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Title ESTIMATING HIGHLEAD LOGGING PERFORMANCE THROUGH STATISTICAL MODELS

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The study of highlead logging operations through the use of statistical models is investigated, and their potential use for estimating and control of operations examined.

During the preliminary phases of the study 16 work elements and 26 influencing variables are identified and measurement criteria developed for each. A coding system is also developed to aid recording the variables previously identified in a manner understandable to an electronic computer. Based on the variables and elements to be measured and recorded, data sheets and field procedures are developed and tested. It was proven necessary to use a two man field team to insure that all of the data on each turn, or cycle, was recorded accurately.

The procedures necessary to convert the field data into computer input are explained and illustrated with a set of data sheets and summary sheet. The computing methods used in a stepwise

regression analysis are discussed in general and its effects on selected lists of variables for each element are shown and discussed.

Statistical models of each of the ten regular elements are computed from data taken on 590 turns, or cycles. The resulting models are then analyzed as to their effect on total cycle time and their relation to the form expected by logging estimators and supervisors. The majority of the deviations from expected form are explained but several remain unresolved, and pose a problem for future study.

The frequency, mean duration, and proportion of total time consumed by the six irregular elements are computed and their relation to usual job efficiency experienced on similar operations is examined and found to be of the same order.

Ten statistical models for the regular elements are recombined into gross element models to provide more convenient data for field use. The gross element and total cycle models were recomputed from the original field data using the variables from the appropriate element models. The resulting gross element models are then tabularized and sample sheets included to illustrate the general procedure for determining cycle times from the tabular data and correction factors.

The reliability of the existing models is discussed and it is shown that it is impossible to develop statistical measures of spread or deviation from the computed regression line from the existing data. The measures of the probability of observing and computing a model on only a chance variation are very small, all are less than 2.5 percent. Because of this the conclusion is drawn that causal relationships do exist in highlead logging.

To calibrate the existing models an independent data sample is needed. The multivariate calibration procedures necessary are identified and a proposed computing method to reduce the size of the confidence belt is discussed.

The study pointed out several areas for future study. They are:

1. The present element and gross element models should have confidence limits placed on them.
2. Several of the models indicate higher than expected standard error. These should be studied for possible improvements.
3. The range of the variables should be enlarged as soon as possible to reflect conditions in other logging areas.
4. A cause analysis study be instituted to study machine breakdown history and causes.
5. Development of a training manual for future investigators to reduce the instruction time and enable them to better answer questions from the men in the field.
6. A comparison study of the results predicted by the models with the estimates and historical records of logging.

performance.

7. Locate or develop the necessary computer programs to allow full computer estimation of highlead performance using the models, topographic maps and timber cruise data.

ESTIMATING HIGHLEAD LOGGING PERFORMANCE THROUGH STATISTICAL MODELS

by

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
HIGHLEAD LOGGING SYSTEMS	5
PRELIMINARY WORK	7
Regular Elements	8
Regular and Irregular Elements	9
Irregular Elements	11
VARIABLES	12
CODING OF VARIABLES	14
Altitude	14
Brush Condition	14
Butt Rigging Clearance	15
Deck Height	15
Ground Condition	15
Haul Distance	16
Landing Condition	17
Slope, Yarding	17
Slope, Cross	18
Volume	18
Weather	18
FIELD PROCEDURES AND DATA SHEETS	21
FIELD DATA	24
DATA PROCESSING	26
Summary Sheets	26
Stepwise Regression Analysis	27
Variables Used in the Element Stepwise Regression Analysis	33

	Page
STATISTICAL MODELS	38
Regular Element Models	38
Analysis of Regular Element Models	40
Irregular Element Models	44
GROSS ELEMENTS FOR ESTIMATING HIGHLEAD PERFORMANCE	46
Step I. Estimate Yarding Time	49
Step II. Estimate Woods Crew Time	50
Step III. Estimate Landing Crew Time	50
Step IV. Total Cycle Time	50
RELIABILITY OF MODELS	53
Chance of Accidental Relationship	53
Standard Error	54
CALIBRATION OF THE MODELS	56
Development of the Standard Deviation Equations	57
CONCLUSIONS	63
RECOMMENDATIONS	66
BIBLIOGRAPHY	69
APPENDIX A	71
APPENDIX B	73

LIST OF TABLES

Table		Page
1	Slope Values for Mathematical Models	39
2	Independent Variables	41
3	Expected and Calculated Interrelationships	42
4	Irregular Element Models	45
5	Yarding Time	51
6	Woods Crew Time	52
7	Landing Crew Time	52
8	Statistical Estimates of Mathematical Models	65

ESTIMATING HIGHLEAD LOGGING PERFORMANCE THROUGH STATISTICAL MODELS

INTRODUCTION

Highlead logging as practiced in the Pacific Northwest forests consists of wrapping a steel cable, called a choker, around a log; then pulling the other end of the choker with a heavier steel cable called the mainline. Given enough pull and a little luck the log will slide up to the unhook area called the landing. The log is then unhooked and the mainline, with choker, is returned to the woods by a haulback line attached to the mainline near the place where the choker is hooked. This process, repeated over and over, with its almost infinite array of terrain, forest and equipment variations, is highlead logging.

In the late 1800's the motive power was steam. Later the loggers turned to internal combustion engines, and currently engines approaching 500 horsepower are used. Initially the loggers used standing trees to support the mainline off the ground (hence the name for this method of logging). Later, as steeper and steeper slopes had to be logged, raised trees were introduced so that the logger could use the best site, whether or not nature put a tree there for him. We now see the development and extensive use of portable steel towers in place of trees. The newest innovation in logging is the use of balloons to help raise the front end, or in some cases the entire log off the ground, with consequent reduction in power and increase in speed. The introduction of balloons also makes feasible the logging of still steeper country over longer distances (4).

Over the years the machinery has become more productive, but at the same time more expensive. Recent estimates* indicate that a portable tower and yarder combination will cost $80,000 to $100,000, and a balloon operation will cost close to a quarter million dollars to put into the woods! During the same period wages have also gone up. These increasing costs are placing a greater emphasis on accurate estimates of production and costs.

Presently the majority of highlead estimating work is done on the basis of historical records adjusted as required to reflect the differences between conditions encountered where the data was taken and proposed sites. These estimates, by their very nature, are averages over a logging site. As soon as the models are working successfully estimators and supervisors are able to get estimates by feeding the data from cruises and topographic maps into a computer. The results are particularly valuable as a basis for control of day to day production.

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*Conversation with John O'Leary, Professor Forest Engineering, Oregon State University.

Many who are engaged in logging feel that the industry could profit from a better method of estimating production and cost. The mathematical model or formula method is used here, for it seems to best meet the expected requirements. During conversations with loggers both on the Oregon State University campus and in the woods, loggers expressed the opinion that there were too many interrelated variables effecting the time to complete a given job to be successfully analyzed. This study has identified 26 variables and 16 work elements. One of the strongest advantages of the mathematical model approach is its ability to handle many variables with complex interactions. If the loggers' expectations regarding complexity proves correct, mathematical models may well be the only feasible method to analyze elements of the logging cycle. In the past the use of mathematical models has been restricted to the less complex operations because it was practically impossible to develop and manipulate the models by manual methods due to the time and expense involved. With the advent of the electronic computer this barrier has been reduced.

The basic steps of this study are as follows:

1. Division of the logging cycle into managable work elements.
2. Identification of the measurable woods variables.
3. Collection of data on actual logging operations.
4. Development of mathematical models for each of the work elements through use of a stepwise least squares regression analysis.

5. Combination of the element models to simplify the required work for an estimator.

6. Calibration (placing confidence limits) of the models through use of an independent sample.

Mathematical models are developed for the ten regular work elements and are accompanied by frequency and duration data for the six irregular elements. Because the typical estimator doesn't have time to work out the results of ten separate equations, they have been recombined into three gross element models and the results tabularized. Using the gross element tables an estimator can determine the cycle time by adding three numbers taken from the tables and then using the six additive correction factors. The results should be interpreted as the typical cycle time under a given set of conditions, rather than the exact time each turn should take.

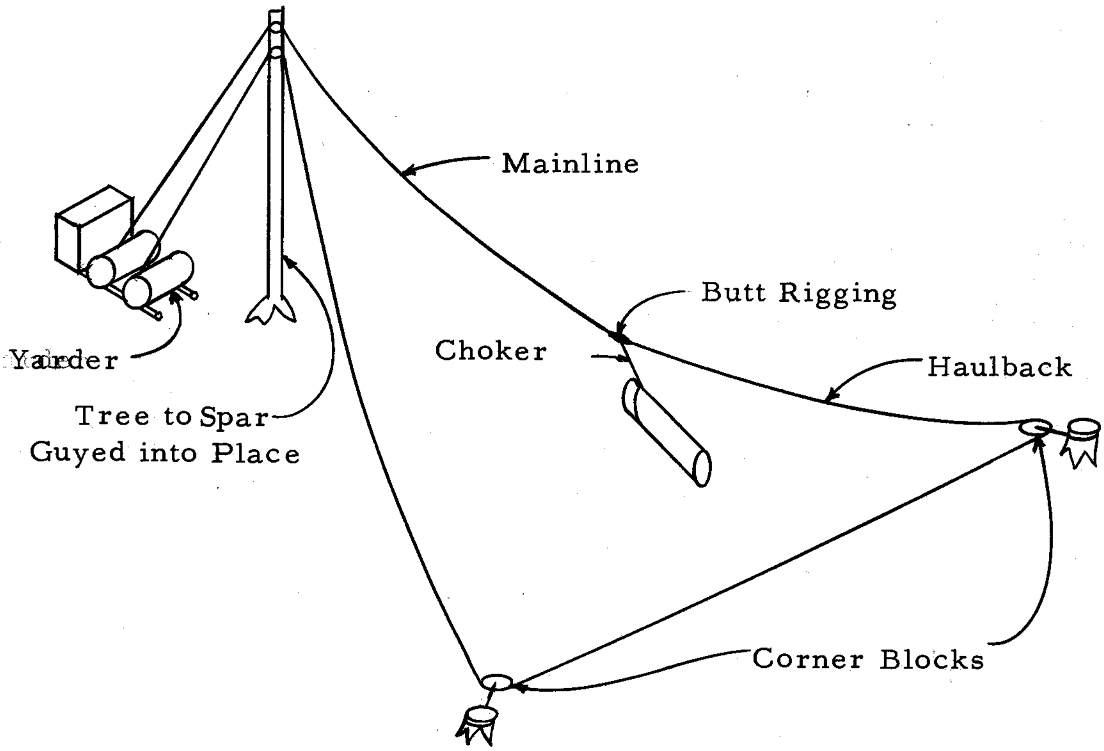
Because of the enormity of the problem if all of the possible variations in terrain, climate, forest, etc. were considered, this investigation has been restricted to a very localized portion of the Oregon rain forest. As a result, this must be considered a preliminary work to evaluate the feasibility of the method, rather than a completed work that may be applied to any logging situation. Throughout the study the methods and procedures used to obtain these results are documented in the hope that it will aid future researchers.

