

An exploratory analysis of skidding in the Rocky Mountain area with emphasis on crawler tractor skidding
by LeRoy Conrad Stevens

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Industrial Engineering
Montana State University
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Abstract:
When the first plans related to this thesis were laid out, a large Monte Carlo simulation program adapted to a computer was foreseen that would relate all of the variables affecting the skidding operation. After only a short period of time in the field it became obvious that, due to the time limit and limited funds, this approach was not feasible for a Master's thesis. This author estimates it would take at least five years of full-time work to accomplish the original objective.

Because the original objective was not feasible, a more practical approach was taken. This approach was to present the thesis in two sections.

The first section discusses some of the advantages and disadvantages of non-crawler tractor skidding machines in common use in the Rocky Mountain area. Information for this part of the thesis was attained primarily through personal interviews with logging contractors and operators.

The second and major section of this thesis is devoted to a parametric analysis of the principal variables affecting the economic skidding capabilities of some crawler tractors in the Rocky Mountain area.

The principal variables chosen were the following: 1. Tractor size 6. Operator efficiency
2. Soil 7. Number of men
3. Slope 8. Log type
4. Number of logs per turn 9. Size of logs
5. Distance 10. Altitude Data to be used for the parametric analysis were collected by utilizing continuous stop watch studies with some modification to fit the needs of the analysis.

Time was used as the dependent variable in determining the effect of the principal variables.

After basic times and factors were determined for the variables, they were related to the costs of running different crawler sizes. This was accomplished by determining cost curves for different combinations of variables.

The most important conclusion is that although large crawlers cost more per hour to operate than small or medium crawlers, they generally yield the lowest cost per thousand board feet for skidding logs. It is also shown in this thesis that as the number of men increases, skidding costs increase, and as the number of logs per turn decreases, skidding costs decrease.

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AN EXPLORATORY ANALYSIS OF "SKIDDING" IN THE ROCKY MOUNTAIN AREA WITH EMPHASIS ON CRAWLER TRACTOR SKIDDING

by

LEROY CONRAD STEVENS

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

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ABSTRACT

When the first plans related to this thesis were laid out, a large Monte Carlo simulation program adapted to a computer was foreseen that would relate all of the variables affecting the skidding operation. After only a short period of time in the field it became obvious that, due to the time limit and limited funds, this approach was not feasible for a Master's thesis. This author estimates it would take at least five years of full-time work to accomplish the original objective.

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The second and major section of this thesis is devoted to a parametric analysis of the principal variables affecting the economic skidding capabilities of some crawler tractors in the Rocky Mountain area.

The principal variables chosen were the following:

1. Tractor size
2. Soil
3. Slope
4. Number of logs per turn
5. Distance
6. Operator efficiency
7. Number of men
8. Log type
9. Size of logs
10. Altitude

Data to be used for the parametric analysis were collected by utilizing continuous stop watch studies with some modification to fit the needs of the analysis.

Time was used as the dependent variable in determining the effect of the principal variables.

After basic times and factors were determined for the variables, they were related to the costs of running different crawler sizes. This was accomplished by determining cost curves for different combinations of variables.

The most important conclusion is that although large crawlers cost more per hour to operate than small or medium crawlers, they generally yield the lowest cost per thousand board feet for skidding logs. It is also shown in this thesis that as the number of men increases, skidding costs increase, and as the number of logs per turn decreases, skidding costs decrease.

CHAPTER I

INTRODUCTION

HISTORICAL BACKGROUND OF THE PROBLEM

The forest products industry is one of the major industries in the Rocky Mountain area. In Montana the forest products industry is the third largest industry following mining and agriculture. (8, p. 3)

The forest products industry may be divided into two major activities:

1. Harvesting of the raw material and its transportation to the mills.
2. Manufacture of the raw material into finished products for the consumer.

The harvesting of the raw material and its transportation to the mills is known as the logging industry. The forest products industry is no different from any other industry in that it must produce a quality product at the lowest possible cost to be competitive. The cost of logging is so high in areas where steep slopes and small stems prevail that often times a less expensive, equally suited material can be found to substitute in place of wood. The Rocky Mountain States and western Montana in particular have many areas characterized by substantial volumes of small stemmed trees, such as lodgepole pine growing on steep slopes.

To help the logging industry a long range forest engineering program has been set up to develop systems to economically harvest the timber in areas characterized by steep slopes and small stems.

This long range program is designed to develop new logging methods and improve existing methods.

Before new logging methods can be developed and existing methods improved, a knowledge of the economic capabilities of the present methods must be obtained. After this knowledge is obtained it can be used to develop plans for future engineering research studies.

