AN ABSTRACT OF THE THESIS OF


Title: Logging With A Hydraulic Excavator: A Case Study

Abstract approved:

This paper presents a production study of a modified hydraulic excavator used for yarding and loading logs. The machine utilized in this study is a Caterpillar 245. Approximately 3067 cunits (4053 pieces) of old growth Douglas fir were logged from a 29 acre setting in the Coast Range of southwestern Oregon.

The purpose of the study is to develop and present important information concerning the application of a logging technique that is generating increasing interest from the forest industry in the Pacific Northwest. This purpose is accomplished by, 1) identifying the conditions affecting production, 2) providing a description of operating techniques, and 3) providing a preliminary investigation of soil impacts.

Time study and regression techniques are used to develop equations for predicting yarding production.
Significant independent variables include piece size, ground slope, and yarding distance. The relationships between production and piece size and yarding distance are nonlinear.

On relatively flat ground the machine travels in a serpentine pattern, methodically swinging logs closer to the road on each pass. On steeper ground slopes (>30%), the terrain may preclude adherence to this otherwise efficient pattern; here the operator uses several techniques to increase the effective reach of the machine.

A preliminary investigation of soil impacts indicated that off road soil compaction was not a significant problem; a 2 percent decrease in seedling height growth on 5 percent of the area. The high road density (7 percent of area) appeared to be the main impact on site quality. Mitigation measures could include tillage of the road surface and sidecast pull-back.

The actual yarding production rate on the setting was 54.47 cunits/scheduled yarding hour. The yarding cost was $2.02/cunit. Total cost including road construction within the setting and loading was $9.61/cunit. The regression equation overpredicted actual cunit/hour production by 5 percent.
Logging with a Hydraulic Excavator: A Case Study

by

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I. INTRODUCTION

Shovel logging refers to the use of a hydraulic excavator, modified and fitted with a grapple, as the principal means of yarding logs on a particular setting. This is accomplished by the hydraulic excavator, hereafter called a shovel, traveling through the setting and systematically swinging the logs closer to a truck loading site. The shovel travels unloaded. Log movement occurs as the stationary shovel picks up logs and, by rotating on the car body, swings the logs closer to the road. On steeper ground (>40%) construction of primitive roads facilitates the shovel travel.

Shovel logging has proven cost effective during a period that has forced the forest products industry to be very conscious of logging and manufacturing costs. This paper presents a case study of a shovel logging operation. The effects of stand and ground conditions on production are investigated through a time study. Techniques of operation, equipment modifications, and planning considerations are discussed.

Shovel logging has been present in the Pacific Northwest since the mid seventies (Blackman, 1984). The system has been used principally on relatively flat ground, most notably on the Olympic Peninsula of Washington State. Bill Tometitch of Mason Timber in Aberdeen, Washington stated that all the independent
loggers in the area that have kept busy during the recent hardtimes have at least one shovel logging side.

This study was conducted on a Weyerhaeuser Company operation taking place on company lands, the Millacoma Tree Farm, located between Coos Bay and Roseburg, Oregon. Approximately 3067 cunits (4503 pieces) of old growth douglas fir were shovel logged from about 29 acres of moderate (0%-60%) terrain during a three week period in the summer of 1985. Equipment consisted of a Caterpillar 245 excavator for yarding and a Caterpillar D-8 tractor used mainly for road construction. The dozer appeared to be underutilized on the setting. This under utilization was mitigated somewhat by occasionally operating on nearby settings.

The labor force consisted of the shovel operator, dozer operator, and "second loader". The shovel operator was considered by the logging superintendent to be highly skilled in this application of the machine. The shovel operator made decisions as to how the setting was to be logged, requiring a good deal of planning and judgement on his part. The dozer operator was very experienced. The "second loader" performed tasks on the landing such as limbing, bucking, and assisting truck drivers securing the load. The shovel operator was the designated crew leader. The crew appeared highly motivated by the Weyerhauser
incentive program, having received substantial bonuses on six of the last ten settings on which they worked.

The ranges of slope, yarding distance, and piece size included in the analysis are limited to those encountered in the operation.

The relationship of ground slope, yarding distance, and piece size to yarding production are determined through the application of regression analysis techniques to time study data. Dependent variables are pieces per delay free hour and cunits per delay free hour. The independent variables are ground slope, yarding distance, piece size, and log diameter.

A gross time study was undertaken to determine relative activity times and machine availability. The author was merely an observer of the operation and had no control of, or influence on, the execution of the operation.
II. Objectives

1. Develop regression equations which predict the production rate and cost of logging for the case conditions.

2. Identify important conditions affecting production.

3. Provide a description of shovel logging operations on moderate to steep slopes (0 to 60 %)

III. ACKNOWLEDGEMENT

This study was an independent undertaking of the author. Funds for travel and living expenses incurred during data collection were provided by the Oregon State University, School of Forestry, Department of Forest Engineering. The Weyerhaeuser Company provided cost and production information, and the opportunity to observe company logging operations.
IV. FIELD STUDY

A. The Setting

The study took place in the Coast Range of southwestern Oregon, on the Weyerhauser Company Millicoma Tree Farm between Coos Bay and Roseburg. The initial logging plan for the setting was to log 50 percent by shovel and 50 percent by a Madill yarder with grapple. The cable logging was planned for the steeper (30 to 60 percent) slopes. The shovel operator decided that it would be feasible to yard the entire setting with the shovel, enhancing the potential bonus the crew would share. The setting was logged 100 percent by the shovel at about two thirds of the appraised logging cost.

The percent ground slope on the setting ranged from 0 to 60 percent, averaging about 35 percent. The average yarding distance (the distance from the log to the truck road) was calculated from road density to be 57.5 feet. Average road spacing was 184 feet. Piece size ranged from 16 cubic feet to 434 cubic feet, averaging 68 cubic feet. Log diameters ranged from 5 inches to about 60 inches, averaging about 16 inches. Figure 1 provides a map of the setting.
Figure 1. Setting Map

Area = 29 acres
Scale 1" = 400'
- Roads in place
- Truck road constructed
- "Cat" road constructed
- Yarding direction
- Drainage
- Setting boundary
+ Corners, lot 4, section 5
 T26S R8W
B. Methodology

The time study recorded detailed yarding times for individual logs as well as gross times for machine activities over a three week period. The detailed time study involved the timing of the yarding element for individual logs. Logs were scaled and numbered for identification prior to yarding. Distance to the road and ground slope were also measured prior to yarding. The recorded ground slope was the average slope between the log and the road. Downhill yarding was recorded as a negative slope. The distance to the road was measured from the near end of the log to the road edge. The cubic log volume was determined by using the conic log rule (Dillworth, Bell, 1985) and a taper rate estimated from the analysis of 400 logs.

The elapsed time for each yarding element was measured with a stopwatch and recorded in 100ths of a minute. If a log was handled more than once the element times were summed. Rehandling occurred when the shovel was unable to swing the turn all the way to the road because of distance. This occurred in only 12 percent of the observations. Usually only one log was yarded at a time. When more than one log was yarded the observation was discarded unless all logs in the turn had been scaled. If all logs in the turn had been scaled then the individual log volumes were summed for the purpose of
The yarding element begins when the operator makes the initial effort to position the boom for grappling a turn. Each yarding element is defined as ending when the boom is parallel to the slope contours on the way to grasp the next turn.

In addition to the detailed time study of the yarding element, a gross time study of machine activity was done to provide further insight into the productivity, availability, and operation of the machine. A program was written (Appendix C) for a handheld computer, a Hewlett-Packard 71B, enabling it to prompt for and record the time associated with six identified elements and other information related to the particular element. The six identified elements are 1) travel, 2) travel to load, 3) swing, 4) load, and 5) delay. The time recorded was continuous time in seconds at the beginning of each activity. These times were later converted to elapsed times for each activity. The beginning of an activity identified the end of the previous activity.