HIGHLEAD LOGGING SYSTEMS

Highlead logging as practiced in the Pacific Northwest is basically a very simple system. Its predecessor was first introduced about the time railroads were starting to be used to haul logs out of the woods. Because of the relatively high expense of relocating track, a machine was needed to move logs to the track for loading. The predecessor to the highlead was ground skidding. The motive power, yarding donkey or donkey engine, was a steam-powered double drum winch. One drum held the larger-diameter mainline and the other held the haulback line. The haulback line ran from the yarder out to the far end of the logging area and then back toward the yarder until it met the mainline. The two were fastened together by a specialized swivel arrangement known as the butt rigging. The chokers were also fastened to the butt rigging on swivels.

In operation using either system the yarding engineer releases the brake on the mainline drum and applies power to the haulback drum. This moves the chokers out into the woods. Through use of a signaling system the engineer is told when to stop the haulback and set both brakes. The men then move into the butt rigging, untangle chokers if necessary, and wrap them around the logs. After the men have cleared the area and the engineer is given the signal, he releases both brakes and applies power to the mainline drum. The logs are winched up to the landing, unhooked, and the cycle is started again. In some cases the engineer will ride the brake on the free spooling drum to tighten the line and attempt to hold it up.

Highlead logging is the same as ground skid except that both lines, as they leave the yarding donkey, pass over large pulleys placed on trees or spars. Typically, today these are from 80 to 130 feet in the air. This higher positioning allows the engineer to exercise more control of the log by tightlining and raising the front up to clear obstacles. The plowing of the log is also reduced so that the same power can move a given load faster. The sketch below illustrates details of the arrangement.



PRELIMINARY WORK

Before field work could be started a considerable amount of work was required to make sure the field time would be productive. Conversations were held with loggers and members of the School of Forestry faculty regarding the components of the highlead cycle and factors that might influence work times. Using these talks as a basis, the cycle was broken down into 16 work elements of two classes, regular and irregular. Regular elements are defined as those which occur during every, or almost every, cycle; the elements that occur less frequently (hang up, road changing, etc.) are called irregular. Both regular and irregular elements are measured by the length of time required for the appropriate members of the crew to complete the task.

The factors affecting the element times were also identified and a means of measurement or estimation was developed for each. These factors are called variables. A total of 26 measurable ones were identified.

Once the elements and variables were known, the proposed field procedure was developed and data sheets were designed and tested.

Each of the above topics are discussed in detail on the following pages.

Regular Elements

The complete logging cycle is composed of a number of elements. Each element is a carefully defined portion of the total cycle. We have used standard Industrial Engineering practice for breaking the cycle into its components. Barnes (2, p. 360) states the following rules:

1. The elements should be as short in duration as can be accurately timed.
2. Handling time should be separated from machine time.
3. Constant elements should be separated from variable elements.

These rules have been followed and one additional one added.

4. Whenever one portion of a cycle seemed to be controlled by a different set of variables than its neighbor, each portion was considered to be a separate element.

The fourth rule was added to the list to enable a proper cause analysis to be made. It is quite likely that the brush condition, butt rigging clearance, number of men setting chokers, etc., effect the elements men to hook, set chokers, and men to safety; but there is no reason to expect the effect to be the same. The elements were separated so the individual effects could be measured.

See the following page for a complete list of all elements and their descriptions.

Regular and Irregular Elements

H_1 . Outhaul. Starts the instant the rigging moves to clear the landing and ends the instant the rigging stops in the woods.

H_2 . Final Positioning.* Starts the instant the rigging stops and ends the instant the rigging stops moving after the repositioning.

H_3 . Men to Hook. Starts the instant the rigging stops and ends when half the crew have grasped the rigging.

H_4 . Untangle Chokers. Starts when one half the men grasp the rigging and ends the instant they turn to set the chokers on the log or pull the hook sideways.

H_5 . Pull Hook Sideways.* Starts the instant the men turn to the logs and ends when they start to set chokers.

H_6 . Set Chokers. Starts the instant the men turn to the logs and ends the instant the last choker is set.

H_7 . Men to Safety. Starts the instant the last choker is set and ends the instant the main line starts to tension.

H_8 . Yard In. Starts the instant the main line tensions and ends when the logs are on the ground at the landing, or position logs start.

H_9 . Hang Up.* This is an element within the yard in and starts

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*These elements are classified as irregular elements because they do not occur on every cycle.

the instant the mainline stops moving and ends when the logs are again moving toward the landing. Hang ups can be either man or machine-cleared.

H_{10}. Position Logs. Starts the instant the logs are on the ground or stationary in the unhook area and ends the instant they are positioned, shaken, etc., to locate the choker bell where the chaser can reach it.

H_{11}. Chaser In. Starts the instant the logs are on the ground and ends the instant the chaser touches the first choker bell.

H_{12}. Unhook. Starts the instant the chaser touches the first bell and ends the instant the last choker is released.

H_{13}. Chaser Away. Starts the instant the last choker is released and ends the instant the rigging starts to pull the chokers clear of the logs.

H_{14}. Road Changes.* Starts the instant the straw line is grasped by the chaser and ends when the mainline starts on the next outhaul.

H_{15}. Work on Rigging.* Starts the instant the appropriate men turn from their regular task to correct a defect in the rigging or chokers and ends when they return to their normal task or the next element starts. Includes opening knots in chokers, etc.

H_{16}. Waits and Delays.* Starts whenever the next normal portion of the logging cycle does not start when it should. The cause of the delay should be determined if possible, and recorded.

Irregular Elements

In any operation delays occur, machines break down, trucks are not available, somebody is not in the right place at the right time, logs hang up, etc. From conversations with loggers during the meetings held on the Oregon State University campus during the winter of 1964, it became evident that they felt this was one of the major trouble spots in the industry.

Highlead irregular elements were divided into seven distinct types:

1. Final positioning.
2. Pull hook sideways.
3. Work on rigging (includes opening knots, changing chokers, etc.)
4. Hang up - machine-cleared.
5. Hang up - man-cleared.
6. Road changes
7. Waits and delays (all others)

All of the above can be expected to have some form of probability distribution with the exception of road changing.

The frequency of road changes can be calculated, knowing the logging rate and the road width, length, and volume per acre. Data relating to the time it takes to change roads under different conditions and the controlling variables is still sketchy, and the various methods of road changing are not yet defined.

VARIABLES

In any logging situation there exist a tremendous number of variables. The 26 directly measurable variables influencing highlead production are listed below and are of two distinct types:

I. Forest Characteristics and Terrain (uncontrollable)

1. Log Density
2. Brush condition
3. Ground condition
4. Temperature
5. Moisture
6. Slope
7. Specie
8. Altitude

II. Machines and Procedures (Controllable)

1. Yarder
   a. Horsepower
   b. Spar height
   c. Automatic shift
   d. Mainline diameter
2. Brush crew and equipment
   a. Number of choker setters
   b. Number of chokers
   c. Weight of choker
3. Landing Conditions
   a. Number of chasers
   b. Deck height
   c. Ground condition
   d. Landing size
   e. Landing slope
   f. Slash
4. Other
   a. Haul distance
   b. Logs per turn
   c. Volume per turn
   d. Clear cut or selective cut
   e. Butt rigging clearance

---

*In addition to the directly measurable variables listed above there are a few we have chosen not to consider. Our reasoning here is that although they unquestionably affect the cost of a unit of production, they have no affect on the time required to perform the woods operations. In particular the following are not considered: (1) Quality of the timber; (2) Differences between gross and net scale; and (3) Costs of moving and rigging.

In addition to the directly measurable variables, there is a complete second set of variables that are at present largely undefined. These fall into the general class of planning and supervision skills of management, engineers, hook tenders, and rigging slingers. Because of their characteristics they are very difficult to measure directly, but probably will be measured over a span of years when a suitable basis for comparison is developed.

It seems likely that one of the major long range uses of mathematical models of logging will be to provide the basis for evaluating crew performance relative to normal performance, considering the existing conditions. In this manner we will be able to evaluate the effectiveness of alternative supervision methods.

No attempt has been made to evaluate the crew level, engineering or management skills at this time. It is assumed that they will average zero, given data on enough crews.

CODING OF VARIABLES

Computers are made to deal with numerical quantities rather than general impressions of conditions; therefore, considerable effort was devoted to quantifying variables. In some cases the quantification tended to introduce artificial divisions into a continuous range of conditions. In other variables some natural form of measure was available and was used. To expedite the recording of data the variables were recorded directly in the numerical form. The following coding system was used.

Altitude

Use the altitude above mean sea level to the nearest foot. Then drop the last two digits and record the remaining digits directly.

Brush Condition

Code	Description
0	Light to none. Does not interfere with travel.
1	Light to medium. Thick enough to cause minor detours in walking.
2	Medium to heavy. Continual detours are necessary to reach objective. Occasionally necessary to force through.
3	Heavy. Usually necessary to force a way through. Slow travel.

4	Very heavy. Difficult to move; must climb over or push through brush always. A hard fight for any progress.

Note: For snow deep enough to cause difficulty (usually more than six inches) add 5 to the brush class or code.

Example: Code 3 brush with 9 inches of snow. Code 8 (3 plus 5).

Butt Rigging Clearance

The height in feet at which the butt rigging is suspended above the logging site is estimated from the length of the chokers or a typical man's height. This value is recorded directly.

Deck Height

The height in feet the chaser has to climb to reach the highest log to be chased. This height is recorded directly in feet.

Ground Condition

Moisture

Code	Description
0	Frozen
1	Over wet, soupy, or sloppy
2	Wet and sticky
3	Moist. Packs well when compressed. Also ruts easily.

4	Dry and dusty.

Type of Soil

Code	Description
0	Sand
1	Sandy gravel
2	Gravel
3	Sandy loam or gravelly loam
4	Loam
5	Loamy clay
6	Clay
7	Rock
8	Humus and decomposed vegetation

Example: If the ground were wet clay the code is 2 6. The moisture is written first and the soil type second.