The skidding operation (i.e. movement of the logs from the stump to the landing) was selected as the area of the logging industry to study because:

1. Considerable work has been done on the logmaking operations. (9)
2. Skidding follows logmaking in the logging system.
3. Skidding represents one of the biggest costs in the logging industry.

STATEMENT OF PROBLEM

After spending some time observing skidding in the field it becomes obvious that there are nearly as many different variations of skidding methods as there are logging contractors. There is little agreement among these contractors concerning the best method. This should be expected because of the differences in soils, slopes, stand densities, personal preferences, and many other variables inherent in the logging industry.

In the Rocky Mountain area four basic skidding methods are in common use. The basic methods are:

1. Crawler tractors
2. Rubber-tired tractors
3. Jammer skidders
4. High lead skidders.

Each basic method has its own advantages and disadvantages.

There are two major objectives of this thesis. They are:

1. To present preliminary conclusions reached concerning non-crawler tractor skidding (i.e. rubber-tired tractors, jammer skidders, and high lead skidders),

2. To present an exploratory analysis of the effect of the principal variables affecting some crawler tractor skidding in the Rocky Mountain area.

Data collection was confined to eleven weeks during the summer of 1965. Due to the large number of variables inherent in the logging industry, it was impossible to gather enough data on all the basic skidding methods to make a thorough analysis comparing the basic methods. Therefore, it was decided to talk to the logging contractors to determine what the major limitations and advantages are of the basic non-crawler tractor skidding methods. Pictures, advantages, and limitations of these non-crawler tractor skidding machines will be presented.

The major part of this thesis will be devoted to a parametric analysis to determine the effect of the principal variables on the economic skidding capabilities of some crawler tractors in the Rocky Mountain area. A partial list of variables affecting crawler tractor skidding includes:

1. Tractor size
2. Soil (coefficient of traction)
3. Use of an arch
4. Tree-length versus log-length skidding

5. Size of logs
6. Number of logs per turn
7. Slope of terrain
8. Season of the year
9. Operator efficiency
10. Condition of equipment
11. Use of a choker setter
12. Altitude
13. Ownership of equipment
14. Log scale used
15. Stand density
16. Skidding distance
17. Type of chokers used
18. Type of landing
19. Felling practices
20. Branch road spacing
21. Brush density and height
22. Silvicultural requirements
23. Non-effective time
24. Resistances (grade, sliding, and rolling).

Time did not permit gathering enough data to compare all of the above variables. Therefore, those variables which contribute the most to the economic effectiveness of the crawler tractor skidding methods were considered. After considerable reading and discussions with individuals who understand the logging industry, it was decided that the following variables are the principal ones affecting crawler tractor skidding:

1. Tractor size
2. Soil (includes brush density, soil moisture content and rockiness of the soil)
3. Slope
4. Number of logs per turn
5. Distance
6. Operator efficiency
7. Number of men
8. Log type
9. Size of logs
10. Altitude.

The major objective of this thesis may then be said to determine the inter-relationships among the above principal independent variables and dependent variables (time and cost). This information will then be used to determine which crawler tractor yields the lowest skidding cost per thousand board feet for a given combination of variables.

CHAPTER II

LOGGING IN GENERAL

THE LOGGING SYSTEM

Logging in the Rocky Mountain area is done by both independent contractors and people who work directly for the mills.

An independent contractor is known as a "gyppo" in the logging industry. A gyppo owns his own equipment and agrees to deliver the logs to the mill for a stated amount. This amount is generally so much per thousand board feet (e.g. $28.00 per MBF). Having gyppo contractors deliver the logs to the mill is an advantage for the mill owners because they need not have so much money invested in equipment. The major disadvantage for the mill owners is that they do not have good control of the logging operations when they let gyppo contractors do the actual logging. In the Gallatin National Forest and much of southwestern Montana most of the logging is done by gyppo contractors. In northwestern Montana and other areas where larger trees prevail, the mills often buy their own equipment and do their own logging.

The logging system may be divided into four major interrelated processes. These processes are:

1. Logmaking
2. Skidding
3. Loading
4. Hauling.

Logmaking is the process of transforming the standing tree into log sizes that will meet the mill requirements. In the Rocky Mountain area most mills require 16, 25, and 32 foot log lengths.

The logmaking process includes three major operations which are felling, limbing, and bucking.

Felling is the operation of cutting down the standing tree. This operation is generally performed with a power chain saw.