The travel activity includes all machine travel other than travel to load a truck or travel included in the yarding activity. Examples of this activity would include travel to fuel, travel to another part of the setting for yarding and travel from a truck loading site to resume yarding. The travel to load activity was kept separate in order to facilitate its inclusion in the loading cost.
The distance travelled was recorded for both the travel and the travel to load activities. The travel to load activity includes only that travel which is required for the machine to get from the location of the previous activity, usually yarding, to the truck loading site. The swing activity is the actual yarding operation. The time attributed to the swing activity includes some travel of short distances, generally less than twenty feet. The load activity includes all time spent loading trucks. The activity began with the off lifting of the first trailer (trucks were hauling double loads) and ended at the beginning of the next activity (travel, swing, delay, etc.). The delay activity includes all time that the machine is unproductive during the work day. The source of the delay is identified and recorded as being either 1) mechanical, 2) personnel, 3) administrative, or 4) other. Mechanical delays are further identified by source as grapple, boom, power train, or undercarriage. Fueling was often accomplished during mechanical delays, when production was stopped for the singular purpose of refueling the delay source was identified as "other".

C. Data Handling Techniques

The HP-71B computer worked well as a data recorder. Utilization of the internal clock and the ease of inputting data enabled the observer to perform other tasks.
(scale logs, record detailed time study data via stopwatch and clipboard) at the same time. The push of a single button would record the time and the activity type. The need for transcribing field notes was eliminated, as well as the potential for introducing errors while doing so. Recovery from a recording error was more difficult when using the computer as a recorder than when using the traditional stopwatch and clipboard. Erroneous data was corrected at a later date from field notes describing the error.

The greatest problem encountered in the use of a computer for data collection was the inadvertant termination of the data recording program. The program termination was caused by the accidental depression of keys while the observer was navigating the brush or performing other tasks related to the study. The consequences of the program termination were initially to require that further data be collected by stopwatch and clipboard until the computer memory could be transferred to a mass storage device and the program reinitiated. Restructuring the program memory requirements allowed the program to be reinitiated several times without the necessity of transferring computer memory to mass storage to prevent the loss of data. The loss of about thirty seconds of recorded activity time is then the consequence of having to reinitialize the program in the midst of the
study. A simple field note makes it possible to correct this at a later date.

The HP-71B had insufficient memory (21K) to store more than several days data. For this reason, and as a precaution against losing data, the data was transferred to mass storage every evening after a day of study. The data was transferred to diskettes via a Hewlett-Packard 86 microcomputer. This process required two additional programs. A program called "Transmit" (Appendix C) was written for the HP-71B, directing the sending of data to the HP-86. A program, "Datatrans" (Appendix C) was written for the HP-86 directing it to receive the data from the HP-71B.

After completion of the field work the data was transferred to an IBM PC via modem and Cyber mainframe. Once on the IBM, the memory conserving format of the data was changed to one convenient to analysis.
V. HYDRAULIC EXCAVATOR MODIFICATIONS

The development of the hydraulic machine for logging applications consisted of the modification of machines designed for excavation. Modifications made to convert an excavator into a log loader are, for the most part, also appropriate for conversion to a shovel logging machine.

The excavator bucket is replaced with a rotating grapple. The grapple rotor and cylinder(s) for opening and closing the grapple require additional hydraulic circuits. The grapple is the key to success (Simpson 1985). Simpson (1985) cites reliability and design problems of the grapple. Of the mechanical delays recorded in this study, 40% were attributed to the grapple. Broken hydraulic hoses and rotor design were the most common problems. Once hydraulic requirements are met the conversion from bucket to grapple can be made in one-half hour according to one manufacturer. A logging supervisor however, estimates that it takes his crew three to four hours to make the change (Shook, 1986).

A live heel is recommended because it allows better control of the load as well as increased effectiveness during yarding. The improved control during loading enables easier loading from the rear of the truck, decreasing the need for constructed landings. The increased yarding effectiveness is due in part to the ability of the machine to grapple the log at one end,
Figure 2. Modified Hydraulic Excavator

1. Rotating grapple
2. Live Heel
3. Stick
4. Stick cylinder
5. Boom
6. Elevated cab
7. Undercarriage
8. Carbody
9. Counterweight
increasing the distance that a log may be moved on each swing by up to one log length.

The boom, typically banana shaped for excavation, may be replaced with a longer, straight boom to increase above ground reach, lifting height, and maximum lifting capacity. The greater maximum lifting capacity attributed to the straight boom is a result of the fact that the load can be brought in closer to the machine. The straight boom may, however, decrease the below ground level reach, particularly if the stick cylinder is mounted below the boom. A below mounted cylinder, however, gives greater lifting capacity.

Operator visibility can be increased by elevating the cab. This increased visibility improves the operator's ability to locate and grasp turns as well as his ability to build loads. Cab elevation can usually be accomplished by attaching the original cab to the top of a fabricated steel box bolted to the original cab location. Control linkages are joined with extensions.

Because the machine is often working off the road amidst stumps and logging debris, additional protection to the under side of the carbody in the form of a belly pan is essential. Most operators use 3/4 inch Ti steel plate, reinforced with 2 inch by 4 inch Ti steel bars, under the car body (Hemphill, 1986). Good ground clearance is important for off road machine navigability, and should be
considered when evaluating a machine's potential for conversion to shovel logging.

Lifting capacity is usually determined by machine stability rather than hydraulic lifting capacity. Machine stability can be improved by increasing undercarriage length, width, and weight. Undercarriage width is determined by shoe width. While greater width increases stability and decreases ground pressure, it can greatly increase the rate of wear of the undercarriage. The rule of thumb is to use as narrow a shoe as possible (Caterpillar, 1984). Undercarriage operating cost for the Caterpillar 245 was estimated to be about 12 dollars per hour using the estimating technique presented in the Caterpillar Performance Handbook (Caterpillar, 1984). Hemphill (1986) cites high undercarriage maintenance costs for shovel logging, "...one operator has found that a set of tracks will last about 4000 to 6000 hours, compared to 16000 hours for a loader not traveling off the road". The log yarder/loader is likely to require more counter weight than an excavator due to the greater lifting requirements. The appropriate counter weight will increase lifting capacity by improving machine stability.

The machine utilized in this study was a Caterpillar 245 outfitted with a custom built, 51-foot, Young boom and 60-inch Pierce grapples. The boom was straight, with the stick cylinder mounted below the boom. The grapples were
capable of full 360 degree rotation. The carbody was protected with a 1 inch steel plate. The cab was elevated. The ground clearance of a Caterpillar 245 is 30 inches. Shoe width was 36 inches.
VI. YARDING METHODS AND OPERATOR TECHNIQUES

Hydraulic excavators may be used effectively to yard and load logs independently or in conjunction with other systems. The settings on which the data for this study were collected were logged and loaded almost exclusively with the modified hydraulic excavator described previously. The exceptions were, the relatively few logs skidded by the D-8 Cat, and a small area where the Cat was used in conjunction with the shovel.

The principal method of operation was for the shovel to walk along the predetermined location of a road, yarding the logs within a 100 foot swathe and decking them above or below the intended road. The D-8 would work behind the shovel constructing a truck road. The truck road was unimproved native material, servicable only when dry. Compaction was only to the extent that D-8, shovel, and truck traffic provided it. After yarding the road right of way, the shovel would work above it, swinging logs to the roadside.

