 probability level for the total time model, (2) The coefficient of multiple determination ($R^2$) was improved by at least one percent by adding that independent variable to the equation, (3) The mean square error did not increase by adding that independent variable to the equation, (4) The coefficient of determination was tested on the total turn cycle model to see if the equation was significant.

Table 5 summarizes the accepted regression coefficients for the yarding elements. For outhaul times, no difference from what was normally expected was found. For lateral outhaul times, the SLOPEDIST coefficient was either negative or not significant. This indicates that as the slope distance increased, the lateral outhaul time decreased. This was probably due to the ground slope being flatter at the back end of the corridor which allowed easier walking and slack pulling.

The coefficients for hook time show a common occurrence in regression analysis. The coefficients are related to
### TABLE 5. REGRESSION COEFFICIENTS OF YARDING ELEMENTS

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</tr>
<tr>
<td>( R^2 )</td>
<td>.7665</td>
<td>.8763</td>
<td>.6405</td>
</tr>
<tr>
<td>SWING</td>
<td>.40997</td>
<td>.41089</td>
<td>4.4454</td>
</tr>
<tr>
<td>SCALE</td>
<td>.00255</td>
<td>.00739</td>
<td>.00094</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>.0276</td>
<td>.0967</td>
<td>.0837</td>
</tr>
<tr>
<td>UNHOOK</td>
<td>.47399</td>
<td>.64652</td>
<td>.56752</td>
</tr>
<tr>
<td>SCALE</td>
<td>---</td>
<td>.0042</td>
<td>.01467</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>---</td>
<td>.0228</td>
<td>.1011</td>
</tr>
</tbody>
</table>

9. The probability values are less than .05 unless noted by "*" which indicates the probability of .05<P<.10.
each other so that either one or the other usually shows up in an equation. When both are tried in the same equation, they divide the amount of variation explained so that neither is significant. This happened in hook times where the coefficient of correlation was .49 between SCALE and NUMLOGS and only one of the two variables can be used. This also holds true for swing and unhook times where only one of the same two variables was used. For inhaul times, CRHT is insignificant in two of the treatments. CRHT was defined as the height of the carriage at the end of the outhaul cycle. This causes problems where the ground profile (Appendix 1) causes higher carriage heights at irregular distances down the corridor. Unless the ground profile is very uniform, CRHT is a poor predictor of inhaul time. No regression equations were found for unhook times on the control treatment, or for hook times on the six chokers treatment. The mean value was therefore used as the best estimate of those elements for the respective treatments.

Table 6 summarizes the regression coefficients for the total time (without delays) per turn. These equations were generated by using the observed total time as the dependent variable. The variables found to be significant in the yarding element regressions were tested as independent variables. The acceptance or rejection criteria was the same as that for the yarding element regressions except as noted.
### TABLE 6. REGRESSION COEFFICIENTS FOR TOTAL TIME.

<table>
<thead>
<tr>
<th>Element</th>
<th>Control</th>
<th>Preset</th>
<th>Six chokers</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL TIME</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONSTANT</td>
<td>2.1832</td>
<td>2.2838</td>
<td>4.4305</td>
</tr>
<tr>
<td>SLOPEDIST</td>
<td>.00248</td>
<td>.00304</td>
<td>.00267</td>
</tr>
<tr>
<td>LINEDIST</td>
<td>.00662</td>
<td>.00526</td>
<td>---</td>
</tr>
<tr>
<td>NUMLOGS</td>
<td>.32165</td>
<td>.13111</td>
<td>---</td>
</tr>
<tr>
<td>SCALE</td>
<td>---</td>
<td>.01263</td>
<td>.03435</td>
</tr>
<tr>
<td>ANGLE</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>CRHT</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>$R^2$</td>
<td>.3566</td>
<td>.4378</td>
<td>.2094</td>
</tr>
<tr>
<td>OBSERVATIONS</td>
<td>160</td>
<td>197</td>
<td>87</td>
</tr>
</tbody>
</table>
MODEL ANALYSIS

After choosing the "best" set of independent variables to be included in the model, the models were tested to see if the amount of variation they explained was significant. The hypothesis tested was that the population's coefficient of determination was zero ($H_0: \rho = 0$) versus the alternative that the population's coefficient of determination was not zero ($H_a: \rho \neq 0$). If the hypothesis is not rejected, then the amount of variation explained by the model is not significantly different from zero. If the hypothesis is rejected in favor of the alternative hypothesis, then the amount of variation explained by the model is significant. The $F$ statistic for this test can be expressed directly in terms of $R^2$ as follows (Neter and Wasserman, 1974):

$$F = \frac{R^2}{1-R^2} \frac{n-q-1}{q}$$

Where $n$ = Total number of observations  
$q$ = Number of predictor variables  
$R^2$ = Best estimate of $\rho$, found in the analysis of variance for the model.  

$F$ critical = $F(\alpha/2,q,n-q-1)$

Table 7 summarizes the values used in the tests, the calculated $F$ value, the critical $F$ value, and the decision. A 95 percent probability level was used. For all three treatments, the models explained a significant amount of the variation.
The number of observations needed in building regression models depends on the precision desired and the inherent variability of the sampled population. Past research has not looked at sample size calculations to see if they had the required number of observations for the precision they desired. More importantly, sample size calculations will aid future studies by indicating the number of observations that should be gathered. There is a possibility that experiments can be better designed by decreasing the observations per treatments and increasing either replications of the treatment or the range of treatments.

The desired precision for this study was to be 95 percent confident that we estimate the mean turn time (w/o delays) to within plus or minus 5 percent. The equation for the desired sample size is as follows (Freese, 1967):

\[
\text{Sample Size} = \left( \frac{z_{\alpha/2} \cdot \sigma}{E} \right)^2
\]

where:
- \(z_{\alpha/2}\) is the critical value from the standard normal distribution for the desired level of confidence (1.96 for 95% confidence).
- \(\sigma\) is the standard deviation of the population.
- \(E\) is the margin of error (0.05 for 5% precision).

### TABLE 7. TESTING THE CORRELATION OF DETERMINATION

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Preset</th>
<th>Six chokers</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>160</td>
<td>198</td>
<td>87</td>
</tr>
<tr>
<td>q</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>(R^2)</td>
<td>.3566</td>
<td>.4378</td>
<td>.2094</td>
</tr>
<tr>
<td>(F) calculated</td>
<td>28.82</td>
<td>37.57</td>
<td>11.12</td>
</tr>
<tr>
<td>(F) critical</td>
<td>2.68</td>
<td>2.45</td>
<td>3.12</td>
</tr>
<tr>
<td>DECISION</td>
<td>FAIL TO REJECT</td>
<td>FAIL TO REJECT</td>
<td>FAIL TO REJECT</td>
</tr>
</tbody>
</table>
\[ n = \frac{s^2}{E^2} \]

Where:
- \( n \) = Number of observations
- \( t \) = Student \( t \) value at level of probability
- \( s^2 \) = Estimate of population variance
- \( E \) = Specified error

An estimate of the population's variance was not available before the experiment, so the number of observations that should have been gathered was not calculated prior to the study. When designing experiments in areas where past research has been done, the estimated variance from the past research could be used as a guide. After the study, and after the analysis of variance for the regression equations have been computed, the mean square error (MSE) is the best estimate of the population's variance. The desired sample size was calculated and is shown in Table 8 along with the actual sample size.
In the control and preset corridors an adequate number of samples were taken. In the corridor where six chokers were used, the actual number of observations was slightly under the desired sample size. A smaller sample of observations per control and preset corridors, using the additional turns for the six chokers would have been a better designed experiment.

**VALIDATION**

Because the equation building process requires repeated analysis on the same set of data, the equations may be subject to "prediction bias". Neter and Wasserman (1974) define prediction bias as, "the indicated predictive ability of the model (equation) for the data on which the model is based may be greater than the models predictive ability for new data."