Limbing is the operation of removing live limbs and large knots from the stem. Limbing nearly always follows the felling operation and is generally performed with the same implement. With the advent of smaller power chain saws some fellers now cut down the tree with a large saw and limb with a small saw. Dead limbs need not be removed because they will break off during the skidding operation.

Bucking is the operation of cutting the stem into acceptable log lengths (i.e. 16, 25, and 32 foot lengths) which the mills require. If the stem is not bucked until after it has been skidded, but before loading, this is called "hot logging" by many logging contractors. If the tree is not bucked at all before it reaches the mill, the logging industry refers to this as tree-length logging. Of the 13 logging operations visited during the data collection period only one contractor was engaged in tree-length logging. Whether or not a contractor engages in this type of logging depends primarily on the mill's ability to handle the longer stems.

The second process of the total logging system is skidding. This thesis deals with the skidding process so, at this time, skidding will merely be defined as the movement of the logs from the stump to the landing.

The third process of the total logging system is loading. Loading is the process of transferring the logs from the woods deck to a vehicle for transportation to the mill. In the Rocky Mountain area trucks are the most common vehicle used for transportation.

Three major pieces of equipment are in common use in the Rocky Mountain area for the loading process. They are:

1. Heel boom loader
2. Air tongs loader
3. Front end loader.

A heel boom loader is a small mobile crane that often has a boom attached to a manufactured cab and engine. This type of loader is rated by the manufacturer according to its stated capacity to excavate so many yards of earth with a certain size bucket. Common sizes in the Rocky Mountain area are 3/8, 1/2, and 5/8 yards. A heel boom loader utilizes a set of tongs which is set on the individual logs by a person known as a tong setter. The machine operator then butts the log against the boom for stability of the log, and then places the log on the truck. Often the tong setter or the truck driver has to get on top of the load to release the tongs. This can be dangerous as individuals on the load frequently will walk under a log still controlled by the machine operator. An advantage of a heel boom loader is that it can also be used as a jammer skidder. Jammer skidding is discussed in Chapter III.

An air tongs loader is also a small mobile crane rated in the same manner as a heel boom loader. An air tongs loader utilizes a set of

air operated tongs for loading. Only one man, the operator of the loader, is needed to load with this type machine. An air tongs loader is safer than a heel boom loader because it is not necessary to manually set and release the tongs. A major disadvantage of this type of loader is that it does not have the versatility of a heel boom loader because it cannot be used as a jammer skidder. Many of the small gyppo contractors in the Rocky Mountain area load only three or four loads a day requiring about two to three hours working time. The remaining time an air tongs loader is idle and therefore not fully utilized.

A front end loader used in the woods is generally mounted on a crawler tractor. This type of loader will load a truck faster than a heel boom or an air tongs loader because it can load several logs at a time. A higher initial investment is required for a front end loader than for a heel boom or an air tongs loader. A relatively large and level landing area is required for the operation of this type of loader. Among the larger logging contractors (i.e. those who load at least ten loads per day) this type of loader seems to be the most popular.

Hauling is the final process in the logging system. Hauling includes the transportation of the logs to the mill, unloading the logs, and returning to the logging area for another load. As previously stated, trucks are commonly used for the transportation of the logs. Unloading is a function of the mill and is most commonly done with a large rubber-tired front end loader.

The total logging system is portrayed with a flow process chart in Figure 1.