Haul Distance

The haul distance measured on the slope is recorded in stations or hundreds of feet. If possible this should be measured; if not, it can be estimated by counting the number of log lengths as a turn is yarded in. Seventy feet or greater is considered one hundred, i. e. 480 feet would be recorded as 5 stations.

Landing Condition

Landing condition is recorded as a four digit code, the first two of which are the distance in tens of feet from the tree or spar to the edge along the yarding road. The third digit is the slope value from the table below. The fourth digit is the slash index using the same classification method as for brush condition.

Slope	Up	Down
0-10 percent	0	0
11-20 percent	1	6
21-40 percent	2	7
40-60 percent	3	8
60-100 percent	4	9
over 100 percent	5	5

Slope, Yarding

Code	Description
0	Level or gently rolling.
1	Adverse to 10 percent
2	Adverse 10 to 20 percent
3	Adverse 20 to 30 percent
4	Adverse 30 to 50 percent
5	Adverse 50 to 70 percent
6	Adverse 70 to 100 percent
7	Favorable to 10 percent

8	Favorable 10 to 20 percent
9	Favorable more than 20 percent

Slope, Cross

Estimated at the logging site at right angles to the yarding road. Use the "up" section of the Landing Condition slope table.

Volume

Each log is to be measured on the small end twice, the diameters averaged, and rounded to the next lower inch. The length is to be measured and recorded to the next smaller foot. Later the volumes for a given turn are developed using a table of volumes calculated on a one-inch-in-eight-feet taper. (This should be adjusted for forest conditions encountered.)

Weather

Rain

Code	Description
0	None
1	Light drizzle or fog.
2	Light rain
3	Moderate rain
4	Heavy rain

5	Storming

Temperature

Code	Description
0	Below 0°
1	0° to 20°.
2	20° to 40°
3	40° to 60°
4	60° to 80°
5	Above 80°

It should be noted on the data sheets that haul distance, slope, and ground condition are recorded in the same column. This is recorded as a five digit code composed as follows:

First digit - haul distance

Second digit- slope

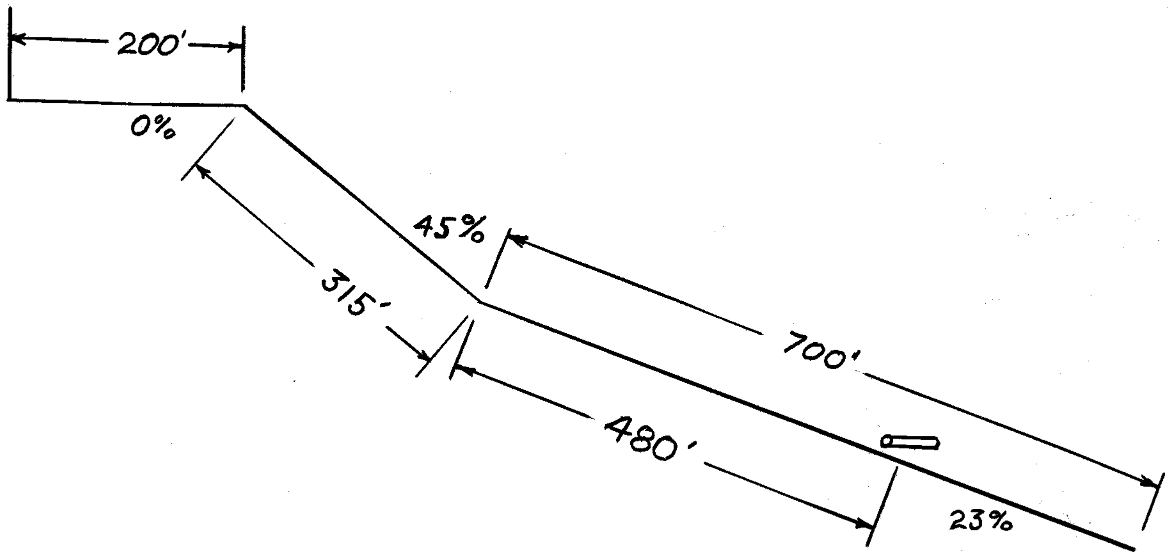
Third digit - ground moisture

Fourth digit - ground type

Fifth digit - cross slope

The usual logging site haul road is not one long continuous slope, but rather a series of slopes. The procedure for recording this is to write the code for the current section of a road in the turn line and then all of the other sections in order form the landing to the current section at the bottom on the page.

Example:



Haul Profile (35 ground code, zero cross slope)

Recorded in the turn line; 52350

Recorded at the bottom of the page: 20350
34350

Note: The total length of the slope the log is lying on is not recorded.

FIELD PROCEDURES AND DATA SHEETS

When the elements and variables had been identified a problem arose. Detailed data both in the woods and at the landing was required. Trial studies showed that the landing elements could be as short as .03 minutes (approaching the limit of a good time study man). Typical times in the woods are considerably longer but due to the brush and possible terrain features a man at the landing could not expect to be able to observe the woods operations. Several preliminary data sheets were designed for use by one observer, but this proved unfeasible if data on all the elements and variables previously identified was to be recorded. When one observer was used on an ideal operation he could handle the timing and log count, but log volume, slope and distance measurements could not be taken at the same time. Under less than ideal conditions complete time data could not be taken both in the woods and at the landing.

After these experiences the field procedure was revised to call for a two-man crew: one to stay at the landing and the other to stay near the woods crew at all times. The work was divided between the two men and the data sheets designed so both men could record the beginning of two different elements. This feature permitted the locking of the two data sheets together in spite of possible variations in the watches. The method was field tested and proved workable.

All timing was taken by the continuous timing method using 12-hour decimal-minute watches. Continuous timing consists of starting the watch at the beginning of the observing period and letting it run continuously. At the start of each element the analyst glances at the watch and records the time. The advantage of this method over other common methods is its inability to "lose" time. The watch runs continuously and therefore forces the analyst to account for all of the time during the day. Prior to starting the study the watches were adjusted to run within .03 minutes of each other over a 12-hour period. When the analysts arrived at the job site the watches were synchronized and the wrist watch readings noted also. The watches were again checked against each other at noon if possible, and then at the end of the day. Any discrepancies were noted and taken into account later.

Timing at the landing was done to the nearest .01 minute if possible; however, due to the longer elements in the woods, timing was usually to the nearest .05 minutes. As seen from the data sheets, (p. 28, 29) the woods man was responsible for all of the woods elements and the butt rigging clearance, haul distance-slope-ground condition, crew size, and weather information. The log density, altitude and species were taken from the foresters records at a later date. The landing man was responsible for the landing elements and equipment, landing, and log volume variables. Quite often it proved difficult, if not impossible, to measure the size of each log. When this occurred the sizes were estimated with reference to logs of known size in the log deck. When, for some reason, an observation was missed an "M" was substituted for the missing data. If an irregular element occurred each man was to record it in the "other" column and describe the cause.

FIELD DATA

In order to provide as universal a picture as possible, data was taken on all of the operating highlead crews in the area rather than concentrating on only one. This procedure has both advantages and disadvantages. The biggest disadvantage is the inclusion of more variability in the models. The advantages and, and the reason this method was chosen, are that data could be gathered over the widest range of conditions in the shortest possible time, and it was possible to produce figures that more nearly represent what the typical crew should do on the job. If data were taken on one crew only, one would have a very good picture of how that crew performs but no idea of their relationship to the typical crew.

To avoid introducing any more bias than necessary, the original study design called for taking an equal number of turns on each of the operating crews. After the study had been under way for some time, a crew that had not been operating because their machine was being overhauled returned to work. This crew was followed intensively during the final stages of the study. All of the other crews were studied on an essentially random basis. At the beginning of each day the crew was told who was operating and chose the side to study that day. The decision was made on the basis of which side had the fewest number of recorded turns. The only exception to this rule was in the case of a major breakdown of equipment during the day. Under this circumstance the analysts were given instructions to go to the nearest operating unit and complete the day there. This instruction also introduced a bias into the wait and delay irregular element for none of the longer machine repair times were recorded.

The actual number of turns recorded on each crew are:

Crew	Turns
A	105
B	120
C	115
D	114
E	79*
F	57**
Total	590

*This machine was down for maintainance at the start of the study and returned to work near the end of it.

**This crew was working in another area and visited for one day only.

DATA PROCESSING

Reducing the field data to usable results is an operation of many steps. First, the continuous timing on the data sheets must be converted into element times, the results of both sheets combined onto one summary sheet, and keypunched. When the information was on cards it was run through the OSU Statistics Department 1410 computer on a stepwise regression analysis program. The preliminary element models were formed at this time and analyzed for variables that could be eliminated. This completed, the data was rerun with the remaining variables and the final element models produced. During the computer run standard error and F test were calculated.

Summary Sheets

Because the data for a given turn was taken on two different sheets and all of the times were continuous, it was necessary to combine the information and subtract the times to produce element times for later use. In datail the steps required were:

1. Subtracting the continuous time in each box from its successor to produce the element time for the first element.
2. Whenever the times go from the woods sheet to the landing sheet or back, carefully checking for discrepancies and adjusting these times if necessary.

3. Using a table of log volumes, converting the individual log size into cubic feet. For the purposes of this study it was assumed that all logs had a taper of one inch in eight feet.
4. Transfering the results of the above steps onto summary sheets along with all other data on the field data sheets.

At this point the summary sheets were rechecked to see that all blanks were filled in, and then the data was key-punched. Examples of these sheets occur on the following pages.

Stepwise Regression Analysis

Because of the number of turns (590), the author decided to use computer analysis and run a standard stepwise regression analysis for each of the ten basic elements of the highlead cycle. Due to the missing data, first the data was run using only those turns that contained no missing data in the relevant variables.(227 to 496 turns used depending on the element). The results of this first pass were then used as a guide for determining which variables to retain for the second pass through the computer. Because the number of relevant variables were reduced after the first pass, fewer turns had to be thrown out for missing data (227 to 537 turns used depending on the element), and it was possible to reduce the error in the models developed.