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Preset</td>
<td>Six chokers</td>
</tr>
<tr>
<td>$\bar{y}$ (Table 3)</td>
<td>4.3727</td>
<td>4.3407</td>
<td>6.8462</td>
</tr>
<tr>
<td>$t^{<em>}=.05, df=n</em>-1$</td>
<td>1.975</td>
<td>1.972</td>
<td>1.988</td>
</tr>
<tr>
<td>MSE</td>
<td>.909348</td>
<td>.451625</td>
<td>.342310</td>
</tr>
<tr>
<td>$E(\pm 5% \bar{y})$</td>
<td>.218635</td>
<td>.217035</td>
<td>.342310</td>
</tr>
<tr>
<td>$n=desired$</td>
<td>74.2</td>
<td>37.3</td>
<td>95.5</td>
</tr>
<tr>
<td>$n=actual$</td>
<td>160</td>
<td>198</td>
<td>87</td>
</tr>
</tbody>
</table>

TABLE 8. SAMPLE SIZE
This study was designed so that the second unit of corridors would be used as a new set of data to test the equations generated on the first unit of corridors. The test consisted of adding the recorded times for all elements in a turn as a measure of the observed total time (Y-OBS). Then the regression equation derived for the total time of a treatment was used with the independent variables of the second corridor (same treatment) to arrive at an estimate of the total time (Y-HAT). For each of the treatments, the Y-OBS and Y-HAT times were compared using a paired t-statistic. The hypothesis is that the difference of the means between the two samples is zero, indicating that the regression equation can predict the yarding time on a different set of data than used to generate the equation. The significance level was set at $\alpha = .05$. Table 9 summarizes the paired t-test results.
On the basis of comparing the calculated t-value with the table t-value the test failed to reject the $H_0$ hypothesis for the control and six chokers treatments, but to reject the $H_0$ hypothesis and accept the $H_a$ hypothesis for the preset chokers treatments. It is concluded that the regressions generated for the control and six chokers treatments are valid equations at $\alpha=.05$. The equation generated for the preset chokers treatment is not valid ($P>.999$) as it cannot predict the yarding time for a new set of data. Before a comparison of the production rates

<table>
<thead>
<tr>
<th>TABLE 9. PAIRED T STATISTIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_0$: $u_i = u_j$</td>
</tr>
<tr>
<td>$H_a$: $u_i \neq u_j$</td>
</tr>
<tr>
<td>Where: $i = Y\text{-HAT}$</td>
</tr>
<tr>
<td>$j = Y\text{-OBS}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Control</th>
<th>Preset</th>
<th>Six chokers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>129</td>
<td>137</td>
<td>58</td>
</tr>
<tr>
<td>Mean of $Y\text{-HAT}$</td>
<td>4.27649</td>
<td>3.98269</td>
<td>5.99128</td>
</tr>
<tr>
<td>Mean of $Y\text{-OBS}$</td>
<td>4.28751</td>
<td>4.28927</td>
<td>5.69586</td>
</tr>
<tr>
<td>Mean difference</td>
<td>-.01102</td>
<td>-.28657</td>
<td>.29542</td>
</tr>
<tr>
<td>STD error of difference</td>
<td>.07848</td>
<td>.07545</td>
<td>.18600</td>
</tr>
<tr>
<td>T-value</td>
<td>-.14413</td>
<td>-3.7978</td>
<td>1.5882</td>
</tr>
<tr>
<td>T-Table value at (.95)</td>
<td>1.9767</td>
<td>1.9776</td>
<td>2.0025</td>
</tr>
</tbody>
</table>

no significant  significant  no significant
difference       difference       difference
between the treatments can be made, delay times must be added to the treatments. This is required in a study of different treatments where the delay times may be related to the treatments and not assumed constant over all treatments.

**DELAYS**

Delay times for the corridors used in the regression analysis are summarized in Table 10 and Table 11. Time was recorded for moving the carriage-stop only if no other activity, typically unhooking, was occurring. If the unhooking activity was long enough, the carriage-stop could be moved without requiring any elapsed time. The difference between the mean times required for the movement of the carriage-stop per treatment was due to a difference in the mean of the unhooking times. A lower unhooking time required the recorded time for the movement of the carriage-stop to be larger. Comparing the means for sorting rigging times, flying six chokers meant longer sorting times than the control treatment of the three chokers on sliders. The mean times for landing delays also was higher when flying six chokers versus the other treatments. Of special interest is the delay time required for bunching a turn. When six chokers were used at once, sometimes a full turn could not be hooked at one spot. If there was a turn that had empty chokers and a few logs situated so they would not make a full turn by themselves, these logs
TABLE 10. SUMMARY OF DELAY TIMES PER OCCURRENCE

<table>
<thead>
<tr>
<th>Delay category</th>
<th>Treatment</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Preset</td>
<td>Six chokers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Freq</td>
<td>Mean</td>
<td>Freq</td>
<td>Mean</td>
</tr>
<tr>
<td>Carriage-Stop Move</td>
<td>22</td>
<td>1.56</td>
<td>19</td>
<td>0.95</td>
</tr>
<tr>
<td>Sorting</td>
<td>31</td>
<td>0.42</td>
<td>32</td>
<td>0.81</td>
</tr>
<tr>
<td>Rigging</td>
<td>5</td>
<td>1.74</td>
<td>1</td>
<td>0.80</td>
</tr>
<tr>
<td>Transit</td>
<td>10</td>
<td>1.08</td>
<td>12</td>
<td>1.30</td>
</tr>
<tr>
<td>Landing</td>
<td>1</td>
<td>4.60</td>
<td>6</td>
<td>1.74</td>
</tr>
<tr>
<td>Reposition</td>
<td>12</td>
<td>0.51</td>
<td>8</td>
<td>0.59</td>
</tr>
<tr>
<td>Mechanical (carriage)</td>
<td>3</td>
<td>0.37</td>
<td>4</td>
<td>2.31</td>
</tr>
<tr>
<td>Mechanical (yarder)</td>
<td>4</td>
<td>2.08</td>
<td>2</td>
<td>1.80</td>
</tr>
<tr>
<td>Personal</td>
<td>0</td>
<td>--</td>
<td>0</td>
<td>--</td>
</tr>
<tr>
<td>Bunching</td>
<td>3</td>
<td>4.36</td>
<td>1</td>
<td>0.70</td>
</tr>
<tr>
<td>Other</td>
<td>36</td>
<td>2.16</td>
<td>74</td>
<td>2.02</td>
</tr>
<tr>
<td>Total Time</td>
<td>221.03</td>
<td>238.55</td>
<td>197.21</td>
<td></td>
</tr>
<tr>
<td>Total Turns</td>
<td>193</td>
<td>202</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td>Reset (per turn)</td>
<td>0.63</td>
<td>0.73</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>Total Delay time per turn</td>
<td>1.145</td>
<td>1.181</td>
<td>1.933</td>
<td></td>
</tr>
</tbody>
</table>