The felling pattern of trees was along the contour, as if for a cable setting. The effect of different felling patterns is unknown but the author suspects that an opportunity for savings exists in this area. Paul Shook (1986) suggests a method of falling trees downhill to a shovel. Stems were topped, partially limbed, and bucked. The shovel performs much of the limbing task
while handling the logs. If adequate limbing is not achieved through typical yarding and decking activities then limbing is accomplished by positioning the log vertically and running the grapples down the log. The bucking of logs has advantages and disadvantages, dependent on site and timber factors. Trees with a butt diameter over 24 inches are usually bucked and yarded log length (Hemphill, 1986). Smaller wood is more likely to be yarded tree length. The advantage of handling log length pieces is that the entire piece is swung, gaining one log length in distance towards the landing. Tree length pieces are usually dragged. The advantage of tree length pieces is the reduced number of pieces to be handled, and on steep ground a reduction in the need for traveling off of the road.

On the gentler (<30 °) slopes the shovel would begin furthest from the road, travel through the area, systematically swinging logs closer to the road. The shovel follows a serpentine pattern that allows it to swing all the logs successively towards the road with a minimum of back tracking (figure 3). The economy of handling logs more than three times, about 400 feet, is dubious (Shook 1986). A study done in Southeast Alaska indicated that the handling time for each log increased after three passes, suggesting that log deck height affects production (Starnes 1985).
Figure 3. Serpentine Yarding Pattern on a Hypothetical Setting

1" = 400'

- Truck road
- Path of machine travel
- Direction of log flow
- Log deck
- Start of machine travel
On steeper slopes the operator is required to be more innovative. The terrain can preclude adherence to a serpentine pattern, or require the construction of landings from which trucks can be loaded out. In this case the shovel still operates in a methodical manner, but one defined by the concentration points or landings. The travel pattern may resemble that of a series of hubs and spokes (figure 4).

The shovel operator employed several techniques that effectively increased the range of the machine. One such method was to heel a long log (50 to 80 feet) against the heel on the boom and use it as an extension. On steeper slopes this extension could be slipped underneath a log above the machine, lift the log over a stump or whatever is holding it on the slope and allow it to roll down the heeled log. Likewise, when working below the machine the heeled log can be used to flip up one end of a log sending it further down the hill, toward a lower road. If there is no lower road, tongs can be attached to the end of the heeled log, and the log can be brought up the hill. Machine stability is likely to limit this technique in large timber. Another method effective on steep ground is to place a couple of logs perpendicular to the slope contours and to roll logs down them, towards a road below. One section of steep ground (45 to 55 percent) was logged by throwing logs downhill to a road below. The
Figure 4. Hub and Spoke Yarding Pattern on a Hypothetical Setting

1" = 400'

- Truck road
- Off road machine travel
- Direction of log flow
- Truck loading site
- Obstacle to machine travel
shovel operated from a primitive road, unsuitable for truck traffic. The distance to the road below was about 160 feet. The operator chose to throw the logs downhill rather than operate on the steep side slope or build an additional truck road. Although not measured, log damage during this operation appeared to be greater than during the more typical swing technique. When the distance was too great to throw logs within reach of the lower road the D-8 tractor was used in conjunction with the shovel.

The use of the shovel in conjunction with a Caterpillar D-8 tractor occurred on steep ground (45 to 55 percent) where the road spacing was about 250 feet. The shovel had yarded the area that could be reached from the roads, leaving a strip about 100 feet wide unyarded. The D-8, starting from the upper road, came straight down the slope pushing logs in front of it. The logs were pushed down the hill until they could be reached by the shovel from below. While this method did work, it appeared to cause a greater amount of log breakage, soil disturbance, and delay time. The increased delay was associated with getting the D-8 free from being hung up on a stump. The pile of logs in front of the D-8 obstructed the operators view, making navigation difficult and the ground slope made it difficult to back up. Several major delays were encountered due to these problems. The shovel, using a long log heeled against the boom as an extension, was used
to help free the D-8. The use of the D-8 tractor in conjunction with the shovel was included in the gross time study, but not in the detailed time study.
VII. Results of the Gross Time Study

The gross time study provides information on the relative amount of time spent on various activities (figure 5). This information is important for two reasons. It permits a conversion of the productivity relationships developed in the detailed time study from production per pure, delay free, yarding hour to production per scheduled hour. The scheduled hour includes delays and ancilliary activities not included in the detailed time study yarding element. A second use of relative activity times is to indicate opportunities for improvement in the system design, machine design, or operator effectiveness.

The gross time study determined the relative time consumed by the following activities:

<table>
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<th>Activity</th>
<th>Percentage</th>
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<tr>
<td>YARD</td>
<td>29.1 %</td>
</tr>
<tr>
<td>TRAVEL TO LOAD</td>
<td>2.6 %</td>
</tr>
<tr>
<td>LOAD</td>
<td>41.7 %</td>
</tr>
<tr>
<td>TRAVEL</td>
<td>8.5 %</td>
</tr>
<tr>
<td>ROAD</td>
<td>4.1 %</td>
</tr>
<tr>
<td>DELAY</td>
<td>14.0 %</td>
</tr>
</tbody>
</table>

Several inferences can be made from the relative activity times. Evaluation of machine design or modification should consider the fact that the machine is spending the most time loading, not yarding. Modifications that improve yarding capability at the
Figure 5. Relative Machine Activity Times
expense of loading capability may be unwise. The fact that the shovel spends nearly half (48.5%) of non delay time loading indicates that the system may lend itself to the use of two shovels, one loading and one yarding. The elimination of travel required by machines switching from yarding to loading activities could increase the overall productive time.

Analysis of the gross time study data indicated that the shovel spent 29 percent of scheduled time, or 34 percent of productive time, yarding. This delay free yarding time includes ancilliary activities such as short travel and brush moving, but does not include any delays. The ancilliary activities were not measured in this study but were estimated to comprise about one third of the gross yarding time. A shovel yarding study in southeast Alaska determined through work sampling that gross yarding time was 38 percent ancilliary activities (Starnes 1985). Delays accounted for 14 percent of the scheduled machine time. Delays included unproductive time due to mechanical break down and repair, fueling, maintenance, administrative, and personal activity. The conversion from pure, delay free yarding hour production (PYHrP) to
scheduled yarding hour production (SYHrP) is made as follows:

\[ \text{PYHrP} \times 0.86 \times 0.62 = \text{SYHrP} \]

Where:

productive time/scheduled time = 1 - .14 = .86

pure yarding time/gross yarding time = 1 - .38

= .62

The relationship between scheduled, delay free, and pure yarding times is illustrated in figure 6.
Figure 6. Relationship of Pure Yarding Hours to Scheduled Hours
VIII. RESULTS OF THE DETAILED TIME STUDY

Two distinct yarding categories were defined for the purpose of analysis. Data for each were analyzed separately. The two techniques were, 1) the conventional swinging of a turn, and 2) the throwing of a turn downhill. Log and ground variables were analyzed for their significance in determining logging production. Logging production was expressed in terms of both volume per hour and pieces per hour.

The histograms for yarding distance, piece size, slope, and time per turn for the conventional swing technique are presented in figures 7 thru 10. All variables had 102 observations. Figure 7 illustrates the range and distribution of the observed yarding distances. The mean and median of the observed yarding distances are 79 feet and 60 feet respectively. Observed yarding distances ranged from 5 feet to 205 feet.

Observed piece size range and distribution for the swing technique are illustrated in figure 8. The mean and median of observed piece sizes are 133 cubic feet and 88 cubic feet respectively. The range of observed piece sizes was from 16 cubic feet to 434 cubic feet.