The stepwise regression program is one that takes into account

High Lead Woods

Observer: B
Date:
Hooktender:
Company: XYZ
Location: SYZ

2 of 7

Turn No.	Outhaul	Final position	Men to hook	Untangle chokers	Pull hook sideways	Set chokers	Men to safety	Yard in	Deflection	Brush condition	Haul distance Slope Ground condition	Other	Remarks
1	15.00		15.30	15.45		15.70	16.60	16.75	5	2	15340		
2	17.50		17.80	17.90		18.10	19.20	19.50	3	2	15340		
3.	20.40		20.75	21.10		21.30	23.75	24.10	2	2	15340		
4	25.15		25.35	25.60		25.85	26.90	27.05	3	2	15340		
5	28.05		28.30	28.55		28.80	32.00	32.30	2	2	25340		
6	34.45		34.80	35.00		35.60	41.40 39.35	42.65 41.70 39.65	5	2	25340		HANG-UP MAN CHANGE CHOKER
7	44.10		44.50	44.85		45.35	46.65	47.25	5	2	25340		
8	48.50		48.90	49.25		49.35	51.55	51.80	3	2	35340		
9	53.70		54.20	54.35		55.30	57.10	57.55	7	2	18342		
10	60.00	.	0.60	0.80		1.25	3.20	3.50	10	2	18342		

Circle

Weather Rain (0), 1, 2, 3, 4, 5

Temperature 0, 1, 2, 3, (4), 5

No. men setting chokers 0, 1, 2, (3), 4, 5

Haul distance, slope, ground condition (Starting with the segment closer to the landing to the segment shown in the data on each turn.) 35340 (ALL)

Log density

Altitude

%	Species

High Lead Landing

Observer: A
Date:
Hooktender:
Company: XYZ
Location: 5YZ

2 of 7

Turn No.	Yard in	Chaser in	Unhook	Chaser away	Position logs	Outhaul	Other	No. logs	Avg. diameter (in.) Avg. length (ft.) on each log	No. chasers	Deck condition	Ground condition	Remarks
1	16.74	17.32	17.38	17.46	17.09	17.50		4	40×11 30×8 34×10 28×8	2	0		
2	19.48	20.15	20.19	20.37	19.88	20.43		4	40×9 32×8 36×13 40×11	1	0		
3	24.08	24.85	M	25.09	24.65	25.15		4	34×16 40×11 12×10 32×11	1	0		
4	27.05	27.69	27.80	27.93	27.53	28.04		3	40×14 32×11 16×9	1	2		
5	32.27	34.08 33.14	34.16 33.24	34.27 33.78	33.82 32.86	34.34		5	40×16 30×8 38×16 16×6 40×12	1	2		
6	42.58 39.62	43.95 43.27	44.02 43.36	44.04	43.65 43.03	44.10	39.88	3	40×10 40×14 16×14	2	0		HANG-UP (LOST LOG)
7	47.20	48.12	48.19	48.32	47.97	48.40		3	40×18 32×9 28×9	2	0		
8	51.78	53.18	53.25	53.58	52.95	53.62		3	36×23 40×14 24×10	1	0		
9	57.35	59.62	59.69	59.88	59.17	59.97		3	32×16 32×14 36×32	1	0		
10	3.43	4.63	4.70	4.89	4.42	4.93		1	34×22	1	0		

Yarder Make L HP 285 Spar: ✓ Tree ___ Portable ✓
Model 3 Power shift YES Height Mainline Block 90'
Rigging Mainline, Diameter and Length 1.3" x 1200'
Haulback, Diameter and Length .8" x 3000'
Chokers, Diameter and Length 1.1" x 25'
No. Chokers 2
Landing Condition 0660

HIGHLEAD
ANALYSIS
SHEET

Date ______

Company XYZ

Location SYZ

2 of 7

	Turn	Outhaul	Final Positioning	Men To Hook	Untangle Chokers	Pull Hook Sideways	Deflection	Set Chokers	Brush Condition	Men to Safety	Yard In	Haul Dist-Slope-Grd	Chaser In	Unhook	Chaser Away	Position Logs	Deck Condition	No Logs	Volume	Work On Rigging	Waits & Delays	Hang Up-Machine	Hang Up-Men	Remarks
1.	11	.30		.10	.20		3	1.10	2	.30	.40	15340	.04	.18	.06	.27	0	4	133					
2.	12	.32		.35	.20		2	2.45	2	.35	.57	15340	M	M	.06	.20	0	4	144					
3.	13	.35		.25	.25		3	1.05	2	.15	.48	15340	.11	.13	.11	.16	2	3	107					
4.	14	.25		.25	.25		2	3.20	2	.30	.56	25340	.18	.65	.11	.54	2	5	204					
5.	15	.45		.20	.60		5	3.75	2	.30	.68	25340	.13	.31	.06	.54	0	3	113	1.85			.85	CHANGE CHOKER
6.	16	.40		.35	.50		5	.30	2	.60	.77	25340	.07	.13	.08	.15	0	3	131					
7.	17	.50		.35	.10		3	2.20	2	.25	1.17	35340	.07	.33	.04	.23	0	3	201					
8.	18	.58		.15	.95		7	1.80	2	.25	.77	18342	.07	.19	.09	.45	0	3	315					
9.	19	.63		.20	.45		10	1.95	2	.23	.99	18342	.07	.14	.09	.21	0	1	108					
10.	20	.72		.35	.70		4	2.10	2	.35	1.33	28342	.09	.43	—	.41	0	2	55	.39		.20		PUT ON NEW CHOKER

Hooker ______

Machine No. ______

Bull Block Height 90'

Main Line Dia. 1.3"

Wt. Choker 52 LBS.

Temperature 4

HP 285

PS YES

No Chokers 2

No Chr Setters 3

Moisture 0

Lndg Grd Cond 0660

No. Chasers 1

Pcs/Acre 222 Vol/A 108

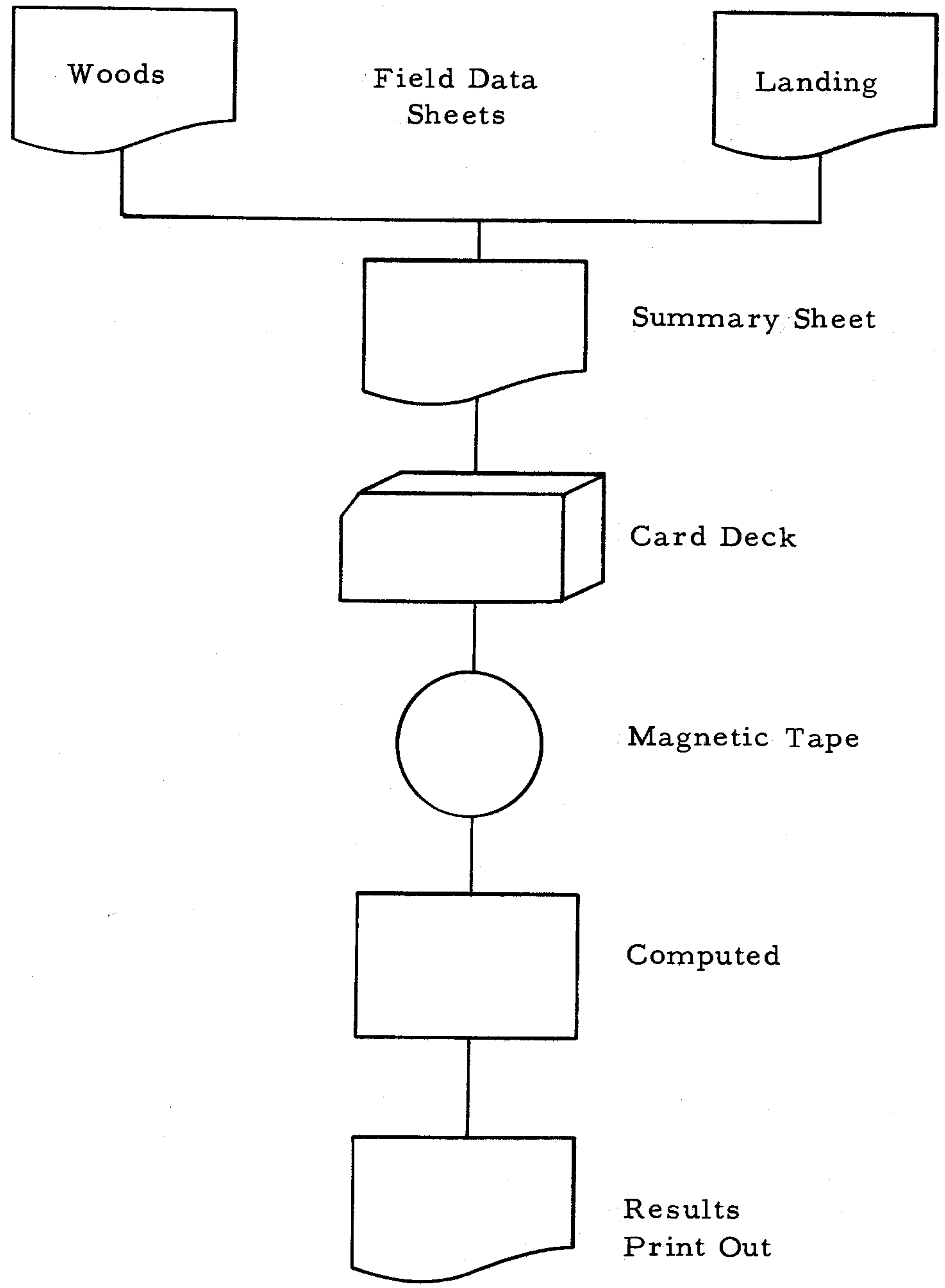
Altitude 11

Species

%	Type
98.2	HEM.
1.5	SPRUCE
.3	D.F.

*Haul Dist-Slope-Grd

35340 (ALL)



Information Flow - Data Processing

all of the variables under consideration in relation to the element time and then chooses the variable that is the best for predicting element time. This process is repeated using the previous variable as a base, until all of the variables are included, or a predetermined level of accuracy is obtained. As this was the first run of this kind of material, all variables were included that were thought to influence the particular element time. Also included were those variables which could not be proven not to affect the element time. The computer was set to run until it had processed all of the variables.

The decision concerning which variables to retain for the second pass was based on the particular variable's effect on error of prediction. The decision rule used was as follows:

1. Each new variable introduced must reduce the error of prediction by at least two percent to be included.
2. If the error of prediction reached a minimum, the variables to yield the minimum were used, provided rule one was satisfied.

The decision rule for the second pass was the same as before except the value of one percent was used.

Variables Used in the Element Stepwise Regression Analysis

It is basically uneconomical, when using a computer for regression analysis, to have the computer consider all of the variables recorded as well as all of their combinations. To keep the cost to realistic figures, judgment was used to reduce the total number of variables considered when determining the model for an individual element. These decisions were based on the following considerations:

1. Experience and opinions of loggers
2. Engineering mechanics
3. Logical considerations
4. Prior work in this field (1; 3; 13)

These can all be illustrated by considereing the yard in element. Many loggers have stated that the taller the tree or spar in relation to the yarding distance, the easier a log will yard. Two measures of height were available, but as one (spar height) had only minor variations (90 to 110 feet) it was not used, and the butt rigging clearance was used as a measure of the available lift.