10. Mean times measured in minutes
TABLE 11. SUMMARY OF DELAY TIMES AS A PERCENTAGE OF TOTAL TURN TIME.

<table>
<thead>
<tr>
<th>Delay category</th>
<th>Control Total</th>
<th>Treatment Preset</th>
<th>Treatment Six choker</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Carriage-stop move</td>
<td>34.22</td>
<td>16.05</td>
<td>17.64</td>
</tr>
<tr>
<td>Sorting rigging</td>
<td>13.02</td>
<td>25.92</td>
<td>20.93</td>
</tr>
<tr>
<td>Transit</td>
<td>8.70</td>
<td>0.80</td>
<td>0.1</td>
</tr>
<tr>
<td>Landing</td>
<td>10.80</td>
<td>15.60</td>
<td>18.00</td>
</tr>
<tr>
<td>Reposition</td>
<td>4.60</td>
<td>10.44</td>
<td>5.16</td>
</tr>
<tr>
<td>Mechanical (carriage)</td>
<td>6.12</td>
<td>4.72</td>
<td>5.76</td>
</tr>
<tr>
<td>Mechanical (yarder)</td>
<td>1.11</td>
<td>9.24</td>
<td>0.0</td>
</tr>
<tr>
<td>Personal</td>
<td>8.32</td>
<td>3.80</td>
<td>0.0</td>
</tr>
<tr>
<td>Bunching</td>
<td>0</td>
<td>0.0</td>
<td>19.32</td>
</tr>
<tr>
<td>Other</td>
<td>13.08</td>
<td>0.70</td>
<td>10.08</td>
</tr>
<tr>
<td>Reset</td>
<td>120.96</td>
<td>123.48</td>
<td>100.32</td>
</tr>
<tr>
<td>TOTAL PERCENT</td>
<td>20.8%</td>
<td>21.4%</td>
<td>22.0%</td>
</tr>
<tr>
<td>DELAY FREE TURN TIME</td>
<td></td>
<td>4.373</td>
<td>6.846</td>
</tr>
<tr>
<td>(Table 3.)</td>
<td></td>
<td>4.341</td>
<td></td>
</tr>
<tr>
<td>DELAY TIME PER TURN</td>
<td></td>
<td>1.145</td>
<td>1.933</td>
</tr>
<tr>
<td>(Table 10.)</td>
<td></td>
<td>1.131</td>
<td></td>
</tr>
<tr>
<td>TOTAL TURN TIME</td>
<td></td>
<td>5.518</td>
<td>8.779</td>
</tr>
<tr>
<td>(different corridors)</td>
<td></td>
<td>5.522</td>
<td></td>
</tr>
</tbody>
</table>

11. Total time measured in minutes.
would be bunched into the same full turn. This was done by lateral outhauling, hooking, and lateral inhauling of part of the turn. Then lateral outhauling, hooking, and lateral inhauling a number of logs usually in a different location to "build" a full turn. This happened on 14 percent of the turns where six chokers were used. The average time for the second lateral and hooking cycle was 1.38 minutes.

Of all delays, the resetting of turns due to hang-ups was thought to be most related to the specific treatment. By comparing the mean reset time per occurrence, the preset treatment required the least time, the control treatment slightly more, and flying six chokers required the most. This follows the logic that more time is spent deciding the extraction path when the logs are preset. When trying to yard six logs, there were twice as many logs as the control treatment for hangup problems. When the reset time is compared on a per turn basis, the preset treatment requires more time per turn than the control treatment. The reset times for the control and the preset treatments were tested using an unpaired t-statistic and it was found there was no significant difference (90% probability) between the mean reset times per turn. Then the mean reset times for the flying six chokers treatment was compared with the control treatment. A significant difference (90% probability) was found between the mean reset time. Table 12 summarizes the t-statistic values.
<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
</tr>
<tr>
<td>Observations</td>
<td>193</td>
</tr>
<tr>
<td>Mean value</td>
<td>62.818</td>
</tr>
<tr>
<td>STD error of mean</td>
<td>9.594</td>
</tr>
<tr>
<td>Different between means</td>
<td>11.019</td>
</tr>
<tr>
<td>t-value</td>
<td>- .8264</td>
</tr>
<tr>
<td>Table value P = 90%</td>
<td>1.650</td>
</tr>
</tbody>
</table>

No significant difference

Significant difference

12. Comparing preset and six chokers treatment to control
COMPARISON OF TREATMENTS

It was shown in the Validation subsection that the equation found for the control and flying six chokers treatments could be validated. But the equation found for the treatment of preset chokers could not be validated.

When comparing the production rates of the treatments, they must be calculated over the same set of independent variables. Because the equation for preset chokers was not validated, the observed average total turn time was used as the estimated production rate. Then the regression equations for the other treatments were used with the independent variables for the preset chokers treatment to arrive at their average total turn time. The average delay time per turn for a specific treatment was added on to the average total time for that treatment to arrive at an average total time per turn including delays. Finally, the average total time per turn including delays was divided by the average number of logs per turn (for each treatment). These calculations gave the production rates for the treatments based on the same independent variables so statistical comparisons could be made. Table 13 summarizes the production rates over the set of independent variables for the preset treatment for all the treatments.

There is no significant difference ($P > 0.80$) between the mean times for the control and preset chokers treatment. There is a significant difference ($P < 0.999$) between
TABLE 13. T-TEST VALUES FOR EQUALITY OF MEAN TURN TIME VALUES

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Preset</td>
<td>Six chokers</td>
</tr>
<tr>
<td>Observations</td>
<td>190</td>
<td>190</td>
<td>190</td>
</tr>
<tr>
<td>Mean turn time per log</td>
<td>1.729</td>
<td>1.713</td>
<td>1.527</td>
</tr>
<tr>
<td>Difference between means</td>
<td>0.0157</td>
<td>0.2022</td>
<td></td>
</tr>
<tr>
<td>STD. error of difference</td>
<td>0.0160</td>
<td>0.0098</td>
<td></td>
</tr>
<tr>
<td>t-value</td>
<td>.9784</td>
<td>20.5237</td>
<td></td>
</tr>
<tr>
<td>Table value (P=95%)</td>
<td>1.9726</td>
<td>1.9726</td>
<td></td>
</tr>
</tbody>
</table>

No significant difference  
Significant difference

Variable Values:

NUMLOGS = 3.24  
CRHT = 28.18 ft  
SCALE = 23.68 ft³  
SCOPEDIST = 345.89 ft  
ANGLE = 35.14 deg  
LINEDIST = 54.73 ft
the mean times for the control and flying six chokers treatment. The treatment of flying six chokers takes about 12 percent less time per turn than the treatment of presetting chokers or flying three chokers on sliders. Table 14 shows the production rates on a volume per hour basis. These rates are based on the set of average conditions from Table 13.

ROAD CHANGES

Table 15 summarizes the rig-up times recorded for the six corridors. The categories were determined while recording the actual rigging of corridor 1. Then the later corridors were timed under the same categories of activities. No other categories were needed for any activity not occurring in corridor 1. If more than one activity occurred at the same time, only one received a value of elapsed time so there were activities occurring but without a time value recorded. The "move and position yarder" time for corridor 1 included changing both the skyline and mainline. This particular logging contractor did not have enough 3/4 inch skyline for the length of the corridors, so he changed to 5/8 inch skyline. The contractor also used his 9/16 inch haulback line and haulback drum as his mainline, so he completely wound in his mainline and pulled his haulback line through the mainline sheave. The "move and position yarder" times for corridor 2 and 3 involve the yarder being
**TABLE 14. PRODUCTION RATES INCLUDING DELAYS WITHOUT ROAD CHANGE TIME.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment</th>
<th>Control</th>
<th>Preset</th>
<th>Six chokers</th>
</tr>
</thead>
<tbody>
<tr>
<td>MINUTES(^{13}) TURN</td>
<td></td>
<td>5.585</td>
<td>5.533</td>
<td>8.093</td>
</tr>
<tr>
<td>TURNS HOUR</td>
<td></td>
<td>10.74</td>
<td>10.84</td>
<td>7.41</td>
</tr>
<tr>
<td>CUBIC FEET TURN</td>
<td></td>
<td>23.68</td>
<td>23.68</td>
<td>38.86</td>
</tr>
<tr>
<td>CUBIC FEET HOUR</td>
<td></td>
<td>254.4</td>
<td>256.8</td>
<td>288.1</td>
</tr>
<tr>
<td>BOARD FEET(^{14}) HOUR</td>
<td></td>
<td>870.0</td>
<td>878.2</td>
<td>985.2</td>
</tr>
<tr>
<td>CUBIC METERS(^{15}) HOUR</td>
<td></td>
<td>7.2</td>
<td>7.3</td>
<td>8.2</td>
</tr>
<tr>
<td>LOGS HOUR</td>
<td></td>
<td>34.69</td>
<td>35.01</td>
<td>39.27</td>
</tr>
</tbody>
</table>

\(^{13}\) Found by multiplying mean turn time (Table 13) by 3.23 logs for control and preset and by 5.3 logs for six chokers.