The ground slopes on which detailed time study data was obtained for the swing technique are presented in figure 9. These slopes ranged from -55 to +50, negative slopes being downhill yarding.
Figure 7. Range and Distribution of Observed Yarding Distances
Figure 8. Range and Distribution of Observed Piece Sizes
Figure 9. Range and Distribution of Percent Ground Slopes
Figure 10. Range and Distribution of Observed Turn Yarding Times
Figure 10 illustrates the range and distribution of turn times for the swing technique. The mean and median turn times were .59 minutes and .50 minutes respectively. Turn times ranged from .15 minutes to 1.68 minutes.

A. Volume per Hour - Conventional Swing

Log volume, yarding distance, and ground slope were found to be the most significant factors determining production in terms of volume per hour for conventionally yarded turns. Log volume was most significant in the form of the natural logarithm of cubic log volume (LNV). The transformation to the natural logarithm is logical because the increased production with increasing log size drops off as log size approaches the machine limitations and handling time increases more rapidly (figure 11). The transformation also reduced a heteroscedasticity (increasing variance in production at higher log volumes) problem in the data (figures 12A and 12B). Log sizes recorded during the time study ranged from 16 to 434 cubic feet. The distance that a fully supported log may be swung over firm, flat ground begins to decrease as log size exceeds 9,400 pounds or 170 cubic feet (55 lbs. per cubic foot) (appendix D). On less stable footing maximum swing distances would be diminished for even smaller logs. Log volume was the most important variable in accounting...
Production vs Piece Size

Figure 11 A. Nonlinear Relationship Between Production and Piece Size
95% Confidence Intervals for Mean and Predicted Values

Regression of Production on Piece Size

Figure 12 A. Heteroscedasticity and Confidence Intervals
Figure 12 B. Heteroscedasticity and Confidence Intervals

Confidence Intervals for Mean and Predicted Values

Regression of Production on Natural Logarithm of Log Volume

$95\%$ Confidence Intervals for Mean and Predicted Values

Regression of Production on Natural Logarithm of Log Volume

Figure 12 B. Heteroscedasticity and Confidence Intervals
for the variation in hourly volume production of the swing technique.

Yarding distance, in feet, (DISTANCE) was of nearly equal significance in either of two forms. The square root of distance was selected, over its linear form, for use in the equation for two reasons: 1) there is a rational physical explanation for this relationship, and 2) to maintain consistency with the relationship of yarding distance to hourly piece production. The square root transformation of distance improves the fit of the hourly piece production equation more than the fit of the hourly volume production equation. This anomaly is explained by the fact that piece size and distance were found to be nonlinearly related. This nonlinear relationship is thought to be only an incidental occurrence in the detailed time study observations, not an actual description of the setting. The effect of yarding distance on hourly volume production is believed to be understated due to the few recorded yarding distances over 150 feet.

A logical explanation for the square root transformation is that as the yarding distance increases, so too does the likelihood that the machine is moving more than one log at a time over some portion of that distance. A study done in southeast Alaska determined that the number of pieces handled per hour increased as the pieces
became more concentrated due to decking of previously handled logs, (Starnes, 1986). This trend continued until logs had been handled three times. The swinging of multiple stems, facilitated by the decking of previously handled logs, mitigates the effect of greater yarding distances on hourly production, flattening out the curve as distance increases. None of the turns included in the data for this study were handled more than three times.

Ground slope was found to be significant in two forms, indicating a multifaceted effect on hourly volume production. The real value of percent ground slope (SLOPE), expressed as a positive (uphill yarding) or negative (downhill yarding) value, gives an indication of the effect of yarding direction (uphill or downhill) on production. The use of these signed values alone do not account for the effect of machine stability on production. The absolute value of percent ground slope (ABSLOPE) is included as an independent variable to account for the effect of machine stability on production. Figure 13 exhibits the relationship between ground slope and production. The effect of slope on machine stability was more important than whether the machine was yarding uphill or downhill in explaining the variation in hourly volume production.
Figure 13. Relationship Between Production and Percent Ground Slope
The regression equation for hourly volume production (HVP) follows:

\[ HVP = -13176.06 + 10340.218057 \times \text{LNV} - 248.616487 \times \text{ABSLOPE} - 1448.609938 \times \text{DISTANCE}^\frac{1}{2} - 91.402326 \times \text{SLOPE} \]

\[ R^2 = .6417 \]

HVP in cubic feet per hour

\( n = 102 \) (12% handled more than once)

All variables significant at 95% level
Production in terms of pieces per hour is best predicted by log diameter, ground slope, and yarding distance. Yarding distance (DISTANCE), in feet, transformed to its square root, is the most significant in accounting for variation in hourly piece production. The relationship of yarding distance to hourly piece production is illustrated in figures 14 A and B. The nonlinearity of this relationship is thought to be a result of the greater probability of more distant logs being yarded in multiples, and is explained in the section on hourly volume production.

Log diameter, measured at the small end inside bark in inches, (DIAMETER) was also significant in explaining the variation in hourly piece production. As log diameter increased, the hourly piece production decreased. Three factors could explain this relationship, 1) the capacity of the grapples to handle multiple log turns of larger diameter logs, 2) the capacity of the machine to quickly handle the weight associated with turns of larger log(s), 3) the perception by the operator of a need to handle small logs in multiples. The volume (i.e., weight) of turns did not enter the production equation because log diameter overshadows its effect.

The third variable found to be significant in predicting hourly piece production is absolute value of
Figure 14 A. Nonlinear Relation of Piece Production to Yarding Distance
Figure 14 B. Nonlinear Relation of Piece Production to Yarding Distance
percent ground slope (ABSLOPE). As previously stated, this variable provides a measure of machine stability while yarding. The fact that yarding was uphill or downhill was more significant for predicting hourly volume production than for predicting hourly piece production (HPP).

Regression analysis resulted in the following equation:

\[ HPP = 350.5439 - 3.259746 \times \text{(DIAMETER)} - 1.927939 \times \text{(ABSLOPE)}^{1/2} - 10.18297 \times \text{(DISTANCE)}^{1/2} \]

\[ R^2 = 0.3832 \]

All variables significant at 95% level

HPP in pieces per hour
C. Volume Per Hour - Throw Technique

Three variables were found to be significant in predicting hourly volume production attained while using the throw technique: log diameter, ground slope, and cubic log volume. Log diameter was significant beyond its correlation with volume. While observing the operation it became apparent that the significance of diameter was due to the tendency of larger diameter logs to roll faster and farther down the hill once they were set in motion by the shovel.

The throw technique is employed on steep slopes where the shovel is capable of working above the truck road, from a bench, ridge top, or primitive mid-slope road. Practical yarding distance is limited with this technique, probably to about 200 feet, and somewhat dependent on slope. Breakage was not recorded but was probably greater than that experienced with the more usual swing technique.

Ground slope was significant in predicting hourly volume production despite the fact that the range of slopes on which this technique was observed was quite limited. The preponderance of slopes were -45 or -50 percent with just a few observations made on -30 and -40 percent slopes. All ground slopes were negative (logs were thrown downhill). Greater negative ground slopes were associated with greater productivity. During the use of the throw technique the shovel operated almost
exclusively from a constructed "Cat road". This may explain why the effects of decreased machine stability on steeper slopes did not counteract the advantage of throwing logs down steeper slopes.

Cubic log volume (VOLUME) was by far the most significant variable in predicting hourly volume production achieved by the throw technique.