The laws of physics indicate that the work required to pull a log into the landing is a function of the sliding resistance and the grade resistance. Using the variables we have available the work required to overcome the sliding resistance is:

Work (sliding) = volume x distance x constant

Distance times slope gives the vertical rise of the log. Volume is used again as an estimator of weight.

It is logical that the number of men in the brush crew and deck height, etc., would have no effect on the yard in time; hence, these are examples of variables that were not included on logical grounds. However, if there was doubt about any variable it was included on the initial run.

For the initial run the appropriate variables or combinations of variables were selected for each element. Anywhere from four to nine variables for each element were used initially. The final models contained from two to five variables; the typical element model had three variables.

The following is a tabulation of the variables used in each step of determining the element models:

First Run	Second Run	Final Model
H_1. Outhaul		
Yarding distance	Yarding distance	Yarding distance
Butt rigging clearance	Butt rigging clearance	Butt rigging clearance
Number of chokers		
Horsepower	Horsepower	Horsepower
H_3. Men to hook		
Butt rigging clearance	Butt rigging clearance	Butt rigging clearance
Brush condition		
Pieces per acre	pieces per acre	pieces per acre
Slope at the log	slope at the logs	

First Run	Second Run	Final Model
H_4. Untangle Chokers		
Butt rigging clearance	Not rerun	Butt rigging clearance
Brush condition		Pieces per acre
Pieces per acre		Number of choker setters
Slope of the log		
Number of chokers		
Number of choker setters		
H_6. Set Chokers		
Yarding distance	Yarding distance	Number of chokers
(Yarding distance)^2	(Yarding distance)^2	Volume per choker
Brush condition	Number of chokers	
Slope at the log	Volume per choker	
Number of chokers		
Number of choker setters		
Weight of choker		
Volume		
Volume per choker		
H_7. Men to Safety		
Yarding distance	Yarding distance	Yarding distance
(Yarding distance)^2	(Yarding distance)^2	(Yarding distance)^2
Brush condition	Slope at the log	Slope at the log
Slope at the log		
Number of chokers		
Number of choker setters		
Weight of choker		
Volume		
Volume per choker		
H_8. Yard In		
Yarding distance	Yarding distance	Yarding distance
(Yarding distance)^2	(Yarding distance)^2	(Yarding distance)^2

First Run	Second Run	Final Model
H_8. Yard In (Cont.)		
Yarding distance times volume	Yarding distance times volume	Yarding distance times volume
Yarding distance times slope times volume	Number of chokers	Number of chokers
Number of chokers	Butt rigging clearance	Butt rigging clearance
Number of logs	Altitude	Altitude
Butt rigging clearance		
Altitude		
H_{10}. Position Logs		
Deck height	Deck height	Deck height
Number of logs	Landing size	Landing size
Volume	Landing slope	Landing slope
Landing size	Landing size times slope	Landing size times slope
Landing slope		
Landing size times slope		
H_{11}. Chaser In		
Deck height	Deck height	Deck height
Landing size	Landing slope	Landing slope
Landing slope	Number of logs	Number of logs
Landing size times slope		
Landing slash		
Number of logs		
Number of chokers		
Volume		
H_{12}. Unhook		
Deck height	Landing size times slope	Landing size times slope
Landing size	Number of logs	Number of logs
Landing slope	Volume	Volume
Landing size times slope		
Landing slash		
Number of logs		

H_{12}. Unhook (Cont.)

Number of chokers
Volume
Weight of choker

H_{13}. Chaser Away

Deck height
Landing size
Landing slope
Landing size times slope
Landing Slash
Number of logs
Number of chokers
Volume

Deck height
Landing size
Landing slope
Number of logs

Deck height
Landing size
Landing slope
Number of logs

Note: 1. Because of insufficient data irregular elements H_9, H_{14}, H_{15}, H_{16} were not analyzed with the stepwise regression and are discussed separately.

2. Elements H_2 and H_5 did not occur in this study.

MATHEMATICAL MODELS

Using the results of the computer analysis, statistical estimates of the models were developed for each of the elements. The models of the regular elements are considerably more detailed than those of the irregular elements, due to the relative quantity of data on each rather than to any more basic differences.

Regular Element Models

The following models were developed for the regular elements and are shown with their standard error. These standard error values measure the fit of the model to the data and should not be used in the same manner as a normal standard deviation. For a more complete discussion of the standard error see page 54.

Element Models	Std Error
Outhaul	
$H_1 = 3.274 + 5.519D - .492d + .130\,p$	1.676
Men to Hook	
$H_3 = 5.165 + .281\,d + .145\,pcs/A$	.985
Untangle Chokers	
$H_4 = 60.267 + .383d + .128\,pcs/A - 18.153M$	.995
Set Chokers	
$H_6 = 42.432 + 86.027C + .314\,V/C$	14.518
Men to Safety	
$H_7 = 23.668 - .558D + 6.98D^2 + .981s$	1.073
Yard In	
$H_8 = 124.011 + 19.220D - .540D^2 + .042DV$ $-32.219C - .764d - .860A$	3.178

Element Models	Std Error
Position Logs	
$H_{10} = 58.320 + 647H - 2.229L - 6.266T + 985LT$	2.768
Chaser In	
$H_{11} = 13.336 + .382H - .995T + 1.615N$	.674
Unhook	
$H_{12} = 11.200 + .171LT + 6.39N$	.780
Chaser Away	
$H_{13} = 5.460 + .343H + .186L - 1.090T + 1.731N$	.623

Nomenclature

D	Yarding distance in stations (100 feet)
d	Butt rigging clearance at the logs (feet)
P	Horsepower of the yarder
pcs/A	Logs per acre
M	Number of men setting chokers
C	Number of chokers
V	Turn volume in cubic feet
S	Ground slope at the log (See Table 1 below)
A	Altitude in hundreds of feet
H	Height the chaser must climb to unhook the logs
T	Tilt of the landing (See Table 1 below)
N	Number of logs
L	Length of the landing in tens of feet

Table 1. Slope Values for Mathematical Models

Slope	Value
Level	0
Adverse to 10%	1
Adverse 10-20%	2
Adverse 20-30%	3
Adverse 30-50%	4
Adverse 50-70%	5
Adverse 70-100%	6
Favorable to 10%	-1
Favorable 10-20%	-2
Favorable 20 + %	-4

Analysis of Regular Element Models

At this point it might be interesting to compare the models produces by the computer with the variables thought to be important in the earlier stages of the study. The interrelationship table (Table 2) is reproduced from the progress report submitted to Western Management Science Institute in June 1964. At that time a somewhat smaller list of variables were considered, and several of the irregular elements were not included. This table was checked by several groups of loggers and members of the School of Forestry and thought to represent typical highlead operation.

Because of the limited field work to date, some of the variables have not been observed to change or, if they did change, only over a minor range. If any of the element rows has a line drawn through it, this indicates that it was not analyzed by the regression method. Final positioning , H_2, and pull hook sideways, H_5, did not occur during the field study. If a variable has a line drawn down its column, it indicates the variable is considered not to have changed in the present study. Circled letters show the variables used in the element models developed from the stepwise regression analysis.

The relationship between the predicted results and the computed models is interesting to study. In the following table the numerator of each fraction indicates the number of variables in that class

Table 2. Independent Variables

Dependent Variables	Highlead (a) H. P.	~~(b) Height~~	~~(c) Main Line Dia.~~	~~(d) Power shift~~	Chokers (e) No.	~~(f) Weight~~	Brush Work (g) No. Men	(h) Condition	~~(j) Temperature~~	~~(k) Moisture~~	(l) Butt Rigging Clearance	Skid Trail (m) Haul Dist.	(n) Slope	~~(o) Ground Cond.~~	Logs (p) No. /turn	(q) Vol/turn	(r) Density/acre	Landing ~~(s) Ground Cond.~~	(t) Decking	~~(u) No. Chasers~~
H_1 Outhaul Time	(S)	N	N	S	N	N	N	N	N	N	(N)	(M)	N	N	N	N	N	N	N	N
~~H_2 Final Positioning~~	~~N~~	~~N~~	~~N~~	~~S~~	~~N~~	~~N~~	~~N~~	~~S~~	~~N~~	~~N~~	~~S~~	~~S~~	~~S~~	~~N~~	~~N~~	~~N~~	~~N~~	~~N~~	~~N~~	~~N~~
H_3 Men to Hook	N	N	N	N	N	N	S	L	S	S	(N)	N	M	S	N	N	(N)	N	N	N
H_4 Untangle Choker	N	N	N	N	M	L	(M)	M	S	N	(S)	N	M	S	N	N	(N)	N	N	N
~~H_5 Pull Hook Sideways~~	~~N~~	~~S~~	~~M~~	~~N~~	~~M~~	~~M~~	~~L~~	~~M~~	~~S~~	~~S~~	~~M~~	~~N~~	~~M~~	~~M~~	~~N~~	~~N~~	~~N~~	~~N~~	~~N~~	~~N~~
H_6 Set Chokers	N	N	S	N	(L)	L	L	M	S	S	S	N	M	S	L	(M)	S	N	N	N
H_7 Men to Safety	N	N	N	N	N	N	S	M	S	S	N	(N)	(L)	M	N	N	N	N	N	N
H_8 Yard In	M	L	L	M	(N)	N	N	S	N	N	(S)	(L)	M	S	S	(L)	N	N	N	N
~~H_9 Hang Up~~	~~M~~	~~M~~	~~L~~	~~S~~	~~N~~	~~L~~	~~N~~	~~N~~	~~N~~	~~N~~	~~N~~	~~S~~	~~S~~	~~S~~	~~S~~	~~S~~	~~S~~	~~N~~	~~N~~	~~N~~
H_{10} Position Logs	N	S	N	S	N	N	N	N	N	N	N	N	S	N	M	S	N	N	(M)	N
H_{11} Chaser In	N	N	N	N	N	N	N	N	S	S	N	N	N	N	N	N	N	M	(M)	N
H_{12} Unhook	N	N	N	N	S	S	N	N	S	S	N	N	N	N	(L)	S	N	S	M	L
H_{13} Chaser Away	N	N	N	N	N	N	N	N	S	S	N	N	N	N	(N)	N	N	M	(M)	N

N Negligible Interrelationship
S Slight Interrelationship
M Moderate Interrelationship
L Large Interrelationship

Note: Elements H_{14}, Road Changes; H_{15}, Work on Rigging; H_{16}, Waits and Delays. were not included in the earlier work.

chosen by the multiple regression analysis. The denominator of the fraction indicates the total number of variables in that class for the element under consideration. The results are shown below on an element by element basis.