\(^{14}\) 1 cubic foot = 3.42 board feet

\(^{15}\) 1 cubic foot = 0.0283168 cubic meters
### TABLE 15. RIGGING UP TIMES

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Move, Position Yarder</th>
<th>Pull Bollard Down</th>
<th>Set Guylines</th>
<th>Raise SL</th>
<th>Any Adjust</th>
<th>Climb Trees, set</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45.0</td>
<td>14.0</td>
<td>9.0</td>
<td>2.0</td>
<td>7.0</td>
<td></td>
<td>77.0</td>
</tr>
<tr>
<td>2</td>
<td>110.0</td>
<td>11.0</td>
<td>10.0</td>
<td>0</td>
<td>5.0</td>
<td></td>
<td>145.0</td>
</tr>
<tr>
<td>3</td>
<td>95.0</td>
<td>12.0</td>
<td>9.0</td>
<td>0</td>
<td>11.0</td>
<td></td>
<td>127.0</td>
</tr>
<tr>
<td>4</td>
<td>21.0</td>
<td>11.4</td>
<td>0</td>
<td>5.3</td>
<td>16.0</td>
<td></td>
<td>53.7</td>
</tr>
<tr>
<td>5</td>
<td>2.6</td>
<td>10.0</td>
<td>19.0</td>
<td>0</td>
<td>10.0</td>
<td></td>
<td>41.6</td>
</tr>
<tr>
<td>6</td>
<td>8.0</td>
<td>12.0</td>
<td>15.0</td>
<td>0</td>
<td>22.0</td>
<td></td>
<td>57.0</td>
</tr>
</tbody>
</table>

**AVERAGE** 83.55

---

16. Times are measured in minutes.
stuck in the soft inside shoulder of the skid road. No tractor was available then, so the crew moved the yarder by stringing the skyline up the road, attaching onto a stump on the side of the road, and pulling the yarder by use of the skyline. The “move and position yarder” time for corridor 4 involved moving the yarder much farther than any other road change (Figure 1), but a tractor was used during the move. The average total rig-up time was 83.55 minutes.

Table 16 summarizes the rigging-down times recorded for the six corridors. Again the categories were determined by recording the procedures while rigging-down corridor 1. No other categories were needed for any activity that did not occur in corridor 1. If any activity occurred in conjunction with another, only one received a value for elapsed time. No time was recorded for removing the skyline and block for corridor 2 because the tail tree was felled with the rigging left on (Figure 16). No time was recorded for falling the tail tree on corridor 4 because it was determined to be undamaged enough that it was left. Only the total time required for rigging-down was recorded for corridor 6. The average total rigging-down time was 15.23 minutes. By summing the average for rigging-up and rigging-down, it required an average of 98.78 minutes (1 hour, 39 minutes) per road change.
### TABLE 16. RIGGING DOWN TIMES

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Climb</th>
<th>Tailtree to Block</th>
<th>Fall Tailtree</th>
<th>Pull in Shyline</th>
<th>Pull in Guylines</th>
<th>Lowering Out of Lower</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.0</td>
<td>8.0</td>
<td>8.0</td>
<td>2.0</td>
<td>3.0</td>
<td></td>
<td>21.0</td>
</tr>
<tr>
<td>2</td>
<td>---</td>
<td>9.5</td>
<td>1.2</td>
<td>3.2</td>
<td>NR</td>
<td></td>
<td>13.9</td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>10.5</td>
<td>3.2</td>
<td>0</td>
<td>NR</td>
<td></td>
<td>16.2</td>
</tr>
<tr>
<td>4</td>
<td>5.4</td>
<td>0</td>
<td>3.7</td>
<td>2.4</td>
<td>NR</td>
<td></td>
<td>11.5</td>
</tr>
<tr>
<td>5</td>
<td>NR</td>
<td>NR</td>
<td>3.5</td>
<td>7.3</td>
<td>NR</td>
<td></td>
<td>10.8</td>
</tr>
<tr>
<td>6</td>
<td>Only Total Time was Recorded</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>AVERAGE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>15.23</td>
</tr>
</tbody>
</table>

17. NR means that there is no record of the activity occurring.
Figure 16. Removing the lift block from the tail tree in corridor number 2.
FELLING, LIMBING AND BUCKING

The cutting was done by a contractor independent from International Paper and the yarding contractor. Five different fallers worked on the study, with no more than three working any one day. The skyline corridors were felled first and then the stand was thinned. All trees that were hung up were attempted to be brought down by falling trees higher on the slope on top of them. All trees not hung up were limbed on three sides and bucked. Table 17 summarizes the felling and bucking operation.

The corridors were cut 15 feet wide and the total skyline road width was 150 feet. The average rate for felling, limbing, and bucking for all cutters in both the corridor and the thinning was 9.71 logs per hour (Appendix C). Multiplying by the average volume per log gave a rate of 73.12 cubic feet per hour (250.06 board feet) (Appendix C).

LOADING

The loading times were recorded by the loader operator. Table 18 summarizes the loading operation, and Figure 17 shows a typical log truck being loaded.
TABLE 17. FELLING, LIMBING, AND BUCKING TIMES

<table>
<thead>
<tr>
<th>Faller</th>
<th>Location</th>
<th>No. logs</th>
<th>Hr. total</th>
<th>Mean logs per hour</th>
<th>Stems per hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Corridor</td>
<td>452</td>
<td>39.51</td>
<td>11.44</td>
<td>10.04</td>
</tr>
<tr>
<td>2</td>
<td>Corridor</td>
<td>198</td>
<td>26.84</td>
<td>7.38</td>
<td>6.47</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>650</td>
<td>66.35</td>
<td>9.79</td>
<td>8.59</td>
</tr>
<tr>
<td>3</td>
<td>Thinning</td>
<td>84</td>
<td>6.25</td>
<td>13.44</td>
<td>11.79</td>
</tr>
<tr>
<td>4</td>
<td>Thinning</td>
<td>948</td>
<td>96.97</td>
<td>9.73</td>
<td>8.57</td>
</tr>
<tr>
<td>5</td>
<td>Thinning</td>
<td>981</td>
<td>103.00</td>
<td>9.52</td>
<td>8.35</td>
</tr>
<tr>
<td>6</td>
<td>Thinning</td>
<td>303</td>
<td>32.61</td>
<td>9.39</td>
<td>8.15</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>2316</td>
<td>238.83</td>
<td>9.70</td>
<td>8.51</td>
</tr>
<tr>
<td></td>
<td>GRAND TOTAL</td>
<td>2966</td>
<td>305.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ITEM</td>
<td>TOTAL</td>
<td>PER LOAD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------</td>
<td>---------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of loads</td>
<td>23</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of pieces</td>
<td>2912</td>
<td>126.60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume (MBF)</td>
<td>74.96 MBF</td>
<td>3.26 MBF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume (CUNITS)</td>
<td>219.18 cunits</td>
<td>9.53 cunits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume (METRIC)</td>
<td>620.65 cubic meters</td>
<td>26.98 cubic meters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours</td>
<td>34.5</td>
<td>1.50</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 17. Loading a log truck.
SKYLINE ANALYSIS FOLLOWING YARDING

The conditions assumed for the skyline payload analysis previous to the yarding were changed during the actual yarding. Instead of the 3/4 inch skyline and 5/8 inch mainline, a 5/8 inch skyline and 9/16 inch mainline were used. The haulback drum was used as the skidding line drum. The assumed size Christy carriage was used but 3/4 inch steel plate was added onto both sides to increase the weight to 600 lbs. This was done by the yarding contractor before the study to aid gravity outhaul on relatively flat chord-slopes. The tower on the SJ-2 was a straight boom and not the heel-boom assumed. The height of the skyline sheave was measured at 40 ft. above the ground. The block in the tail trees were rigged at a variety of heights, and the minimum load carriage clearance varied for all the corridors. A second analysis was run using these actual conditions utilizing the same analysis program as before and a factor of safety (FS) for the skyline of 3.0. This hypothetical payload was compared with the maximum payload for the corridor. It was found that in all corridors the actual maximum payload exceeded the predicted payload. Table 19 summarizes the values used in payload determination and the true factor of safety for the skyline.