The regression equation for hourly volume production achieved by the throw technique is:

\[ HVP = -98379.41 + 634.0331 \times \text{DIAMETER} - 1733.478 \times \text{SLOPE} + 155.3929 \times \text{VOLUME} \]

\[ R^2 = .7965 \]

NOTE: Equation limited to slopes of -45 to -50 %

HVP in cubic feet per hour

\[ n = 38 \text{ (number of logs observed)} \]

All variables are significant at 95 % level

If representative values for log diameter (16 inches) and log volume (70 cubic feet) and slope (-50 percent) are used, the throw technique production equation predicts a production rate of 9316 cubic feet per pure yarding hour. Using the same representative values and a yarding distance of 160 feet the swing technique equation predicted a production rate of 4570 cubic feet per pure yarding hour (PYHr). The use of the equations would lead one to concur with the operator's decision to use the
The yarding cost per cunit for the throw technique and the swing technique are calculated as follows:

**Throw Technique**

\[
93.16 \text{ cunits/PYHr} \times 0.62 \times 0.86 = 49.67 \text{ cunits/SYHr}
\]

where:

- PYHr = Pure Yarding Hour
- SYHr = Scheduled Yarding Hour

\[
\frac{110.12/\text{SYHr}}{49.67 \text{ cunits/SYHr}} = \$2.22/\text{cunit}
\]

**Swing Technique**

\[
45.70 \text{ cunits/PYHr} \times 0.62 \times 0.86 = 24.37 \text{ cunits/SYHr}
\]

\[
\frac{110.12/\text{SYHr}}{24.37 \text{ cunits/SYHr}} = \$4.52/\text{cunit}
\]
D. Pieces per Hour - Throw Technique

Log diameter and ground slope, as previously defined, were the only two variables found to be significant in predicting the piecewise production of the throw technique. Again, larger log diameters are associated with increased production. This is believed to be a function of the relative ease with which larger diameter logs can be rolled downhill.

Steeper ground slopes were associated with greater hourly piece production. This relationship is attributed to the role that gravity plays in determining the speed or distance which logs roll or slide downhill.

Regression analysis resulted in the following equation for predicting hourly piece production (HPP) with the throw technique:

\[
\text{HPP} = -111.177 + 3.11288 \text{ (DIAMETER)} - 3.834312 \text{ (SLOPE)}
\]

\[ R^2 = .1850 \]

NOTE: Equation limited to slopes of -45 to -50 %

HPP in pieces per hour

n = 38 (number of logs observed)

DIAMETER significant at 95 % level

SLOPE significant at 90 % level
E. Verification of Equations

As a verification of the regression equations, representative setting parameters for the 29 acre unit were used in the equations in an attempt to predict the known production on the setting. The equations resulted in predicting the following pure, delay free yarding hour (PYHr) production:

128.80 cunits/PYHr
153.77 pieces/PYHr

Conversion to scheduled yarding hour (SYHr) yields:
68.68 cunits/SYHr or 1.4560 SYHr/cunit
132.24 pieces/SYHr or .007562 SYHr/piece

Loading Production is determined as follows:

\[
\frac{(.417+.026)}{(1-.14)} \times 142 \text{ STHr} = 73.144 \text{ SLHr}
\]

where: \( \text{STHr} = \text{Scheduled Total Hours} \)
\( \text{SLHr} = \text{Scheduled Loading Hours} \)

3067 cunits/73.144 SLHr = 41.93 cunits/SLHr
or .02385 SLHr/cunit
4053 pieces/73.144 SLHr = 61.56 pieces/SLHr
or .0162433 SLHr/piece

Combined Yarding and Loading Production:

\[
\begin{align*}
0.01456 \text{ SYHr/Cunit} &+ 0.02385 \text{ SLHr/Cunit} \\
&= 0.03841 \text{ (SYHr+SLHr)/Cunit} \\
&\text{or 26.03 cunits/(SYHr+SLHr)}
\end{align*}
\]

\[
\begin{align*}
0.007562 \text{ SYHr/piece} &+ 0.0162433 \text{ SLHr/piece} \\
&= 0.02380 \text{ (SYHr+SLHr)/piece} \\
&\text{or 42 pieces/(SYHr+SLHr)}
\end{align*}
\]
Account for Travel and Road Construction Time:

\[
\frac{(SYHr+SLHr)}{(1-.041-.085)} = TSHr
\]

26.03 cunits/(SYHr+SLHr) * .874 = 22.75

\[
\frac{42.0 \text{ pieces}}{(SYHr+SLHr)} * .874 = 36.72
\]

Actual Production Figures:

3067 cunits/142 TSHr = 21.6 cunits/TSHr
4053 pieces/142 TSHr = 31.7 pieces/TSHr

Comparison of Predicted and Actual:

22.75/21.60 = 1.053........ 5.3% overestimate
36.72/31.71 = 1.158....... 15.8% overestimate
IX. SOIL IMPACTS

A cursory investigation of soil impacts at the logging site was made. The investigation involved analyzing cone penetrometer readings taken at sixty locations throughout the logging site. The readings, converted to pounds per square inch (psi), represent the resistance of the soil to penetration and are referred to as the cone index. The cone penetrometer provides a direct measure of soil strength. Soil strength is related to bulk density and can be increased through compaction. Soil bulk density is related to site productivity.

At each of the sixty locations, five cone indexes were taken from an area of about four square feet. The mean of these five values was used in the analysis of the sixty sample points. Thirty of these sample points were taken prior to yarding. Of the thirty samples taken after yarding, fifteen were obtained from visible shovel tracks, the remainder from areas with no indication of equipment travel. None of the samples were in a location where any excavation had taken place. All samples were taken when the soil was very dry.

The locations of sample sites were determined by pacing a predetermined distance, usually 200 feet, in a predetermined direction. The direction generally followed the contour. The sample sites were located so as to
include the range of topography present on the logging setting.

Figure 15 shows the notched box and whisker plots (McGill et al., 1978) for the four sample categories. The mean for each category is represented by the horizontal line bisecting the notch. The notch represents the 95 percent confidence interval about the mean. The box represents the interquartile range. The vertical lines extending from the boxes indicate the range of observations up to 1.5 times the interquartile range. Observations beyond this are indicated by individual points.

The results of the cone index analysis indicate that the mean of the 39 pre-yarding samples and the mean of the 30 post-yarding samples were not significantly different at the 95 percent confidence level. The finding of no significant difference occurred despite the fact that fifty percent of the post-yarding samples were taken from visible machine tracks, while less than ten percent of the unroaded land was actually covered by tracks. The mean of cone indexes obtained from visible machine tracks (83.14 psi) was 17.8 psi greater than the mean of post-yarding cone indexes obtained from non-track sites (65.38 psi). This increase of 27 percent is significant at the 95 percent confidence level. The difference between the pre-yarding and in-track means is not significant at the 95
Notched Box and Whisker Plots for Cone Index by Yarding Status and Track Status

Figure 15. Cone Index by Yarding Status and Machine Track Status
percent confidence level. The suspected cause of this anomaly is the small sample size and the fact that woods operations had previously (20 to 30 years ago) taken place in the area. The percentage of unroaded land actually subjected to machine tracks was not measured but is estimated to be less than 5 percent. While this appears to be a very low estimate, it seems appropriate when the road density, and the fact that much yarding can be done from the road, are considered. The 27 percent increase in soil strength indicates an increase in bulk density of about 2 percent (Froehlich et al. 1983). A 2 percent increase in bulk density is likely to cause a decrease in the height growth of seedlings and young stands of about 2 percent (Froehlich et al., 1983).