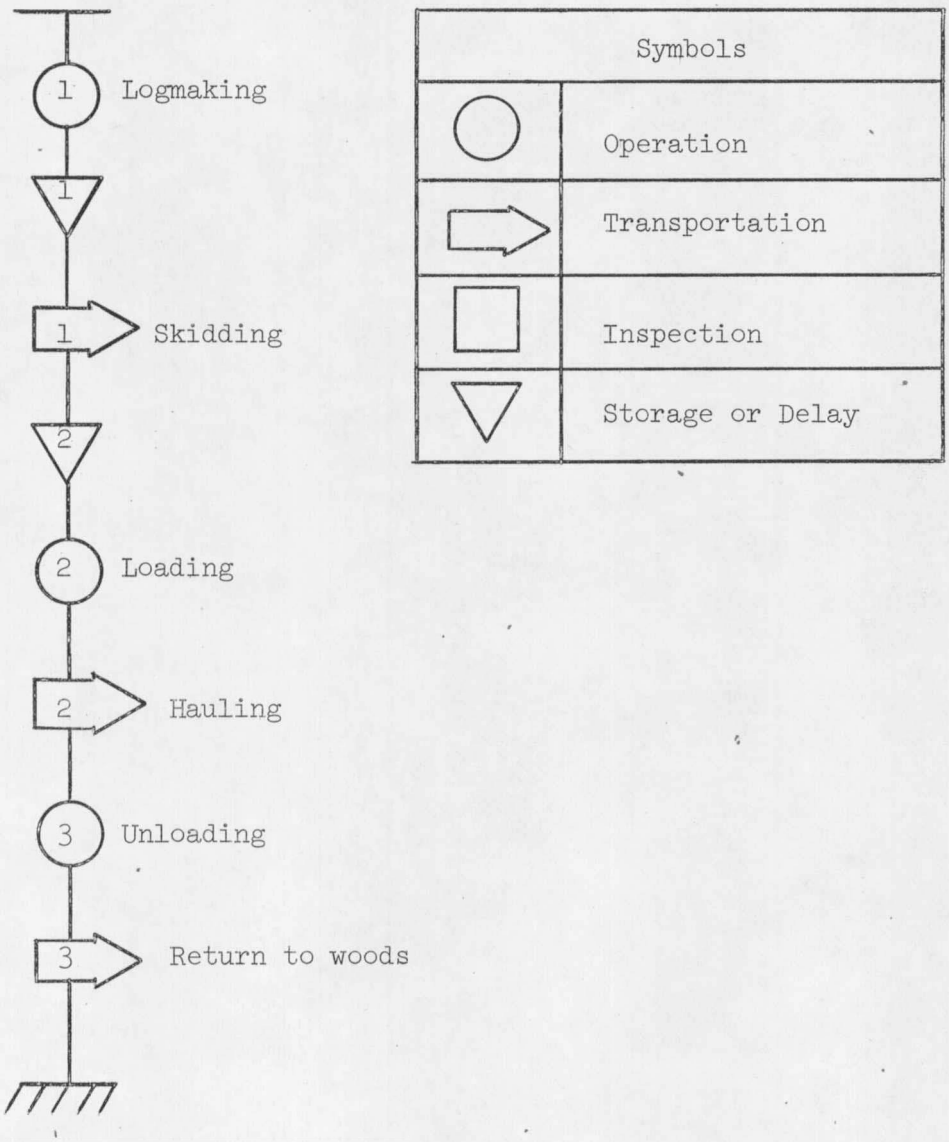

Figure 1. Flow process chart of logging operations.

SKIDDING PROCESSES NOT IN COMMON USE IN THE ROCKY MOUNTAIN AREA

Skidding has previously been broadly defined as the movement of the logs from the stump to the landing. Actually two terms are used to characterize the movement of the logs from the stump to the landing. These terms are skidding and yarding. Skidding is defined as "any method of moving logs from the stump to the landing wherein the logs are skidded along the ground." (4, p. 14) Yarding is defined as "any method of moving logs from the stump to the landing when the logs are in part or wholly lifted from the ground." (4, p. 14)

In this thesis only the term skidding will be used regardless whether the logs are skidded along the ground or are partly or wholly lifted from the ground during the movement from the stump to the landing. This is justified because most of the people in the logging industry use the two terms synonymously.

As previously stated there are four basic methods of skidding in the Rocky Mountain area which are:

1. Crawler tractors
2. Rubber-tired tractors
3. Jammer skidders
4. High lead skidders.

These basic methods are discussed in the next chapter. The remaining portion of this chapter is devoted to acquainting the reader with still other skidding methods in use or being developed in the logging industry.

Helicopters have been proposed for skidding logs from steep rugged terrain. (7, p. 1) A helicopter equipped to carry an external load of

4,000 pounds was tested in Canada in February, 1963. Test results are as follows:

(7, p. 9)

Assumptions:

1. Skidding distance = 3,000 feet
2. Wood weight = 12 pounds/board foot
3. Automatic release at landing takes .10 minutes
4. Hooking in woods takes .50 minutes
5. Aircraft cost = $350.00/hour

Representative cycle times:

Hooking time	= .50 minute
Unhooking time	= .10 minute
Inbound time	= 2.79 minutes
Outbound time	= 2.31 minutes
Total cycle time	= 5.70 minutes

Calculations:

Volume per turn = 4,000 lbs./12 lbs. per B.F.
= 333 board feet

$$\text{Number of turns per hour} = \frac{60 \text{ minutes/hour}}{5.70 \text{ minutes/turn}} = 10.5$$

Number of board feet per hour = 10.5 turns/hour
x 333 board feet/turn = 3,500

$$\text{Skidding cost per MBF} = \frac{\$350.00/\text{aircraft hour}}{3{,}500 \text{ board feet/hour}}$$
$$= \$.10/\text{board foot} = \$100.00$$

By comparison it costs approximately $10.00 per thousand board feet to skid using more conventional equipment such as crawler tractors. From the above helicopter trial it is obvious that this type of skidding is not practical for the present.