The actual factor of safety for the skyline indicates two things: First, even though a factor of safety of between 3.0 to 2.5 is commonly recommended, the loggers in
TABLE 19. SKYLINE ANALYSIS OF ACTUAL CONDITIONS

SKYLINE - 5/8 inch EIPS AT 0.72lb/ft
MAINLINE - 9/16 inch EIPS AT 0.591b/ft
CARRIAGE WEIGHT - 600 lbs
SKYLINE BREAKING STRENGTH - 41,200 lbs
TOWER HEIGHT - 40 ft

<table>
<thead>
<tr>
<th>CORRIDOR</th>
<th>TAILBLOCK HEIGHT (ft)</th>
<th>MINIMUM CARRIAGE HEIGHT (ft)</th>
<th>PREDICTED PAYLOAD (lb)</th>
<th>OBSERVED PAYLOAD (lb)</th>
<th>OBSERVED SKYLINE TENSION (fs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27</td>
<td>8</td>
<td>3055</td>
<td>4037</td>
<td>15801</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>8</td>
<td>2678</td>
<td>5055</td>
<td>20550</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>8</td>
<td>1593</td>
<td>4551</td>
<td>24176</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>5</td>
<td>1234</td>
<td>4986</td>
<td>27400</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
<td>5</td>
<td>4057</td>
<td>3874</td>
<td>15807</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>5</td>
<td>1206</td>
<td>3617</td>
<td>25687</td>
</tr>
</tbody>
</table>
this study operated below this level. In fact, they imposed loads on the skyline beyond the elastic limit (2.0) of wire rope resulting in permanent line damage. Secondly, for these rigging and yarding conditions, there was no extra payload capacity possible for more than six logs per turn as suggested in the payload analysis results done before yarding (see page 22, Table 1).
DISCUSSION OF RESULTS

INDEPENDENT VARIABLES

Although the independent CRHT and ANGLE are significant in the yarding element equations (Table 5), they are not significant in any total time regression equation (Table 6). The first reason for this is that while being significant in explaining the variation of a single element, the amount of variation of the total time equation is much larger and that part of the total equation explained by CRHT and ANGLE is insignificant. A second reason is the small variance about the mean for these two variables. As any independent variable in a regression equation approaches a constant, it tends to explain less variation.

The variable LINEDIST was squared (LINEDIST$^2$) and the two compared to lateral outhaul time to see which was a better predictor. Some past studies have used the square of the lateral distance in their regression equations. It was thought that as the lateral distance increased, the outhaul time increased exponentially rather than linearly. As lateral distance increases the amount of skidding line dragging on the ground also increases. It was found that LINEDIST was the better predictor in this study. The probable reason being with the light lines used in this study, the increase in drag was negligible.

The variable SLOPEDIST was compared with its square root ($\sqrt{SLOPEDIST}$) to see which was a better predictor of
out-haul time. This was done because as the carriage leaves the landing its speed increases as it travels down the corridor, and an exponential relationship might be more accurate than a linear one. In this study, the variable SLOPEDIST and -SLOPEDIST were equal in explaining out-haul time. Although the carriage does increase speed as it travels down the corridor, it also is slowed down as it approaches the carriage-stop. Therefore, the function relationship is more of a cosine curve shape which is equally explained by a linear or exponential function. The choice of using SLOPEDIST over the other variable was made on the basis of inhaul time. In this element, the linear relationship is the best predictor.

The use of only one of the two choices between LINEDIST or LINEDIST^2, and SLOPEDIST or -SLOPEDIST was because including both variables would split the variation explained by just one and neither would be as significant. Including both would also unnecessarily increase the model size.

REGRESSION FOR PRESET TREATMENT

As stated in the VALIDATION subsection, the equation built for the preset treatment could not predict the time required on a new set of data. This does not mean the equation is wrong. Further testing of the two preset treatment corridors was done by the comparison of two re-
gression lines technique (Neter and Wasserman, 1974, Section 5.6). Regression models using the same independent variables were built for both corridors. Then a "reduced" model was built on the combined data of both corridors. Appendix D shows all three models and their respective analysis of variance tables. The goal was to test whether the two regression lines are the same. The two alternative hypotheses were:

\[ \text{H}_0: \text{The two regression lines are the same.} \]

\[ \text{H}_a: \text{The two regression lines are not the same.} \]

Appendix E shows the test statistic. The null hypothesis (\( \text{H}_0 \)) is rejected in favor of the alternative hypothesis (\( \text{H}_a \)). This indicates that the two regression lines are not equal, which is why the equation for the prediction corridor could not be validated by the second corridor. This also indicates that pooling of the two corridors into one data set is statistically inappropriate.

LIMITATIONS ON PAYLOAD

There were two limitations on payload found in this study. The first is the number of logs that were in a close enough proximateness that they can be reached and hooked in one turn. Table 2 indicates that there was no problem in finding enough logs for three chokers. But when six chokers were flown at once, on the average they were not all used. Any additional chokers beyond six would not
be utilized in most of the turns.

The second limitation on payload was the maximum payload capacity. Table 19 shows the predicted maximum payload capacity for the actual yarding conditions. By dividing the average weight per log (56.8 lbs/cu ft. x 7.53 cu ft/log = 428 lbs/log), into the payload, the following maximum number of logs per turn is found:

<table>
<thead>
<tr>
<th>Corridor</th>
<th>Number of logs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.1</td>
</tr>
<tr>
<td>2</td>
<td>6.3</td>
</tr>
<tr>
<td>3</td>
<td>3.7</td>
</tr>
<tr>
<td>4</td>
<td>2.9</td>
</tr>
<tr>
<td>5</td>
<td>9.5</td>
</tr>
<tr>
<td>6</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Even with the very small size timber in this study, some corridors are limited in the number of logs possible for yarding in a single turn. The observed average and maximum number of logs was greater than the above figures due to the yarding taking place with skyline factors of safety less than 3.0.

HUMAN FACTORS--FELLING AND BUCKING

Although the number of stems cut per hour agrees with past studies (Aulerich, 1974), it fell short of the production estimate made by the cutting contractor. Part of the reason for the difference can be attributed to using less
experienced cutters and paying their wages on a per hourly basis. Lack of motivation and experience will cause a lower production in any operational system. It was thought that the cutters might be going through a learning curve effect, whereby the production measured in pieces per hour would increase due to the repetition of the same activity. Analysis of the felling and bucking time for this learning curve effect indicated that no such process was occurring (Appendix F).

SENSITIVITY OF PRODUCTION EQUATIONS

The precision of the regression equations is measured in how close we expect an observed time to be from it estimated time. The more precise an equation, the smaller the difference between estimated values and observed values. In statistics, this precision is called confidence limits. Appendix G shows the 95 percent confidence limits for the regression equations built in this study.

The influence on yarding production rates as the independent variables vary is also of interest. The only variable common to all three regression equations in this study was SLOPEDIST. Figure 18 shows the total turn time including delays, per log, as a function of slope yarding distance. The values for the non-varying variable are the same as in Table 13.

The production rates for the control treatment and the
Figure 18. Total turn time (with delays, per log) as a function of slope distance.
preset treatment cross, indicating at one slope distance they have the same turn time. Going in either direction one treatment has a lower turn time than the other. This slope yarding distance can be found using break-even analysis. For the values used in Figure 18 the break-even point is 457 feet. This means that at slope distances less than 457 feet, presetting chokers requires less time per turn. At distances greater than 457 feet, using chokers hooked to sliders requires less time per turn.

HARVESTING COSTS

Table 20 summarizes the total harvesting cost incurred for this study. Industry standard costs were used. The costs are further calculated per MBF so a comparison with the mill price of the logs can be made.