The high road density is probably the greatest site impact concern. A road width of 14 feet, and density of 28.6 miles per square mile leaves 7.6 percent of the land base in roads. The compaction of roads through usage was great enough to preclude measurement with the cone penetrometer. The pulling back of side cast material and placing it on the road grade following logging was planned for the road sections on steeper side slopes. This effort should mitigate the effect of road density and soil compaction on site productivity, particularly if done following the loosening of the compacted road surface. The pulling back of sidecast material will also improve
slope stability which was decreased by sidecast road construction. The sidecast pull-back would be accomplished by the shovel after replacing the grapple with a bucket. One study, monitoring an FMC Linkbelt 5400 hydraulic excavator, found the cost of excavating sidecast material to be $1.11 per cubic yard. The production rate was 74 cubic yards per hour (Balcomb, 1985). Using these costs on a 40 percent side slope the costs of sidecast pull-back would be about $140 per station. If sidecast pull-back were performed on one half of the constructed road in the setting the cost would be about $5565 or $1.80 per cunit.
X. SUMMARY AND CONCLUSIONS

Hydraulic excavators can be converted into effective yarders. An appropriate boom and grapple are very important. Good ground clearance and protection under the carbody are prerequisite for off-road use. An elevated cab improves operator visibility and effectiveness in yarding and loading.

The application of regression techniques to the time study data resulted in equations for predicting hourly volume and piece production. Piece size was the most important variable in predicting the volume production of the swing technique, followed by the variables ground slope and yarding distance. Hourly piece production was best predicted with log diameter, ground slope and yarding distance. Log diameter was the most significant predictor. The volume and piece production equations overpredicted actual production by 5 percent and 16 percent respectively.

The method of operation on steeper slopes (> 30%) is markedly different than it is on flat ground. The terrain can prevent the machine from traveling in the efficient and usual serpentine pattern while methodically swinging logs towards the road. The operator makes many decisions as to how to log a specific area and employs several techniques to increase the effective reach of the machine.
The preliminary soil impact study indicated that the off road soil compaction was of minor concern. Approximately 5 percent of the off road area was compacted to the extent that seedling height growth would be decreased by 2 percent. The major concern is the result of road density and road surface compaction. The roads in the setting, at an average spacing of 184 feet, covered about 7 percent of the land base. Measures to mitigate the impact could include tillage of the road surface and sidecast pull-back. The sidecast pull-back, planned for this particular setting, is estimated to cost about $140/station or $1.80/cunit.

The 29 acre setting was logged in about 13 days at a total cost of about $29,500 or $9.61/cunit. Yarding accounted for $2.02/cunit, loading for $3.08/cunit, road construction for $3.21/cunit, and landing functions for $1.30/cunit. The average yarding production rate was 54.5 cunits/scheduled yarding hour. The setting was yarded and loaded at the rate of 21.6 cunits/scheduled hour.
XI. RECOMMENDATIONS FOR FURTHER STUDY

1. The effect of tree felling patterns and log length on yarding production has not been quantified.

2. A determination of the cost of limbing with the shovel is needed to determine the amount of limbing that should be done by the felling crew.

3. The development of optimum road spacing guidelines for various ground and timber conditions is needed.

4. The shovel may be used in conjunction with other logging systems. Studies of other applications, i.e. prebunching for a cable system, are needed.
BIBLIOGRAPHY


## Appendix A

**System, Machine, and Activity Cost**

### 1) Depreciation

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Price</th>
<th>Residual Life</th>
<th>AA/3 8</th>
<th>$/Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat 245</td>
<td>490,000</td>
<td>30%</td>
<td>8</td>
<td>339,940</td>
</tr>
<tr>
<td>Cat D-8</td>
<td>265,700</td>
<td>30%</td>
<td>10</td>
<td>195,704</td>
</tr>
</tbody>
</table>

### 2) Interest, Insurance, and Taxes

- **Interest Rate**: 14.5%
- **Insurance**: 3.0%
- **Taxes**: 1.5%
- **Total**: 19.0%

\[
\frac{0.19 \times (AA/3) / (Hr/Yr)}{2625} = 24.60
\]

\[
\frac{0.19 \times 195704 / 2625}{} = 14.16
\]

### 3) Direct Labor

<table>
<thead>
<tr>
<th></th>
<th>Wage*</th>
<th>Benefit**</th>
<th>Bonus</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat 245</td>
<td>15.39</td>
<td>7.69</td>
<td>10.86</td>
<td>33.94</td>
</tr>
<tr>
<td>Cat D-8</td>
<td>13.77</td>
<td>6.88</td>
<td>10.86</td>
<td>31.51</td>
</tr>
<tr>
<td>2nd Loader</td>
<td>12.80</td>
<td>5.40</td>
<td>10.06</td>
<td>30.06</td>
</tr>
<tr>
<td>Total</td>
<td>41.96</td>
<td>20.97</td>
<td>32.58</td>
<td>95.51</td>
</tr>
</tbody>
</table>

* Union wage adjusted for overtime
** Benefits at 50% of wage

### 4) Supervision (10% of wages)
4.20

### 5) Maintenance and Repair

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(65% of Cat 245 depreciation)</td>
<td></td>
<td>10.52</td>
</tr>
<tr>
<td>(65% of Cat D-8 depreciation)</td>
<td></td>
<td>4.84</td>
</tr>
</tbody>
</table>
6) Undercarriage (Track) Costs
   Cat 245 (from Caterpillar, 1984) 11.70
   Cat D-8 (from Caterpillar, 1984) 8.10

7) Fuel, Oil, Filters, and Lube
   Cat 245  (11 gal/hr)*(1.00 $/gal)*(1.07) 11.77*
   Cat D-8  (10 gal/hr)*(1.00 $/gal)*(1.07) 10.70*
   * 1.07 = fuel adjustment factor for oil etc.

TOTAL SYSTEM COST per SCHEDULED HOUR 219.74*
   * Excludes move in and move out costs, and crew transportation costs.

INDIVIDUAL MACHINE COST
   Cat 245.............. $110.12/hour
   Cat D-8.............. $78.16/hour

INDIVIDUAL ACTIVITY COST
   The following costs for yarding, loading, and road construction are attained by applying all D-8 tractor time to road construction, all "second loader" labor cost to landing functions, and applying the hourly rate for the shovel to both yarding and loading based on the relative amount of time spent on each.

   ROAD CONSTRUCTION COST
   $78.16/hr * 126 hr / 66 sta. = $149.21/station
   $78.16/hr * 126 hr / 3067 cunits = $3.21/cunit

   LOADING COST
   .6035 * $110.12 hr * 142 hr / 3067 cunits = $3.08/cunit
LANDING COST

$32.9/hr * 142 hr / 3067 cunits = $1.30/cunit

YARDING COST

0.3965 * $110.12/HR * 142 hr / 3067 cunits

= $2.02/cunit
Appendix B

Determination of Setting Production Rate and Cost

I. Determination of Average Production Rate for the Setting

A) Treatment of nonlinear variables

The use of an average value for the nonlinear variables, yarding distance and piece size, will not give the correct production rate. The production rates for a representative distribution of piece sizes and yarding distances must be determined. The overall production rate may then be calculated. An example follows:

1) Average Value Method

Average Piece Size = 68 cubic feet
Average Yarding Distance = 57.5 feet
Slope = -35

Production Rate (from volume production equation and average setting values) = 140 cubic units/hour

2) Representative Distribution Method

<table>
<thead>
<tr>
<th>Piece Size</th>
<th>Yard Distance</th>
<th>Volume/Hour</th>
<th>Hour/Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>20</td>
<td>10012</td>
<td>.0099880</td>
</tr>
<tr>
<td>50</td>
<td>40</td>
<td>12610</td>
<td>.0079302</td>
</tr>
<tr>
<td>60</td>
<td>57.5</td>
<td>12673</td>
<td>.0078908</td>
</tr>
<tr>
<td>80</td>
<td>70</td>
<td>14512</td>
<td>.0068908</td>
</tr>
<tr>
<td>120</td>
<td>100</td>
<td>16339</td>
<td>.0061203</td>
</tr>
<tr>
<td>Mean</td>
<td>68</td>
<td>13229</td>
<td>.0077640</td>
</tr>
</tbody>
</table>
B) Beware of the fallacy of rate averaging.