Table 3. Expected and Calculated Interrelationships

Element	Class of Relationship Large	Moderate	Slight	Negligible
H_1 Outhaul	0/0	1/1	1/1	1/9
H_3 Men to hook	0/1	0/1	0/1	2/8
H_4 Untangle chokers	0/0	1/4	1/1	1/6
H_6 Set chokers	1/3	1/3	0/2	0/3
H_7 Men to safety	1/1	0/1	0/1	1/8
H_8 Yard in	2/2	0/2	1/3	1/4
H_{10} Position logs	0/0	1/2	0/2	0/7
H_{11} Chaser in	0/0	1/1	0/0	0/10
H_{12} Unhook	1/1	0/1	0/2	0/7
H_{13} Chaser away	0/0	1/1	0/0	1/10
Total	5/8	6/17	3/13	7/72
	62%	35%	23%	10%

The significance of these results are several:

1. The loggers, engineers and foresters who helped draw up these interrelationship tables were right more than they were wrong. Sixty-two percent of the variables they said would have a large interrelationship with the respective element proved to be correct by the calculated models. In addition, a progressively lower percentage of

the variables thought to be less important is included in the models.

2. The moderate interrelationship variables were selected 35 percent of the time. This large a value at the moderate level is to be expected, for in five of the ten elements the moderate interrelationship was the highest order shown in Table 2 (page 41).

3. Ten variables are included that are rated as having only a negligible or slight relationship. These might be included by a chance relationship or may indicate a hidden relationship that needs to be investigated. At this point it is to early to tell which of these alternatives is correct. Only more data and continued study will be able to differentiate between the two.

Several of the models show results that seem confusing or tend to be difficult to explain. To take them in order:

<u>H_1 Outhaul.</u> The effect of horsepower here is to increase the time required to complete the job. This doesn't make sense without analyzing the different machines. The higher horsepower machines were all of the newer combined tower-yarder type. The older machines usually had a four or six-speed transmission, while the newer used a three-speed. Several of the engineers commented that the new ones were slower in returning the rigging. Possibly this is only a gearing problem.

<u>H_4 Untangle Chokers.</u> In spite of the negative effect of the

number of men setting chokers this term cannot be reduced to zero by increasing the number of men. In the field the number of choker setters varied from two to four.

H_6 Set Chokers. The question here is why doesn't the number of men setting chokers influence the time to set. This is probably due to the practice of adding chokers as the woods crew size increases and the volume per choker decreases. The result seems to have all of the effect lumped under number of chokers and volume per choker.

$H_{10, 11, 13}$ Position Logs, Chaser In, Chaser Away. The negative effect of the slope of the landing is difficult to interpret in these three models. A satisfactory explanation of this effect is not available at this time.

Irregular Element Models

Irregular elements did not occur with enough frequency to make a stepwise regression analysis advisable. The irregular elements are listed in Table 4 with their rate of occurance and duration.

In Table 4 it is indicated that only three-fourths of the total time in the woods is used for productive logging. This number may seem small, and indeed it may be small due to the bias in H_{16}, yet it has been standard practice in the earthmoving industry for years to figure 45 to 50 minutes per hour production or 75 to 83 percent efficiency. On this basis it would seem that the woods crews were performing in a normal manner; yet one of the easier routes to improved production may well be through the reduction of irregular elements.

Table 4. Irregular Element Models

Irregular Element	Occurrences /100 Turns	Average Duration Minutes	Total Time %
H_{9a} Hang up, machine	16.4	.572	1.25
H_{9b} Hang up, man	12.7	4.018	6.77
H_{14} Road changes	3.2	14.248	6.10
H_{15} Work on rigging	24.7	2.136	7.01
H_{16} Waits and delays*	12.7	2.535	4.27
Total			25.40

*There may be considerable bias to the low side in this element, for the analysts were instructed to leave any side that had broken down during the day and go to the nearest operating side. The result of this procedure eliminates the longer machine repair times from these figures.

More study is needed to increase our knowledge of these elements. Future studies should log all delays and their causes for further analysis. It is possible that a few delays are responsible for a majority of the time included in these elements. In the future it may be desirable to re-define the irregular elements to exclude delays of catastrophic proportions and handle them separately as a special allowance.

GROSS ELEMENTS FOR ESTIMATING HIGHLEAD PERFORMANCE

The element models as determined by the stepwise regression analysis will prove invaluable in the future when analyzing the effects of proposed methods and equipment changes. They are, however, too cumbersome for field use as an estimating tool. To simplify things the ten element models were studied to identify models with similar sets of independent variables. Three such groups were identified and the gross elements formed. The components of each of the gross elements is shown below.

1. Yarding time - consists of the Outhaul, Yard in, and Men to safety elements.

2. Woods crew time - consists of the Men to hook, Untangle chokers, and Set chokers elements.

3. Landing crew time - consists of the Chaser in, Unhook, Chaser away, and Position logs elements.

The gross element models can be formed by either direct addition of the element models, or can be computed in the same manner as the original element models. If the direct addition method is to be used an underlying assumption must be understood; namely the individual elements must be independent of each other. If this is not the case the models must be developed directly from the original data.

One of the ways to check for independence of the elements of the logging cycle is to compare the cross element results by addition with the results by regression analysis. If these two methods yield the same gross element models the element models are independent.

The following are the gross element models as developed by both the addition and regression methods. The symbols used are the same as those shown on page 39.

Yarding time - minutes

Addition: $= 1.5094 + .2418D - .0125d + .0698D^2 + .0013P + .0098s + .00042DV - .3222C - .0086A$ (Standard Error = .0593)

Regression: $= 1.5869 + .3247D - .0091D^2 + .00040DV - .2527C - .0181A$ (Standard Error = .0389)

Woods crew time - minutes

Addition: $= 1.0786 + .0066d + .0037\ pcs/A - .1815M + .8603C + .0031V/C$ (Standard Error = .1650)

Regression: $= 1.1279 - .0337d + .0121\ pcs/A$ (Standard Error = .1474)

Landing crew time - minutes

Addition: $= .8832 + .0137H - .0835T + .0974N + .0166LT - .0204L$ (Standard Error - .0485)

Regression: $= .7007 + .0170H - .0342T + .0566N + .0046LT$ (Standard Error - .0286)

A study of the above models will show similarities between the models formed by the two methods. The strongest parallel is in the Yarding time models, yet, here too, there are differences. Notice that the D^2 term has changed from positive to negative along with a very significant change in coefficient. The standard error terms also indicate better fitting of the model to the data by the regression method. These facts are strong evidence against the claim of independence of the individual work elements.

A model for the complete logging cycle was also computed by the regression analysis method but the results were disappointing. The effects of the individual variables were masked by the fact that none seem to be powerful enough to control the cycle time. The result was a very large constant term and the variables chosen tended to be those with small effects in the element and gross element models.

All of the models computed indicate less than a .5 percent probability of having occurred by chance alone.

The regression gross elements have been tabulated and are shown in the following tables. By using the tabulated values cycle times can be estimated with much less time and effort. Values are taken from the three tables and added with their four correction factors to give the estimated cycle time based on current operating methods and equipment. For information on proposed methods and procedures it will be necessary to use the element models.

Example--To estimate the cycle time required to bring in 200 cubic feet of logs on two chokers over an 900 foot yarding distance. The yarder is at the 1100 foot elevation and can suspend the butt rigging 20 feet over the logs. The landing is 125 feet long and level with the decking area kept clear by a loader. Usually three logs come in on two chokers. The setting is in a 175 pieces per acre forest.

Step I. Estimate Yarding Time

a. Enter table 5. For a volume of 200 cubic feet and yarding distance of 900 feet find 4.00 minutes.

b. Correction factors:

Altitude = 1100 feet		-.18 minutes
Number of chokers = two		.00 minutes
	total	-.18 minutes

c. Net yarding time = 4.00 - .18 = 3.82 minutes

II. Estimate Woods Crew Time

a. Enter table 6. For 175 pieces per acre and butt rigging clearance of 20 feet find 2.56 minutes.

b. Correction factors: none.

c. Net woods crew time = 2.56 minutes.

III. Estimate Landing Crew Time

a. Enter table 7. For a level landing 125 feet long find .81 minutes.

b. Correction factors:

Number of logs - three	.06 minutes
Deck height = none or zero	.00 minutes
total	.06 minutes

c. Net landing crew time = .81 + .06 = .87 minutes.

IV. Total Cycle Time

Total cycle time = 3.82 + 2.56 + .87 = 7.25 minutes.

Table 5. Yarding Time*

Yarding distance (feet)	Turn volume--cubic feet							
	50	100	150	200	250	300	350	400
0	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
100	1.42	1.44	1.46	1.48	1.50	1.52	1.54	1.56
200	1.74	1.78	1.82	1.86	1.90	1.94	1.98	2.02
300	2.04	2.10	2.16	2.22	2.28	2.34	2.40	2.46
400	2.32	2.40	2.48	2.56	2.64	2.72	2.80	2.88
500	2.48	2.58	2.68	2.78	2.88	2.98	3.08	3.18
600	2.93	3.05	3.17	3.29	3.41	3.53	3.65	3.77
700	3.05	3.19	3.33	3.47	3.61	3.75	3.89	4.03
800	3.26	3.42	3.59	3.75	3.91	4.07	4.23	4.40
900	3.45	3.63	3.82	4.00	4.18	4.36	4.54	4.72
1000	3.62	3.82	4.02	4.22	4.43	4.63	4.83	5.03
1100	3.78	4.00	4.22	4.43	4.65	4.87	5.09	5.51
1200	3.91	4.12	4.40	4.64	4.88	5.12	5.37	5.61

*Yarding time = outhaul + yard in + men to safety (time in minutes).

Correction Factors

Altitude	Time	Number of Chokers	Time
Sea Level - 250 ft.	0 min.	1	.25 min.
250- 750 ft.	-.09 min.	2	0 min.
750-1250 ft.	-.18 min.	3	-.25 min.
1250-1750 ft.	-.27 min.	4	-.50 min.
1750-2250 ft.	-.36 min.	5	-.75 min.
2250-2750 ft.	-.45 min.		