Aulerich, et al., (1974) looked at the times and costs for felling and bucking in a stand of average dbh of 10 inches. Table 21 compares Aulerich’s study with this study. The difference in the cost per MBF is shown to be due to two factors. The first is the difference in board foot volume per tree. As the diameter decreases from 10 inches to 8 inches, the board foot volume decreases approximately half. The second factor is the cost per hour. When inflated, Aulerich's cost is far less than the industry standard now. All this indicates that the felling and bucking operation in young stands becomes increasingly more
<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/unit</th>
<th>Unit</th>
<th>Total cost</th>
<th>Cost/MBF&lt;sup&gt;18&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Move in &amp; Move out</td>
<td>$980.00</td>
<td>1</td>
<td>$ 980.00</td>
<td>$ 13.07</td>
</tr>
<tr>
<td>Felling &amp; Bucking</td>
<td>$ 18.77/hr</td>
<td>305.18 hr</td>
<td>$5728.23</td>
<td>$ 76.42</td>
</tr>
<tr>
<td>Yarding</td>
<td>$ 75.70/hr</td>
<td>112.08 hr&lt;sup&gt;19&lt;/sup&gt;</td>
<td>$8484.46</td>
<td>$113.18</td>
</tr>
<tr>
<td>Loading</td>
<td>$ 21.91/hr</td>
<td>34.5 hr</td>
<td>$ 755.89</td>
<td>$ 10.08</td>
</tr>
<tr>
<td>Hauling</td>
<td>$ 49.35/trip</td>
<td>23 trips</td>
<td>$1135.05</td>
<td>$ 15.14</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>$227.90</td>
<td>($ 77.84/cunit)</td>
</tr>
</tbody>
</table>

18. A total of 74.96 MBF was logged in this study.

19. Found by summing up all observed production times plus road change times from the time study sheets.
Inflated to 1979 by increasing the cost at 9 percent each year for five years.

<table>
<thead>
<tr>
<th>Item</th>
<th>Aulerich study</th>
<th>Present study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trees per hour</td>
<td>8.57</td>
<td>8.52</td>
</tr>
<tr>
<td>Time per tree</td>
<td>7.00 min</td>
<td>7.04 min</td>
</tr>
<tr>
<td>Volume per tree</td>
<td>61.50 bd ft</td>
<td>29.36 bd ft</td>
</tr>
<tr>
<td>Cost per hour (1974)</td>
<td>$7.08</td>
<td>$18.77</td>
</tr>
<tr>
<td>Cost per hour (1979)</td>
<td>$10.89\textsuperscript{20}</td>
<td>$18.77</td>
</tr>
<tr>
<td>Cost per MBF</td>
<td>$20.66</td>
<td>$76.42</td>
</tr>
</tbody>
</table>
pensive as the average diameter of the stand decreases.

**MILL PRICES**

In the summer of 1979, mill prices were between $310 and $285 per MBF for Douglas-fir. And between $230 and $220 per MBF for western hemlock and true fir. The weighted average (by volume for each species) for all sawlogs was $250.24 per MBF. Sawlogs prices were used because this was the destination for the logs in this study.

Subtracting the total harvesting cost from the timber value yields a $22.34 per MBF log price above harvesting cost.

**COMPARISON OF TREATMENTS BY YARDING COSTS**

Table 13 shows the different production rates for each treatment in units of mean turn time per log. To find the time required to yard the corridor that the rates were developed on, the mean turn time was multiplied by the total number of logs yarded. The yarding cost per volume was found by multiplying the hours required by the hourly cost, and then dividing by the different measures of the corridors volume. Table 22 summarizes the different costs per volume found in this study.

By flying six chokers per turn, a savings of $10.21 per MBF was obtained. In comparison of these present day costs, Aulerich (1974) found that in 1973 the total yarding cost for a Shield-Sautan T350 yader was $53.09 per MBF.
### TABLE 22. COMPARISON OF TREATMENTS BY YARDING COSTS

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Time per turn</th>
<th>Hrs</th>
<th>Total cost</th>
<th>Total per cunit</th>
<th>Total per MBF</th>
<th>Total per cubic meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.729</td>
<td>18.85</td>
<td>$1426.85</td>
<td>$29.98</td>
<td>$37.65</td>
<td>$10.59</td>
</tr>
<tr>
<td>Preset</td>
<td>1.713</td>
<td>18.67</td>
<td>1413.45</td>
<td>29.70</td>
<td>36.94</td>
<td>10.49</td>
</tr>
<tr>
<td>Six chokers</td>
<td>1.527</td>
<td>16.64</td>
<td>1259.97</td>
<td>26.48</td>
<td>77.41</td>
<td>9.35</td>
</tr>
</tbody>
</table>

21. Time per turn x 654 logs to be yarded.
22. $75.70 per hour yarding cost.
23. 4759 cubic foot volume in the corridor.
24. 1 cubic foot = 3.42 board feet.
25. 1 cubic foot = 0.0283168 cubic meters.
The average dbh of the trees cut in Aulerich's study was 10.4 inches compared with 8.3 inches for this study. By inflating Aulerich's cost per MBF at 9 percent for six years, the inflated cost is $89.04 per MBF, only 1.5 percent above the control treatment cost.
SUMMARY

This study compares the production rates and yarding costs of a Skagit SJ-2 yonder in a thinning operation in a young forest with an average dbh of 5-8 inches. The study analyzed three different hooking techniques consisting of a control treatment using three chokers and sliders, a treatment using three preset ring chokers and a toggle hook, and a treatment using six ring chokers per turn. A Christy carriage was used for all treatments. The total harvesting cost was compared with the mill price of the logs to determine the price cost difference. The total harvesting cost consisted of move-in and move-out costs, felling and bucking costs, yarding costs, loading costs, and hauling costs.

The study was done in a young stand of Douglas-fir and western hemlock with a volume of 5250 cubic feet per acre (17,850 board feet per acre). The mean log size was 7.53 cubic feet (25.75 board feet), measuring 26 feet in length with a 5.1 inch small end diameter and a 9.5 inch large-end diameter. The thinning intensity was 40 percent (194 trees per acre) of the merchantable stems.

Maximum slope yarding distances ranged from 525 feet to 750 feet. The skyline roads were 150 feet wide and the lateral yarding distances ranged from 120 feet to 193 feet. The average number of logs per turn for the control and preset corridors was 3.0 logs. For the six chokers per turn the average number of logs per turn was 4.8 logs.
Regression equations for each treatment were built using the data from one corridor per treatment. Validation of the equations was made by applying the equation to the remaining corridor with the same treatment and calculating a paired t-test on the estimated times compared to the observed times. The equations built for the control and six chokers per turn were validated, but the equation for preset chokers was not. The results show there is no significant difference between the production rates when using three chokers and sliders and when using three preset ring chokers and a toggle hook. There was a significant difference between production rates when using three chokers and sliders and when using six ring chokers and a toggle hook. Analysis of the production rates measured in total turn time (including delays) per log indicate that using six chokers per turn was 13 percent faster per MBF. Comparison of the production rates measured in cost per MBF indicates a savings of $10.21 per MBF for the six chokers per turn treatment compared to the control treatment.

The total harvesting cost came to $227.90 per MBF. The weighted average mill price for the logs was $250.24 per MBF. The difference between mill price and harvesting cost was $22.34 per MBF. The costs of road construction, engineering and layout, timber tax, and profit and risk are not included in the total harvesting cost.

The difference between the analysis done in this paper and that used in previous studies includes: (1) Validation
of regression equations using separate data sets, (2) Testing of the overall equations significance, (3) Calculating the correct sample size needed for the precision desired, (4) Paired t-testing of production rates of different treatments for significant differences, (5) Analysis of data for learning curve effects.
FUTURE RESEARCH

This report has analyzed a commercial thinning study in a young forest. Besides answering some basic questions about production rates and harvesting costs, it has brought out some new questions.

1. The felling and bucking production was much slower than had been estimated by the cutting contractor. Felling of the tree took very little time, but in this dense young forest stand, many hangups occurred. Extra time was spent by trying to knock down the hangups by dropping other trees onto them. In younger stands, the tree has branches on almost the whole trunk, so limbing is required for most of the tree. Future research should look into whole tree yarding to eliminate the limbing, and strip thinning to reduce hangups.