In order to determine the average rate, first determine the average time, then convert it to a rate. As can be seen in the example above, directly averaging the rates would result in a calculated overall rate of 132.29 cunits/hour. The correct method of averaging the time (.0077640 hour/cubic foot) and then converting it to a rate (1/.0077640 = 12880) results in a calculated overall rate of 128.80 cunits per pure yarding hour (PYHr).

II. Yarding Cost per Cunit

\[
\text{(Hourly Cost)/(Production Rate) = Cost per Cunit}
\]

\[
\frac{\$\text{/SYHr}}{\text{Cunits/SYHr}} = \$\text{/Cunit}
\]

where SYHr = scheduled yarding hour

128.8 cunits/PYHr * .62 * .86 = 68.68 cunits/SYHr

\[
\frac{\$110.12/\text{SYHr}}{68.68 \text{ cunits/SYHr}} = \$1.60/\text{cunit}
\]
## Appendix C

Program Listings for

<table>
<thead>
<tr>
<th>HP-71 Program</th>
<th>SHOVLOG</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP-71 Program</td>
<td>TRANSMIT</td>
</tr>
<tr>
<td>HP-66 Program</td>
<td>DATATRANS</td>
</tr>
</tbody>
</table>
HP-71 Program SHOVLOG

51 TIME STUDY PROGRAM SHOVLOG
10 DISP SHOVLOG
20 INPUT "FILE NAME ?";T2$
30 CREATE DATA T2$,56,28
40 ASSIGN t1 TO T2$
50 OPTION BASE 1
60 DISP "PRESS CONT TO BEGIN"
70 I=0
80 I=1+I
90 INPUT "ACTIVITY?(TSKLRD)";Al$
100 T1=TIME
110 A2=NUM(A1$)
120 IF A1$=Q THEN GOTO 515
130 IF A1$=T THEN GOTO 210
140 IF A1$=S THEN GOTO 250
150 IF A1$=K THEN GOTO 210
160 IF A1$=L THEN GOTO 370
170 IF A1$=R THEN GOTO 290
180 IF A1$=D THEN GOTO 420
190 INPUT "REENTER CODE (TSKLRD)";Al$
200 GOTO 110
210 INPUT "DISTANCE(FT)?";Fl
220 INPUT "UNIT ?";Ul
230 N1=0 @ R2=79 @ G1=0 @ B1=0 @ N2=0 @ V1=0 @ N3=0 @ D2=79 @ M2=79
240 GOTO 480
250 INPUT "UNIT # ?";Ul
260 INPUT "# LOGS ?";N1
270 F1=0 @ R2=79 @ G1=0 @ B1=0 @ N2=0 @ V1=0 @ N3=0 @ D2=79 @ M2=79
280 GOTO 480
290 INPUT "ROAD CODE (XPS) ?";R1$
300 R2=NUM(R1$)
310 INPUT "GROUND SLOPE % ?";G1
320 IF R1$="X" THEN B1=0 @ N1=0
330 IF R1$="P" THEN INPUT "STUMP DIAM (IN)?";Bl
340 IF R1$="S" THEN INPUT "# LOGS ?";N2
350 F1=0 @ U1=0 @ V1=0 @ N1=0 @ N2=0 @ D2=0 @ M2=0
360 GOTO 480
370 INPUT "UNIT # ?";Ul
380 INPUT "TRUCK t ?";Vl
390 INPUT "PARTLOAD # LOGS ?";N3
400 F1=0 @ N1=0 @ R2=79 @ G1=0 @ B1=0 @ N2=0 @ D2=79 @ M2=79
410 GOTO 480
420 INPUT "DELAY CODE (MPAO) ?;D1$
430 D2=NUM(D1$)
440 IF D1$=M THEN GOTO 450 ELSE 470
450 INPUT "SOURCE (GBCP) ?";M1$
460 M2=NUM(M1$)
470 M2=79
480 F1=0 @ U1=0 @ N1=0 @ R2=79 @ G1=0 @ B1=0 @ N2=0 @ V1=0 @ N3=0
490 A=((A2*100+U1)*100+F1)*100000+T1
500 B=((N1*100+R2)*100+R1)*100+G1)*100+N2
510 C=((V1*100+N3)*100+D2)*100+M2
520 PRINT #1,I;A,B,C
530 IF A2=81 THEN GOTO 520
540 GOTO 80
550 IF A2=81 THEN F1=0 @ U1=0 @ N1=0 @ R2=79 @ G1=0 @ B1=0 @ N2=0 @ V1=0 @ N3=0 @ M2=79 @ D2=79
560 IF A2=81 THEN GOTO 480
570 END

HP-71 Program TRANSMIT

10 ! PROGRAM TRANSMIT
20 ! PROGRAM TO TRANSMIT "T$" TO HP-86
30 DELAY 1.5
40 REAL A5,B5,C5
50 DIM T2$(8],Z(250,3)
60 T2$=''''
70 ASSIGN 10 ':Cl'
80 DISP 'THIS PROGRAM TRANSMITS'
90 DISP 'T2$ FILES TO HP-86'
100 INPUT "DATA FILE NAME ?";T2$
110 INPUT 'I=?';I
120 ASSIGN #1 TO T2$
130 DISP "DATA BEING TRANSMITTED"
140 OUTPUT ':Cl' ;T2$
150 OUTPUT ':Cl' ;I
160 FOR W=1 TO I
170 READ #1,W,A5,B5,C5
180 OUTPUT ':Cl' ;A5
190 OUTPUT ':Cl' ;B5
200 OUTPUT ':Cl' ;C5
210 NEXT W
220 ASSIGN #1 TO *
230 DISP "DONE"
240 END
HP-86 Program DATATRANS