Balloons are being tested because of the high aircraft cost (i.e. $350.00/hour for a Sikorsky S58 helicopter) involved in helicopter logging.

If air-born logging (i.e. either helicopter or balloon logging) becomes economically possible, three very distinct advantages will be obtained. These are:

1. The ground will not be disturbed excessively during the skidding operation; thus, the soil will not be nearly so susceptible to erosion after the logging is completed.
2. Fewer roads will be required thus reducing the erosion problem.
3. There will be a method of skidding from areas not accessible by any means other than air.

Animals are still in use in some logging areas as a method of skidding. Horses or mules are used economically when either light timber stands or other factors make volume production impossible.

COMBINED PROCESSES

Machines are being developed to combine some of the processes in the logging system. As far as this author can ascertain, none of these machines are in common use in the Rocky Mountain area. Nevertheless, they should at least be presented to acquaint the reader with some of the newer developments in the logging industry since these machines or variations of them may be used in the Rocky Mountain area in the future.

A combine is now available that will fell, limb, buck, and bind the stems into cords. It is called the Busch Combine. A Busch Combine is essentially a four-wheel drive rubber-tired tractor fitted (13, p. 51) with hydraulic knives used for felling and bucking. Limbing and

measuring devices are also incorporated in a manner such that all phases of preparing the stick are done in one continuous manner. After a cord is harvested the combine binds the cord and drops it behind the machine to be picked up later. This combine would have limited use in the Rocky Mountain area as it is for areas with level ground and heavy stands of medium or large size trees. A Busch Combine costs approximately $37,000.00.

The Vit Feller Buncher was developed in 1957 and 1958 to fell the trees and skid them whole to the landing where another machine limbs and bucks them. The Vit Feller Buncher fells the trees with a hydraulically driven chain saw and collects them on an overhead rack for delivery to the landing. It is basically a crawler tractor that utilizes an overhead rack rather than chokers for skidding trees. Its cost is approximately $15,000.00. A Bombardier Processing Unit (BPU) is used in conjunction with the Vit Feller Buncher. The BPU is a lattice-like structure almost 100 feet long which performs the following functions: (13, p. 55)

1. The tree is pulled through a limbing device.
2. The tree proceeds by conveyer to a stop plate set for different log lengths.
3. A large circular saw bucks the tree after which the logs fall onto the ground.

Another new prototype machine is a Pope Harvester. A Pope Harvester is an attachment for the C-frame of a crawler tractor. The Harvester mounted on a large crawler tractor is a mobile machine (13, p. 58)

which severs the tree from the stump, carries it upright to the landing, limbs it, bucks it, and deposits the logs on the ground. Mounting a Harvester on a crawler tractor does not alter the basic tractor and can be removed at any time restoring the tractor to its original form. A Harvester is basically two jaws and a hydraulically operated chain saw used for felling and bucking. In operation the operator drives the machine up to a tree, grasping it with the main jaw, and severs the tree with the chain saw. The unit then moves to the landing and rotates the tree to a horizontal position. The second set of jaws moves along the tree removing the limbs. Next the tree is held by the limbing jaw and pushed through the main jaws removing the remaining limbs and positioning the tree for bucking. The chain saw rotates for the bucking cuts, makes the cuts, and the logs fall to the gound. It has been estimated that this Harvester could be manufactured on a production basis for about $10,000.00 per unit.

CHAPTER III

NON-CRAWLER SKIDDING MACHINES IN COMMON USE IN THE ROCKY MOUNTAIN AREA

The three major non-crawler type skidding machines in common use in the Rocky Mountain area will be discussed in this chapter. The presentation of any particular manufacturer's equipment does not constitute an endorsement, but is presented only as an illustration of the equipment commercially available.

RUBBER-TIRED SKIDDERS

Rubber-tired skidders are gaining an important place among skidding machines used in the Rocky Mountain area. These skidders, equiped with large pneumatic tires, offer good flotation making them better than crawlers for skidding in muddy or boggy areas and on level to moderate slopes with little slash. Crawler tractors generally have a great amount of difficulty operating in muddy or boggy areas because of their weight and poor flotation. Rubber-tired skidders have a top speed of about 21 miles per hour compared to about seven miles per hour for conventional crawler tractors.

Many of the larger logging companies that wish to reforest their land after logging are using rubber-tired skidders for skidding on level ground because these skidders do not disturb the soil as much as crawlers.