2. Analysis of the hooking techniques proved that building a larger turn, by using six chokers per turn in this study, reduced the yarding costs. Even though hooking more logs per turn increased the average turn time, the reduction in the number of turns required proved to be a savings in overall time required. Future research should look into other hooking techniques combined with building larger turns to find an optimum system for com-
3. In this study, the production as measured in the number of logs per day was just at the point where on some days a loader and log truck could be kept busy. But on other days, there was no use for them. The choice was made to cold deck the logs and have the loader move in after the yarding was finished. This caused problems in the decking activity. The number of logs per corridor was more than could be decked on the road behind the yader. As the deck on the road reached its maximum size, the swing and unhook activities increased in time required. The logs that could not be put onto the road deck were decked in the corridor as close to the yader as possible. This also increased the difficulty of the loading because the loader had problems reaching some of the logs decked in the corridor. Future research should look into the landing and decking process to see what improvements can be made. Some possibilities are whole tree yarding and having a machine on the landing capable of swinging the trees away from the yader, limbing the trees, and either decking or loading the logs. Secondly, a process where logs are yarded and a machine on the landing can swing them away from the yader and load them onto
trailers. A tractor would only come up to bring an empty trailer and remove the full trailer.

With the future of forestry being involved with increasingly younger forests, understanding the processes and results from harvesting these young stands becomes essential for the continuation of the forest industry.


APPENDICES
Landing 40-foot spar

Tail Tree 27-feet
Tail Tree 30-feet
Tail Tree 30-feet

Ground profile
Standing skyline load path
Chordslope
Corridor number
APPENDIX C

AVERAGE FELLING, LIMBING, AND BUCKING RATE

To arrive at the average for combined corridor thinning production, the rates were averaged by the appropriate width ratio:

1: Corridor Weight = 15 ft. + 150 ft. = 0.10
2: Thinning Weight = (150 ft.-15 ft.) / 150 ft. = 0.90

The average production is then calculated as follows:

(0.10)(9.79 logs/hr)+(0.90)(9.70 logs/hr)=9.71 logs/hr
(The ratio of logs to trees for this study is 1.14, therefore 8.52 stems/hr.)

By dividing the total scale by the total number of logs the average volume per log was found:

\[
\text{Mean scale per turn} \times \text{Turns per Corridor} = \frac{21917.81}{2911.46} = 7.53 \text{ ft}^3/\text{log}
\]

The volume per hour is then found by multiplication:

7.53 ft$^3$/log \times 9.71 logs/hr = 73.12 ft$^3$/hr
(250.06 bf/hr)

A conversion rate of 3.42 bf = 1 ft$^3$ is used, based on the ratio of scaled volume to cubic volume from this study.
## APPENDIX D

### ANOVA TABLES FOR COMPARISON OF TWO REGRESSION LINES

#### CORRIDOR 2

<table>
<thead>
<tr>
<th>Equation</th>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME = 235.813</td>
<td>TOTAL</td>
<td>196</td>
<td>1542300</td>
<td>7869.1</td>
</tr>
<tr>
<td>+ 21.288 NUMLOGS</td>
<td>REGRESSION</td>
<td>3</td>
<td>639309</td>
<td>213103</td>
</tr>
<tr>
<td>+ 0.316 SCOPEDIST</td>
<td>ERROR</td>
<td>193</td>
<td>900338</td>
<td>4678.9</td>
</tr>
<tr>
<td>+ 0.378 LINEDIST</td>
<td></td>
<td></td>
<td>5494</td>
<td></td>
</tr>
</tbody>
</table>

\[ R^2 = .4145 \]

#### CORRIDOR 5

<table>
<thead>
<tr>
<th>Equation</th>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME = 173.234</td>
<td>TOTAL</td>
<td>134</td>
<td>1153200</td>
<td>8606</td>
</tr>
<tr>
<td>+ 33.056 NUMLOGS</td>
<td>REGRESSION</td>
<td>3</td>
<td>633572</td>
<td>211191</td>
</tr>
<tr>
<td>+ 0.384 SCOPEDIST</td>
<td>ERROR</td>
<td>131</td>
<td>519681</td>
<td>3897.1</td>
</tr>
<tr>
<td>+ 1.135 LINEDIST</td>
<td></td>
<td></td>
<td>698</td>
<td></td>
</tr>
</tbody>
</table>

\[ R^2 = .5494 \]

#### CORRIDOR 2 & 5 COMBINED

<table>
<thead>
<tr>
<th>Equation</th>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME = 235.799</td>
<td>TOTAL</td>
<td>324</td>
<td>2708950</td>
<td>8380.9</td>
</tr>
<tr>
<td>+ 21.485 NUMLOGS</td>
<td>REGRESSION</td>
<td>3</td>
<td>1207930</td>
<td>402644</td>
</tr>
<tr>
<td>+ 0.321 SCOPEDIST</td>
<td>ERROR</td>
<td>321</td>
<td>1501020</td>
<td>4878.1</td>
</tr>
<tr>
<td>+ 0.532 LINEDIST</td>
<td></td>
<td></td>
<td>365</td>
<td></td>
</tr>
</tbody>
</table>

\[ R^2 = .4459 \]
APPENDIX E

F TEST FOR COMPARISON OF TWO REGRESSION LINES

MODEL: \[ Y_{kj} = \beta_{0j} + \beta_{1j}X_{ij} + \beta_{2j}X_{ij} + \beta_{3j}X_{ij} + \epsilon_{ij} \]

Ho: \[ \beta_{01} = \beta_{02} \text{ and } \beta_{11} = \beta_{12} \text{ and } \beta_{21} = \beta_{22} \text{ and } \beta_{31} = \beta_{32} \]

(there regression lines are the same)

Ha: Either \[ \beta_{01} \neq \beta_{02} \text{ or } \beta_{11} \neq \beta_{12} \text{ or } \beta_{21} \neq \beta_{22} \text{ or } \beta_{31} \neq \beta_{32} \]

(there regression lines are not the same)

SSE(F) = SSE (CORRIDOR 2) + SSE (CORRIDOR 5)

SSE(R) = SSE (CORRIDOR 2 & 5 COMBINED)

\[ F^* = \frac{\text{SSE(R)} - \text{SSE(F)}}{\frac{SSE(F)}{n_1 + n_2 - (q+l)} - \frac{SSE(F)}{n_1 + n_2 - 2(q+l)}} \]

where: \( n_1 \) and \( n_2 \) are the number of observations for corridor 2 and corridor 5, \( q \) = number of \( \beta \) coefficients.

If \( F^* \leq F (0.95, 4, 324) \), conclude Ho
If \( F^* > F (0.95, 4, 324) \), conclude Ha

\[ F^* = \frac{(1501020) - (1422726)}{4} = \frac{1422725}{324} = 4.47 \]

\[ F (0.95, 4, 324) = 2.83 \]

reject Ho and conclude the two regression lines are not the same.
APPENDIX F
LEARNING CURVES FOR FELLING, LIMBING, AND BUCKING
(NOTE, GRAPH IS LOG-LOG SCALE)
APPENDIX G

95% CONFIDENCE LIMITS FOR REGRESSION EQUATIONS

TREATMENT: CONTROL

VARIABLE RANGE

TREATMENT: PRESET

VARIABLE RANGE
TREATMENT: SIX CHOKERS

TURN TIME IN MINUTES

1st quartile  mid  3rd quartile

VARIABLE RANGE
APPENDIX H

BREAKEVEN POINT FOR CONTROL VERSUS PRESET TREATMENTS

The breakeven point between to production rates is calculated by the following steps:

1. Acquire the two production equations:
   
   Control turn time = 2.1831 + 0.0066*LINEDIST + 0.3216*NUMLOGS + 0.0025*SLOPEDIST + 1.145 (delay)
   
   Preset turn time = 2.2839 + 0.0053*LINEDIST + 0.1311*NUMLOGS + 0.0030*SLOPEDIST + 1.181 (delay)

2. Assume values for all variables except the one who’s effect is being explored:
   
   NUMLOGS = 3.23
   LINEDIST = 54.73

3. Substitute in values, multiply out, and simplify by adding numerical values:
   
   Control = 4.7326 + 0.0025*SLOPEDIST
   Preset = 4.4765 + 0.0030*SLOPEDIST

4. Set equations equal to each other and solve for variable:
   
   4.7326+.0025*SLOPEDIST = 4.4765+.0030*SLOPEDIST
   .2561 = .00056*SLOPEDIST
   457 = SLOPEDIST

This value is the point where the two production equations have the same value.
APPENDIX I

MOVE IN & MOVE OUT COSTS

(Based on USFS Region 6 west side logging cost guide, APP 415.816, adjusted to 2nd quarter, 1979).