Table 6. Woods Crew Time*

Butt rigging Clearance - feet	Pieces per acre 100	125	150	175	200	225	250
0	2.33	2.64	2.94	3.24	3.54	3.84	4.14
5	2.17	2.47	2.77	3.07	3.37	3.67	3.97
10	2.00	2.30	2.60	2.90	3.20	3.50	3.81
15	1.83	2.13	2.43	2.73	3.03	3.34	3.64
20	1.66	1.96	2.27	2.56	2.87	3.17	3.47
25	1.49	1.79	2.01	2.40	2.70	3.00	3.30

*Woods crew time = men to hook + untangle chokers + set chokers (time in minutes).

Table 7. Landing Crew Time*

Landing slope	Landing length - feet 50	75	100	125	150	175	200
Level	.81	.81	.81	.81	.81	.81	.81
10- 20%	1.01	1.12	1.24	1.35	1.47	1.58	1.70
20- 40%	1.20	1.43	1.66	1.89	2.12	2.35	2.58
40- 60%	1.40	1.74	2.09	2.43	2.78	3.12	3.47
60-100%	1.60	2.05	2.51	2.97	3.43	3.90	4.35

*Landing crew time = chaser in + unhook + chaser away + position logs (time in minutes).

Correction Factors

Number of Logs	Time	Deck Height - Feet	Time
1	-.06 min.	0	0 min.
2	0 min.	1	.02 min.
3	.06 min.	2	.03 min.
4	.11 min.	3	.05 min.
5	.17 min.	4	.07 min.
		6	.10 min.
		8	.14 min.
		10	.17 min.

RELIABILITY OF THE MODELS

Whenever one proposes an estimating system the first question he is asked is "How sure are you of the results? ", or "How good are the results? " Our position is not too favorable in this regard. The stepwise regression analysis program computed a standard error but due to the method used these figures cannot be used in a normal manner. The other statistic computed is an F test value. This can be used in the normal manner and does yield encouraging results.

Chance of Accidental Relationship

When the regression analysis is run on the computer an F test (11, p. 244) is computed at each step to indicate which variable should be introduced next. After the variable is introduced an overall F test is also computed and printed out on the results. By use of this print-out and tables of F values it is possible to predict the chance of getting the result obtained if there had been no variation within the variables used. When viewed in this manner the results look encouraging. Five of the ten elements are calculated to have much less than . 5 percent chance of producing the models they did by an accidental occurrence. An additional two elements show less than . 5 percent. Two more are in the range between . 5 percent and one percent and the last is between one percent and 2. 5 percent. All of these are relatively low, and it could be expected that the mathematical models we have found are real relationships. There is only one true way to be sure, though; that is to collect the additional data and use it to calibrate the models we have developed. In tabular form the above data looks as follows:

	Element	Probability of a chance relationship
H_1	Outhaul	much less than .5%
H_3	Men to hook	much less than .5%
H_4	Untangle chokers	less than .5%
H_6	Set chokers	between 1.0 and 2.5%
H_7	Men to safety	much less than .5%
H_8	Yard in	much less than .5%
H_{10}	Position logs	less than .5%
H_{11}	Chaser in	between .5 and 1%
H_{12}	Unhook	much less than 5%
H_{13}	Chaser away	between .5% and 1%

Standard Error

Statistically speaking, the standard error is the population standard deviation divided by the square root of the number of samples (11, p. 45). In our situation the computation of the standard error is the same, but the standard deviation is the deviation about the model computed from the data. As a result the standard error is no more than an error of the data about its model. The figure that would be useful is the error of the population about the model. There is no way to deduce this from the data used to build the model; the only answer is to collect another sample of data and use it to calibrate the existing models.

CALIBRATION OF THE MODELS

Before the results of this study can be used with confidence, some measure of their accuracy must be available. To do otherwise would be similar to setting forth to cross the ocean without checking the compass. The first step toward this goal is the accumulation of additional data from the same logging area and with the same crews as those used for the original study. Data should be collected from the same area to minimize the variations due to climate, forest type, ground conditions, crew skills, etc. Placing the required limits on these models is not as simple as the usual confidence limit calculations for two reasons:

1. All of the models are multivariate, with two to six independent variables.

2. The independent variables can vary over a broad range of values rather than being concentrated close to their mean.

Confidence limits can be calculated for a problem of this type using the following expression:

$$\overline{Y} \pm t_z \text{ (standard deviation of Y given variables 1, 2, 3, ...)}$$

The problem here is to compute a value for the standard deviation. Values for t_z can be found in tabulations of the Student's t distribution for the desired confidence level, z.

The following is based on the work of George Snedecor (12, p. 413-445) and conferences with Dr. Lyle Calvin, Chairman and Department Head, Statistics Department, and Kenneth Rowe, Assistant Professor of Statistics, Oregon State University.

Either the standard deviation of variance can be computed in three valid ways depending on the intended use of the statistics. All three are presented here with their probable uses.

1. Computed on the basis of the total population or a very large sample. This would be used to put confidence limits on the expected production of a logging operation over a considerable period of time, and would be most useful when estimating prior to starting work.

2. Computed on the basis of a single turn. This method gives the largest variance and could be used if a supervisor wanted to check production on a turn by turn basis.

3. Computed on the basis of m turns. By use of more than one turn the variance is reduced, and at the same time total data collecting time should be reduced. This approach seems to be the best one for controlling ongoing operations. A secondary advantage of this method is that the range of the variables are also reduced in comparison to the first method.

Development of the Standard Deviation Equations

To simplify the discussion we will first consider the bivariate case.

a	constant
b	slope
c_{ij}	element of the variance-covariance matrix
e	error in an individual observation
m	number of elements in a sample
n	number of elements in the regression data
σ^2	population variance
$\sigma^2_{y \cdot x_1 x_2}$	variance of y given variables x_1 and x_2
s^2	sample variance
V( )	Variance of the element in parentheses
X	independent variable
$\overline{X}$	mean of the independent variables
x	$X - \overline{X}$
Y	dependent variable as calculated from the regression equation
$\overline{Y}$	mean of the calculated dependent variable
$\hat{Y}$	estimate of Y
y	observed dependent variable

The regression equation for the population is:

$$\hat{Y} = a + bX$$

$$= \overline{y} + b(X - \overline{X})$$ and the variance equation

$$V(\hat{Y}) = V(\bar{y}) + (X - \bar{X})^2 V(b)$$

$$s_{\hat{Y}}^2 = \left(\frac{1}{n} + \frac{(X - \bar{X})^2}{\Sigma(X - \bar{X})^2}\right) \sigma_{y \cdot x}^2$$

$$s_{\hat{Y}}^2 = \left(\frac{1}{n} + \frac{x^2}{\Sigma x^2}\right) \sigma_{y \cdot x}^2$$

The regression equation for an <u>individual turn</u> is:

$$Y = a + bX + e$$

$= \bar{Y} + b(X - \bar{X}) + e$ and the variance equation is,

$$V(Y) = V(\bar{y}) + (X - \bar{X})^2 V(b) + V(e)$$

$$s_Y^2 = \left(\frac{1}{n} + \frac{(X - \bar{X})^2}{\Sigma(X - \bar{X})^2} + 1\right) \sigma_{y \cdot x}^2$$

$$s_Y^2 = \left(1 + \frac{1}{n} + \frac{x^2}{\Sigma x^2}\right) \sigma_{y \cdot x}^2$$

For a <u>group of turns,</u> size m.

$$\bar{Y} = a + bX + \frac{e}{m}$$

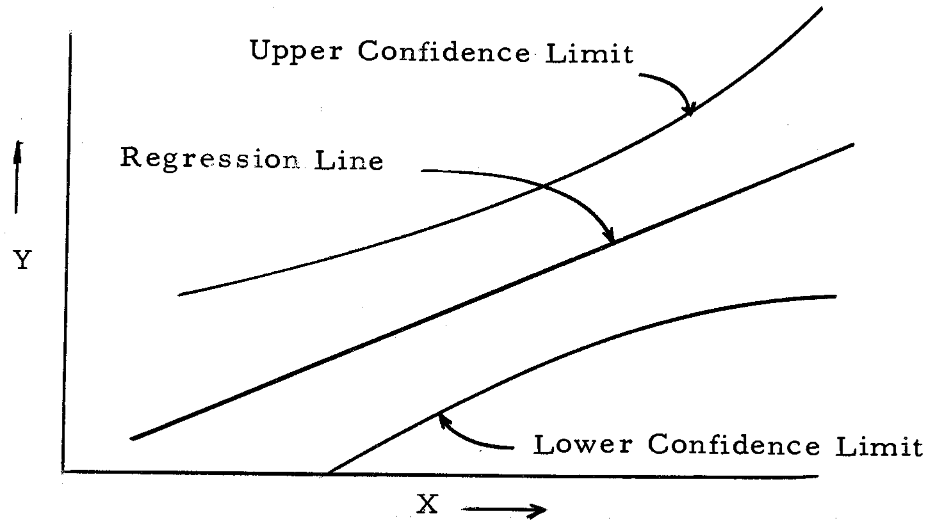
$= \bar{Y} + (X - \bar{X})b + \frac{e}{m}$ and the variance equation is,

$$V(\bar{Y}) = V(\bar{y}) + (X - \bar{X})^2 V(b) + V\left(\frac{e}{m}\right)$$

$$s_{\overline{Y}}^2 = \left(\frac{1}{n} + \frac{(X - \overline{X})^2}{\Sigma(X - \overline{X})^2} + \frac{1}{m}\right) \sigma_{y.x}^2$$

$$= \left(\frac{1}{m} + \frac{1}{n} + \frac{x^2}{\Sigma x^2}\right) \sigma_{y.x}^2$$

Notice that each of the variance expressions above is nonlinear and depends on the independent variable for its exact value. Instead of having linear confidence limits, as is the usual case, we have an upper and lower curve for boundaries. The width of the confidence zone is at a minimum when $X = \overline{X}$ and gets progressively wider as we move to the left or right. The geometric shape of these limits is a pair of hyperbola with center at $\overline{X}$, $\overline{Y}$ and equidistant from the regression line. See the figure below.



The function for the variance leads to an obvious solution in the case of a variable with a very broad range. Instead of computing one equation for the whole range, compute k separate equations for the whole range. The effect of this procedure on the $X - \overline{X}$ values can be made as powerful as desired by altering k. The maximum $X - \overline{X}$ value with one equation is $\frac{\text{Range}}{2}$, but with k equations it is $\frac{\text{Range}}{2k}$.

Up to now we have considered the bivariate case. Now let us look at the trivariate case with two independent variables and one dependent variable.