It was the opinion of most of the interviewed loggers that rubber-tired skidders yield higher production and lower maintenance costs than

conventional crawlers in areas of level to moderate slopes, little slash, and in muddy or boggy areas.

The limitations of rubber-tired skidders may be summarized by saying these skidders lack versatility. These skidders are generally limited to level to moderate slopes (i.e. up to 15%) and little slash. Rubber-tired skidders presently are not used to build roads in logging areas.

Photographs, specifications, and a summary of data collected for two rubber-tired skidders in use in the Rocky Mountain area are shown on pages 18 through 21. Because the sequence of operations for rubber-tired tractor skidding is the same as for crawler tractor skidding, the flow process chart for both methods will be presented later.



Figure 2. The Garrett Tree Farmer is a small rubber-tired skidder.

TABLE I

SPECIFICATIONS AND SUMMARY OF DATA COLLECTED
FOR A SMALL RUBBER-TIRED SKIDDER
(5, p. 1)

Manufacturer: Garrett Enumclaw Company, Enumclaw, Washington

Model: Tree Farmer-Model 15

Engine: Ford, 4 cylinder gasoline, horsepower = 68

Transmission: Warner-Ford, 4 speed

Speeds: .728 m.p.h. to 21.25 m.p.h.

Tires: 13.6 x 28

Clearance at center pin: 21 inches

Dimensions: Length - 193 inches
Width - 79 inches
Height - 98 inches

Drawbar horsepower: 58.3

Weight: 7,000 pounds (estimated)

Cost: Approximately $10,000.00

Hourly operating cost: $2.50 (estimated) - Does not include operator's wage.

Summary of data collected:

Number of turns studied	= 15
Slope	= -11% (skidding downhill)
Distance	= 300 to 450 feet
Soil condition	= Good
Time studied	= 3.2675 hours
Number of board feet skidded	= 7,685
Number of board feet per hour	= 2,350



Figure 3. A Mountain Logger is a medium sized rubber-tired skidder.

TABLE II

SPECIFICATIONS AND SUMMARY OF DATA COLLECTED
FOR A MEDIUM SIZED RUBBER-TIRED SKIDDER
(6, p. 1)

Manufacturer: Mountain Manufacturing Company, Kalispell, Montana

Model: Mountain Logger

Engine: General Motors, 4 valve diesel, 101 BHP at 3,000 RPM

Transmission: 4 speed

Speeds: .75 m.p.h. to 21.5 m.p.h.

Tires: 16.9 x 30

Clearance: 22 inches

Dimensions: Length - 189 inches
Width - Legal
Height - 110 inches

Drawbar horsepower: 65 (estimated)

Weight: 11,500 pounds

Cost: Approximately $16,000.00

Hourly operating cost: $3.90 (estimated) - Does not include operator's wage.

Summary of data collected:

Number of turns studied	= 23
Slope	= -5%
Distance	= 350 to 800 feet
Soil condition	= Fair
Time studied	= 4.7345 hours
Number of board feet skidded	= 12,320
Number of board feet per hour	= 2,600

JAMMER SKIDDERS

Jammer skidding, or shovel logging, is done with a small mobile crane similar to an air tongs or heel boom loader. Jammer skidders utilize a set of tongs at the end of a cable for skidding. These skidders have either a homemade wood or steel boom attached to a manufactured cab. Jammer skidders are rated the same as an air tongs or heel boom loader.

These skidders may be mounted on tracks and be self-propelled or mounted on a truck. If mounted on a truck, they are easier to move from one logging area to another logging area.

Jammer skidders are used by many of the gyppo contractors because most of these machines can be used for both loading and skidding. A smaller investment in equipment results if a small contractor uses jammer skidders. Also by using a jammer skidder for both loading and skidding, the equipment can be more fully utilized.

Besides the unique advantage of being able to both load and skid, a jammer skidder can also skid logs for short distances from ground that is too steep for crawler tractors or rubber-tired skidders.

Most loggers agree that jammer skidders are limited to skidding 50 feet downhill and 150 feet uphill. For short distances (i.e. 50 feet to 150 feet) jammer skidders generally yield high production at low operating cost.

Although skidding trails are not needed for jammer skidding, many more roads are required because of the short distances over which jammers can effectively skid. Roads are very expensive to build and maintain.

Besides being expensive, roads tear up the ground to such a degree that replanting is nearly impossible. This need for many roads is the major limitation of jammer skidding.