<table>
<thead>
<tr>
<th>MOVE IN COST</th>
<th>MOVE OUT COST</th>
<th>TOTAL MOVING COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>$505</td>
<td>$475</td>
<td>$980</td>
</tr>
</tbody>
</table>

APPENDIX J

HOURLY COST FOR FALLING AND BUCKING

COST/HOUR

LABOR

(USFS 10/78 increased by 1.09)

(provides own saw and tools)

TOTAL HOURLY COST $18.77
# DEPRECIATION

## APPENDIX K

### HOURLY OPERATING COSTS FOR YARDING

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SKAGIT SJ2 YARDER</strong> ($50,000 used cost; 10% salvage; 4-yr estimated life)</td>
<td>$ 7.03</td>
</tr>
<tr>
<td><strong>CHRISTY REGULAR SIZE CARRIAGE</strong> ($2800 new cost; 20% salvage; 8-yr. estimated life)</td>
<td>0.18</td>
</tr>
<tr>
<td><strong>RADIO W/2 TRANSMITTERS</strong> ($3036 new cost; 10% salvage; 4-yr. estimated life)</td>
<td>0.43</td>
</tr>
<tr>
<td><strong>GUYLINES; (2) 100 ft. 7/8 in. IWRC</strong> ($272 new cost; no salvage; 4-yr. estimated life)</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>LINES</strong> (1000 ft., 5/8 in. EIPS SKYLINE) ($799 new cost; no salvage, 1 yr. estimated life)</td>
<td>0.50</td>
</tr>
<tr>
<td><strong>1000 ft., 9/16 in. EIPS MAINLINE</strong> ($713 new cost; no salvage, 1 yr. estimated life)</td>
<td>0.45</td>
</tr>
<tr>
<td><strong>TAIL TREE RIGGING</strong> 10 in. block, block strap, 9/16 in. guylines ($500 new cost, 10% salvage; 4-yr. estimated life)</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>MISCELLANEOUS RIGGING</strong> Climbing gear, splicing needle, riggers maul, pass chain, riggers bar, saw wedges (4), axe, maul, chainsaws (2) ($1200 new cost; no salvage; 1 yr. estimated life)</td>
<td>0.75</td>
</tr>
</tbody>
</table>
### APPENDIX K (cont'd)
### HOURLY OPERATING COSTS FOR YARDING

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FUEL AND LUBRICANTS</strong></td>
<td></td>
</tr>
<tr>
<td><strong>YARDER</strong></td>
<td></td>
</tr>
<tr>
<td>FUEL (3.5 gal/hour at $.80/gal)</td>
<td>$2.80</td>
</tr>
<tr>
<td>LUBRICANTS (10% of full cost)</td>
<td>.28</td>
</tr>
<tr>
<td><strong>CREW TRANSPORTATION</strong></td>
<td></td>
</tr>
<tr>
<td>FUEL (0.1 gal/mi. at 50 mi/day; at $.95/gal)</td>
<td>0.59</td>
</tr>
<tr>
<td>LUBRICANTS (10% of fuel cost)</td>
<td>.06</td>
</tr>
<tr>
<td><strong>TOTAL FUEL AND LUBRICANT</strong></td>
<td><strong>$3.73</strong></td>
</tr>
</tbody>
</table>

**CHOKERS**
- (12) - 12 ft., 5/8 in. ring chokers and (2) toggles: 0.28
- (12) - 16 ft., 5/8 in. reg chokers and (6) sliders: 0.17

**CREW TRANSPORTATION**
- Crew cab pickup truck: $10.90

**MAINTENANCE AND REPAIR**
- YARDER (50% of depreciation): $3.52
- CARRIAGE (20% of depreciation): 0.04
- RADIO (50% of depreciation): 0.36
- CREW VEHICLE (50% of depreciation): 0.39
- MISC. RIGGING (50% of depreciation): 0.26
- **TOTAL MAINTENANCE AND REPAIR**: $4.79

**TOTAL DEPRECIATION**: $10.90
### APPENDIX K (cont'd)
### HOURLY OPERATING COSTS FOR YARDING

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INSURANCE, INTEREST AND TAXES</strong></td>
<td></td>
</tr>
<tr>
<td>18% AVERAGE ANNUAL INVESTMENT where: AAI = (purchase cost)+(depreciation)+(salvage value) (\div 2)</td>
<td></td>
</tr>
<tr>
<td>YARDER (18% of $33,125)</td>
<td>$3.73</td>
</tr>
<tr>
<td>RADIO (18% of $2,044)</td>
<td>0.23</td>
</tr>
<tr>
<td>CREW TRUCK (18% of $6,133)</td>
<td>0.69</td>
</tr>
<tr>
<td><strong>TOTAL OVERHEAD</strong></td>
<td><strong>$4.65</strong></td>
</tr>
<tr>
<td><strong>LABOR</strong> (includes 40% benefits and burden factor + $0.60/hour travel time)</td>
<td></td>
</tr>
<tr>
<td>YARDER OPERATOR</td>
<td>$14.08</td>
</tr>
<tr>
<td>RIGGING SLINGER</td>
<td>13.23</td>
</tr>
<tr>
<td>CHOKER SETTER</td>
<td>12.03</td>
</tr>
<tr>
<td>CHASER</td>
<td>12.29</td>
</tr>
<tr>
<td><strong>TOTAL LABOR</strong></td>
<td><strong>$51.63</strong></td>
</tr>
<tr>
<td><strong>TOTAL HOURLY COST</strong></td>
<td><strong>$75.70</strong></td>
</tr>
</tbody>
</table>

26. Based on 200 8-hour days per year.
### DEPRECIATION

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRUCK MOUNTED HEEL BOOM LOADER</td>
<td>$1.41</td>
</tr>
<tr>
<td>($10,000 used cost; 10% salvage; 4-yr. estimated life)</td>
<td></td>
</tr>
</tbody>
</table>

### MAINTENANCE AND REPAIR

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOADER (50% of depreciation)</td>
<td>0.70</td>
</tr>
</tbody>
</table>

### FUEL AND LUBRICATION

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOADER FUEL (3.4 gal/hour at $.80/gal)</td>
<td>2.72</td>
</tr>
<tr>
<td>LUBRICANTS (20% of fuel cost)</td>
<td>0.54</td>
</tr>
</tbody>
</table>

### INSURANCE, INTEREST AND TAXES

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>18% AVERAGE ANNUAL INVESTMENT where $AII = (Purchase cost)+(Depreciation)+(Salvage value) [ \frac{18%}{2} ]</td>
<td>0.75</td>
</tr>
</tbody>
</table>

### LABOR

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>(USFS 10/78 increased by 1.09)</td>
<td>15.79</td>
</tr>
<tr>
<td>LOADER OPERATOR</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL HOURLY COST**

$21.91
## APPENDIX M

### HAULING COSTS

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/trip</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Based on a cost of $1.12/mile (Dykstra and Garland, 1977) and increased by 9% each year for three years)</td>
</tr>
<tr>
<td></td>
<td>$1.46/mile x 33.8 miles roundtrip</td>
</tr>
</tbody>
</table>