For the population.

$$s_{\hat{Y}}^2 = \left(\frac{1}{n} + c_{11}x_1^2 + c_{22}x_2^2 + 2c_{12}x_1x_2\right)\sigma^2_{y.x_1x_2}$$

Similarly for a single turn.

$$s_Y^2 = \left(1 + \frac{1}{n} + c_{11}x_1^2 + c_{22}x_2^2 + 2c_{12}x_1x_2\right)\sigma^2_{y.x_1x_2}$$

And for sample size m,

$$s_{\overline{Y}}^2 = \left(\frac{1}{m} + \frac{1}{n} + c_{11}x_1^2 + c_{22}x_2^2 + 2c_{12}x_1x_2\right)\sigma^2_{y.x_1x_2}$$

The geometric interpretation of these would be a tube of confidence flared at both ends and centered on the regression line. In a multivariate case the formula for the variance are as follows:

For the population

$$s_{\hat{Y}}^2 = s_{Y \cdot 1, 2, \ldots}^2 \left(\frac{1}{n} + \Sigma c_{ii}x_i^2 + 2\,\Sigma c_{ij}x_ix_j\right) \quad i < j$$

Similarly for a single turn

$$s_Y^2 = s_{Y\cdot 1, 2, \ldots}^2 \left(1 + \frac{1}{n} + \Sigma c_{ii} x_i^2 + 2\Sigma c_{ij} x_i x_j\right) \quad i < j$$

and for sample size m,

$$s_{\overline{Y}}^2 = s_{Y\cdot 1, 2, \ldots}^2 \left(\frac{1}{m} + \frac{1}{n} + \Sigma c_{ii} x_i^2 + 2\Sigma c_{ij} x_i x_j\right) \quad i < j$$

It is not logical to expect loggers to work with these formulae in the field, so some better method of presenting this information must be developed. It seems logical to compute and plot these limits for each of the models. Then after inspecting the results, attempt to place some relative error value on the model to indicate the expected variations. This will compromise the true case, yet we feel it is mandatory if this material is to be used. When computing the limits the procedure should be to decide on reasonable ranges for each of the variables and then compute limits using the maximum and minimum values for several of the variables while holding the other constant. To decide which to hold constant and which to vary, an evaluation of the relative magnitude of the c_{ij} and x_i terms must be made. Hopefully, some of these values will be small and can be neglected with only minor errors.

CONCLUSIONS

Studies of this type can be conducted in the woods without major adverse reaction by the woods crews. The goal of the study is best explained to the men as "gathering estimating data." Without exception, the men were friendly and cooperative.

Further discussions with operating people are pertinent. The models we have developed to data have been restricted to a linear combination of variables. A study of the standard error for several of the elements indicates that better models can be constructed with the existing data. To build these better models, we need more information concerning the interaction between the variables. Formal and informal on-campus and on-site training sessions are desirable.

Mathematical models of highlead operations can be developed that indicate a very low probability of a purely chance relationship. Typically the models indicate less than five chances in a thousand of being developed from a chance relationship and the worst element model shows 25 chances in a thousand. This is definite evidence that a cause and effect (not chance), and therefore predictable, relationship exists between the independent and dependent variables in highlead logging.

It is impossible to put any meaningful variability or confidence measures on the existing models. Further data collected on the same crews, in similar conditions, will be required to accomplish this important goal.

The mathematical models developed for highlead logging can be successfully recombined into gross element models. The gross elements considerably simplify the task of estimating and field checking production. In our preliminary work, the ten highlead element models developed were converted into three gross elements.

The time required for the irregular elements has been estimated. However, these results must be considered preliminary findings only. Because of the field procedure employed a bias was unavoidably introduced that tends to distort the true picture. Twenty-five and four-tenths percent of the total highlead time was used for irregular elements.

Table 8. Statistical Estimates of Mathematical Models*

Element Models - .01 minutes	Standard Error
Outhaul	
$H_1 = 3.274 + 5.519D - .492d + .130p$	1.676
Men to Hook	
$H_3 = 5.165 + .281d + .145\ pcs/A$	.985
Untangle Chokers	
$H_4 = 60.267 + .383d + .128\ pcs/A - 18.153M$	.995
Set Chokers	
$H_6 = 42.432 + 86.027C + .314\ V/C$	14.518
Men to Safety	
$H_7 = 23.668 - .558D + 6.98D^2 + .981s$	1.073
Yard In	
$H_8 = 124.011 + 19.220D - .540D^2 + .042DV - 32.219C - .764d - .860A$	3.178
Position Logs	
$H_{10} = 58.320 + .647H - 2.229L - 6.266T + .985LT$	2.768
Chaser In	
$H_{11} = 13.336 + .382H - .995T + 1.615N$	.674
Unhook	
$H_{12} = 11.200 + .171LT + 6.39N$	.780
Chaser Away	
$H_{13} = 5.460 + .343H + .186L - 1.090T + 1.731N$	.623
Gross Element Models - minutes	
Yarding Time	
$GH_1 = 1.5869 + .3247D - .0091D^2 + .0040DV - .2527C - .0181A$	.0389
Woods Crew Time	
$GH_2 = 1.1279 - .0337d + .0121\ pcs/A$	.1474
Landing Crew Time	
$GH_3 = .7007 + .0170H + .0342T + .0566N + .0046LT$	.0286

*See page 39 for Nomenclature.

RECOMMENDATIONS

The present element models should be calibrated as soon as possible. The additional data is available and should be used to develop the necessary confidence limits.

Immediate efforts should be made to improve the models that have been constructed for Set chokers and Yard in. The clues to these improvements will probably be found during conversations with hook tenders and rigging slingers*.

A series of long range conferences or discussions should be held with the loggers to use their experiences for revising the models to improve their predicting ability. This technique has been used quite successfully in the past; in particular, a case where the Oregon State University Statistics Department was attempting to develop a mathematical model for weather predictions*.

Broaden the range of the variables as soon as the calibrations and revisions are completed. At present, the models reflect only conditions in a coastal Oregon Rain forest; possibly, the current models aren't valid in the Willamette Valley or even the Washington rain forest. Because the data was taken in early summer, questions could also be raised as to its validity in the fall or winter.

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*Dr. Lyle Calvin, Head of the Oregon State University Statistics Department during a conference discussing the results of the computer runs. November 1964.

A cause analysis study should be started to determine the reason for delays caused by machine adjustments or breakdowns. The key to making this study useful will be to assign the real cause of the delay and determine what is necessary to prevent it from occurring again. The safety people have been using this technique successfully for accident prevention; it should work here also.

Use work logs to supplement cause analysis and improve control. One of the quickest and least expensive ways to build information is by using work logs. Currently the crews are keeping track of the total log production. Records should be expanded to include:

1. turns per day
2. logs per day
3. estimated yarding distances on each road
4. number of road changes per day
5. number of man-cleared hang-ups
6. number and duration of machine breakdowns or adjustments that delay log productions.

With this data and the information available from engineering, production could be kept under closer control. A secondary advantage would be to get data for a check of the production estimates of our models.

A training manual should be prepared for use by company personnel prior to taking part in a study of this type. By its very nature this kind of study requires a considerable amount of preparation and training before the analyst can operate on his own. Much of the detailed information could be embodied in a concise handbook to be used prior to starting, and for reference during the study, thereby reducing training time considerably.

Encourage estimators to use the data in the gross element tables when they are figuring new jobs and compare the results with their estimates. If sufficient data is available on completed logging shows, the estimates from the models could be compared with actual results.

Investigate to determine whether the information or systems are available:

1. Conversion of topographic maps into yarding road profiles and butt rigging clearance information.
2. Combine the cruise data with the road profile to indicate where the logs will be found and the expected quantity at each location.
3. Gather data on logging road logged widths and lengths to determine road spacings and frequency of change.

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APPENDICES

APPENDIX A

DEFINITIONS

Brush Crew	The men who work in the woods as separated from those on the landing, usually choker setters, etc.
Butt Rigging Clearance	As used in this report it indicates the effectiveness of the overall highlead layout in suspending the chokers off the ground at the choker setting site. Desirable as this reduces the amount of heavy work the choker setters must do to choke a log.
Chaser	The man who unhooks the choker from the logs at the landing.
Choker	A steel cable, one end of which is passed around the log and hooked into a sliding block on the main portion of the cable. When the other end is pulled the block slides down closing the loop, hence, choking the log.
Cruise	The estimation of potential timber on a site. Usually taken in log diameters and length for the individual trees.
Deck or Decking	To stack logs in a pile for storage preparatory to rehandling.
Hooktender or Hooker	The foreman of an individual logging operation usually consisting of the woods crew, landing crew, and loading crew. Seven to ten men make up the typical crew.
Landing	The first place to which the logs are brought when taken out of the woods. Usually loading equipment is stationed at a landing to load the logs onto trucks.
Model	An abstraction from real life. In this study used to indicate the mathematical or statistical representation of a portion of the logging cycle.

Rigging slinger	The second in command of the crew and usually directly in charge of the woods crew.
Side	A general term denoting the entire logging operation being conducted from one landing.
Show	See side.
Skid	To slide a log forward while its full length is in contact with the ground.
Turn	One complete cycle in logging. Also applied to the logs brought to the landing on each trip as a turn of logs.
Yard	To slide a log forward while exerting an upward pull on the front of the log. Usually raising the front of the log clear of the ground.

APPENDIX B

COST OF COMPUTER WORK

It is almost manditory to use some for of a high speed computer to compute the stepwise regression analysis programs. Without a computer the costs of such work would be much higher and the time required much longer. The work during this study was done on the Statistics Department IBM 1410 Computer. The first time something is done many extra precautions are taken and many problems solved that won't have to be solved again. Future work will have the benefit of some 20 hours of programming work and standardized procedures that should reduce the costs considerably. The costs reported here will be high compared with the expected costs if the same type of work were to be done again.

The experienced costs for the work to data reflect a sample run of almost 600 turns requiring 1200 punched cards.

Keypunching	$ 40.00
Programming	102.00
Computer time	
First run-stepwise	215.00
Second run-stepwise	99.00
Gross element tables	83.00

Gross elements-stepwise	$ 70.00 (estimated)
Calibration (150 to 200 turns)	150.00 (estimated)

Costs in the future using the standardized methods developed during this study have been estimated as follows:*

Keypunching	$ 40.00
Programming	----
Computer time	
First run	130.00
Second run	100.00
Gross elements by stepwise	50.00
Calibration	130.00
Total	450.00

These estimates are based on a sample run of 600 turns punched into 1200 cards.

*Estimated by Larry L. Janssen, Supervisor, Statistics Computing Laboratory, Oregon State University.