Jammer skidding utilizes two men, one for operating the equipment and one for setting tongs. This results in three disadvantages. The first is that during periods of downtime two men are idle. Another disadvantage is that the tong setter is often in some danger because an experienced operator maneuvers the skidder in such a way that the tongs are tossed to the tong setter. The tong setter could be hit and injured by the tongs. It is common practice among loggers to let dead trees and trees under a certain diameter stand during the logmaking process. When a log is being skidded to the deck, it may hit one of these trees, knocking it over subjecting the tong setter to additional danger.

Jackstrawed decks are usually made by jammer skidders. There are also more decks because of the small area that can be skidded with one set-up of the skidding machine. These jackstrawed and numerous small decks tend to increase the loading time.

A flow process chart of steps involved in one cycle of jammer skidding is shown in Figure 4.

Pictures of two typical jammer skidders used in the Rocky Mountain area are presented in Figures 5 and 6. Because most jammer skidders are converted back-hoes or small draglines, specifications are not too meaningful.

The Link Belt jammer skidder shown in Figure 5 costs about $30,000.00 new and the P & H jammer skidder presented in Figure 6 costs about

$12,000.00 used.

These skidders can skid about 50 logs per hour and load about 60 logs per hour. These estimates are from actual studies and discussions with the operators. Neither of these estimates include set-up times.

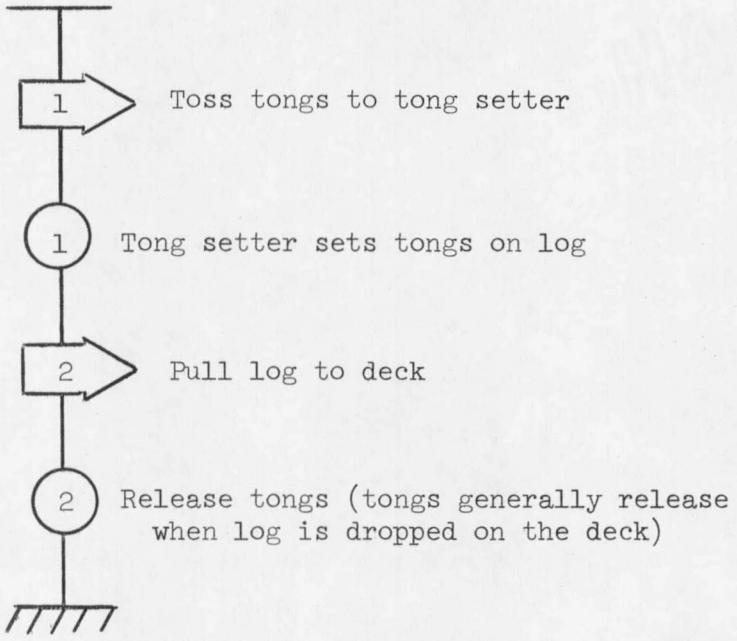

Figure 4. Flow process chart of steps involved in jammer skidding.



Figure 5. A 5/8 yard, steel boom jammer skidder mounted on tracks.



Figure 6. A combination 3/8 yard heel boom loader and jammer skidder mounted on a truck.

HIGH LEAD SKIDDERS

The two major components of high lead skidders are a tower and a "donkey" which contains the main power unit and the haulback and main drums. Figure 7 shows a simplified sketch of a high lead system.