10 I HP-86 PROGRAM TO RECEIVE DATA FROM HP-71
20 PAGESIZE 24 @ CLEAR
30 OPTION BASE 1
40 INTEGER I
50 REAL A5,B5,C5
60 DIM T$(10],Z(250,3)
70 OFF KEY#
80 MAIN_MENU:
90 CLEAR
100 I
110 MAIN MENU FUNCTIONS
120 DISP USING "10/,K" ; "USE THE APPROPRIATE FUNCTION
130 ON KEY# 1, "HP-71 INPUT" GOTO INPUT_DATA
140 ON KEY# 2, "STORE" GOTO STORE_DATA
150 ON KEY# 3, "RECALL DATA" GOTO RECALL_DATA
160 ON KEY# 4, "PRINTOUT" GOTO PRINTOUT
170 ON KEY# 5, "EXIT" GOTO EXIT
180 KEY LABEL
190 I
200 INPUT_DATA : **************************************
210 CLEAR
220 DISP "ENTER I (THE NUMBER OF RECORDED TIMES)
230 INPUT I
240 DISP USING "4/,K" ; "READY TO RECEIVE DATA - RUN
250 TRANSMIT PROGRAM ON HP-71"
260 ENTER 9 ; T$
270 ENTER 9 ; I
280 K1=I+1
290 DISP USING "2/,K" ; "FILES BEING RECEIVED"
300 FOR J=1 TO I
310 ENTER 9 ; A5
320 ENTER 9 ; B5
330 ENTER 9 ; C5
340 NEXT J
350 DISP USING "2/,K" ; "DATA RECEIVED"
360 GOTO MAIN_MENU
370 I
380 STORE_DATA : **************************************
390 CLEAR
400 DISP USING "5/,K" ; "LOAD DATA DISC IN LEFT DRIVE"
410 DISP "PRESS (CONT) TO CONTINUE"
420 PAUSE
430 CREATE T$,I+2,24
440 ASSIGN# 1 TO T$
450 PRINT# 1 : T$
460 PRINT# 1 ; I
470 FOR J =1 TO I
480 PRINT# 1,Z(J,1),Z(J,2),Z(J,3)
490 NEXT J
500 ASSIGN# 1 TO *
510 DISP "FILE STORED UNDER NAME";T$ @ WAIT 3000
520 GOTO MAIN_MENU
530 !
540 CALL DATA*************************************************************************
550 OFF KEY#
560 DISP "ENTER PRINTER ADDRESS"
570 INPUT P1
580 PRINTER IS P1
590 CLEAR
600 DISP "ENTER NAME OF FILE TO BE RECALLED"
610 INPUT H$
620 ASSIGN# 1 TO H$
630 READ# 1 ; T$
640 READ# 1 ; I
650 FOR J=1 TO I
660 READ# 1 ; Z(J,1),Z(J,2),Z(J,3)
670 NEXT J
680 ASSIGN#1 TO *
690 DISP USING "2/K,K,K" ; "FILE ",T$,"RECALLED FROM STORAGE" @ WAIT 3000
700 GOTO MAIN_MENU
710 !
720 PRINT_OUT !*************************************************************************
730 CLEAR
740 OFF KEY#
750 DISP USING "2/,K" ; "TURN ON PRINTER"
760 DISP "PRINTER IS ",P1
770 DISP "PRESS (CONT) TO CONTINUE" @ PAUSE
780 OFF KEY#
790 PRINT @ PRINT
800 PRINT "FILE NAME IS ";T$
810 PRINT "NUMBER OF TIMES RECORDED IS ";I
820 PRINT
830 PRINT USING 840 ; A2U1F1-TTT11", "N1R2G1B1N2", "VVV111N3D2M2"
840 IMAGE 12A,5X,1OA,5X,12A
850 FOR Q=1 TO I
860 PRINT USING 870 ; Z(Q,1),Z(Q,2),Z(Q,3)
870 IMAGE 12D,5X,1OD,5X,12D
880 NEXT Q
890 DISP USING "2/,K" ; "PRINTING COMPLETED" @ WAIT 3000
900 GOTO MAIN_MENU
910 !
920 EXIT*************************************************************************
930 OFF KEY#
940 CLEAR
950 DISP USING "5/,K" ; "********PROGRAM COMPLETED**********
960 END
Lifting values shown are in thousands of pounds and, from top to bottom, are:

<table>
<thead>
<tr>
<th>Hydraulic Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tipping Over Front</td>
</tr>
<tr>
<td>Tipping Over Side</td>
</tr>
</tbody>
</table>

Capacities measured at the tip of the heel boom and are net capacities (less estimated grapple weight). Capacities based on PCSA Standard No. 3 - rated loads do not exceed 87% of hydraulic capacity or 75% of tipping capacity.

Table rows and columns contain lifting capacities for horizontal and vertical position, respectively, of the grapple.

**YOUNG MODEL Y-48 for Cat 245 Excavator**

<table>
<thead>
<tr>
<th>20'</th>
<th>25'</th>
<th>30'</th>
<th>35'</th>
<th>40'</th>
<th>45'</th>
</tr>
</thead>
<tbody>
<tr>
<td>40'</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>39.5</td>
<td>27.6</td>
<td>26.4</td>
<td>18.3</td>
<td>18.3</td>
<td>18.3</td>
</tr>
<tr>
<td>45.5</td>
<td>34.5</td>
<td>25.5</td>
<td>18.3</td>
<td>18.3</td>
<td>18.3</td>
</tr>
</tbody>
</table>

| 35' | --- | --- | --- | --- | --- |
| 39.5 | 32.2 | 28.2 | 22.2 | 22.2 |
| 45.5 | 34.6 | 25.9 | 19.7 | 19.7 |
| 32.9 | 25.3 | 18.7 | 13.8 | 13.8 |

| 30' | --- | --- | --- | --- | --- |
| 34.0 | 32.7 | 28.3 | 24.4 | 24.4 |
| 45.5 | 33.9 | 25.6 | 19.8 | 19.8 |
| 33.0 | 24.7 | 18.4 | 13.9 | 13.9 |

| 25' | --- | --- | --- | --- | --- |
| 30.8 | 33.7 | 28.6 | 24.3 | 19.7 |
| 45.0 | 32.6 | 24.9 | 19.4 | 15.3 |
| 32.5 | 23.6 | 17.7 | 13.5 | 10.4 |

| 20' | --- | --- | --- | --- | --- |
| 25.9 | 29.2 | 28.7 | 24.0 | 19.2 |
| 42.6 | 31.3 | 24.0 | 18.9 | 15.1 |
| 30.3 | 22.1 | 16.8 | 13.1 | 10.2 |

| 15' | --- | --- | --- | --- | --- |
| 35.6 | 36.4 | 28.1 | 23.0 | 17.9 |
| 63.7 | 41.7 | 22.9 | 18.3 | 14.8 |
| 44.8 | 29.5 | 15.9 | 12.5 | 9.9 |

| 10' | --- | --- | --- | --- | --- |
| 55.0 | 43.1 | 24.6 | 25.5 | 21.1 |
| 59.0 | 39.7 | 28.7 | 22.2 | 17.7 |
| 40.6 | 27.6 | 19.8 | 15.1 | 11.9 |

| 5' | --- | --- | --- | --- |
| 55.2 | 41.4 | 25.5 | 24.1 | 17.7 |
| 34.8 | 37.5 | 27.7 | 21.6 | 17.3 |
| 36.8 | 25.5 | 18.8 | 14.6 | 11.5 |

| 0' | --- | --- | --- | --- | --- |
| 20' | 25' | 30' | 35' | 40' | 45' |
Appendix D

Machine Lifting Capacity

The following is an excerpt from the Caterpillar Performance Handbook, 1984:

"...In some situations the lifting requirements may be so critical that they determine the size excavator selected for a job.

The amount an excavator can lift depends on the weight and center of gravity location of the machine, the position of the bucket hook ... and the hydraulic capability of the unit. For any given bucket hook position the excavator's lifting capacity is limited by either machine tipping stability or hydraulic capability.

Because changes in boom stick and bucket position affect attachment geometry and can drastically reduce a machine's hydraulic lifting capability, excavator lifting capability is defined using the following SAE guidelines.

Tipping Condition - An excavator is considered to be at the point of tipping when the weight acting at the center of gravity of bucket load will cause the rear rollers to be clear of track rails. Suspended loads are considered to be hung by a sling or a chain from a hook on the back of the excavator's bucket, and the weight of attachments, slings or auxiliary lifting devices are considered part of the suspended load.

Thus, the tipping load is defined as the load producing a tipping condition at a specified radius. The radius of load shall be measured as the horizontal distance from the axis of upper structure rotation (before loading) to the center of the vertical load line with the load applied...

Rated Hoist Load - The rated load is established using the vertical distance of the bucket hook to the ground and the radius of the load. Ratings for the ability of a specific machine attachment to lift a load slung from the designated bucket are defined as follows:

a. The rated load will not exceed 75 % of the tipping load.

b. The rated load will not exceed 87 % of the excavator's hydraulic capacity. This means the machine should be able to lift 115 % of the rated load.

c. The rated load will not exceed the machine's structural capability.