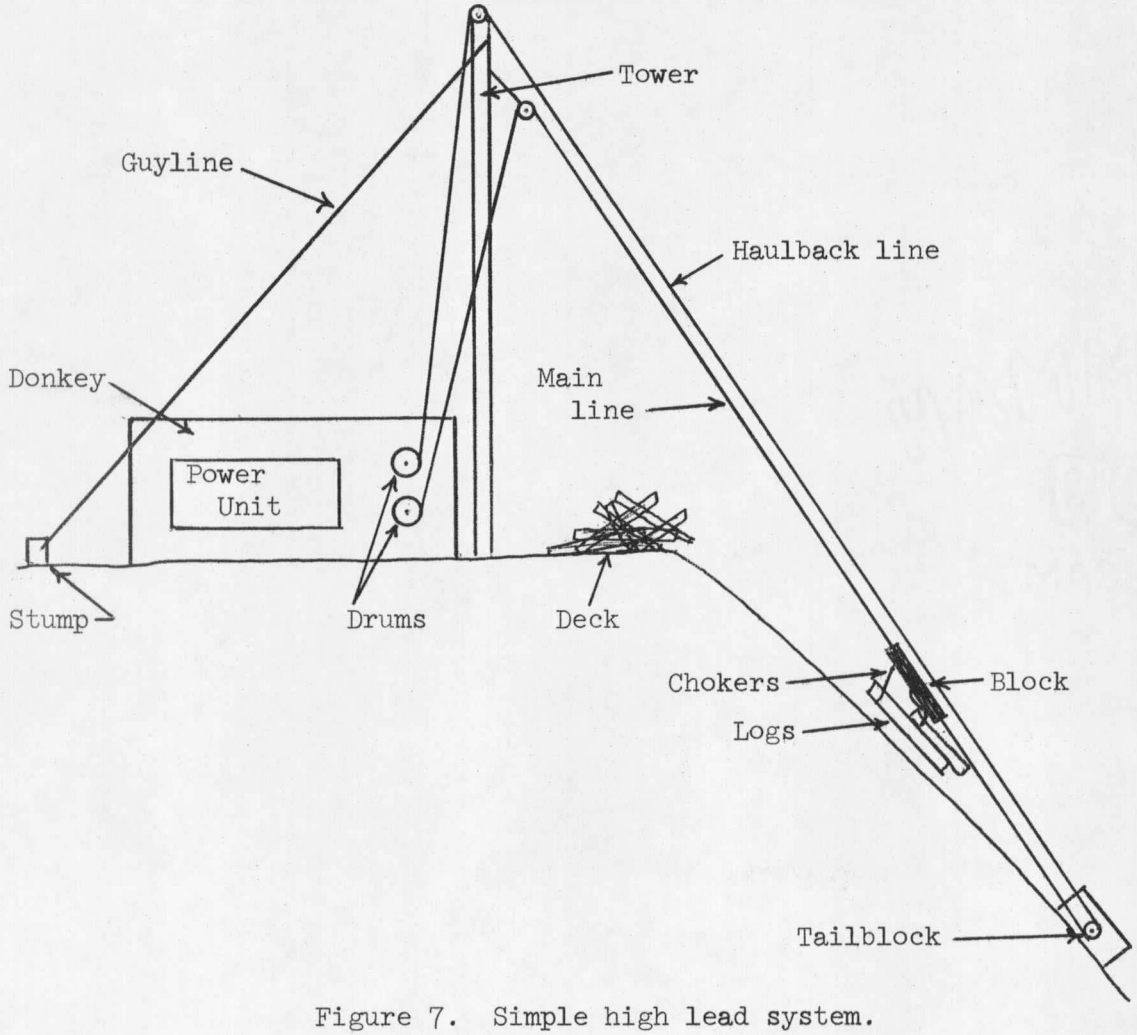

Figure 7. Simple high lead system.

In operation the operator sends the block with attached chokers to the choker setter in the woods. The choker setter sets the chokes and signals the operator to pull the logs up to the deck where someone releases the chokes from the logs.

High lead skidders yield high production in areas of dense stands. They are particularly advantageous in areas of very steep slope. These skidders work very well on slopes over 45% which are nearly impossible to negotiate with crawler tractors or rubber-tired skidders. These skidders work very well for distances over 1,000 feet which can not be skidded economically by other methods.

Skidding trails are not needed for this method of skidding. Few roads are needed with high lead skidders because a large area can be worked from one set-up of the machine. Because this method does not need skidding trails, requires fewer roads, and lifts the logs off the ground during the skidding process, the ground is left virtually undisturbed from the logging operations.

The major limitation of high lead skidders is their high initial cost. A gyppo contractor generally can not afford the initial investment for a manufactured system. For this reason there are very few high lead systems in areas logged primarily by small independent contractors. These systems are extensively used in the Pacific Northwest where large logging companies are working in dense stands of fir and other large diameter trees.

Homemade high lead skidders can be made to overcome the limitation of high initial cost. A picture of a homemade skidder is presented in

Figure 9. It is this author's opinion that these low cost homemade skidders have much potential and should be thoroughly investigated by the small logging contractor.

Another limitation is that at least two and often up to nine or ten men are needed to operate a high lead system. One man is used to operate the machine, one or more men run crawler tractors pushing the logs to an area where chokers can be hooked, one or two men release chokers at the deck, and the rest hook chokers in the woods.

A deck made by a high lead skidder is the most jackstrawed of any deck observed. Therefore, the loading time from a deck made by a high lead skidder is generally longer than from decks made by the other skidding machines.

Another limitation in some areas is that the stumps that are used to anchor the tower pull out during wet weather, therefore, making the system inoperable.

A picture of a manufactured high lead system is presented in Figure 8. The Skagit system costs approximately $80,000.00 new. The homemade system as shown in Figure 9, costs about $2,000.00. (1, p. 1) Two men skidded 42 logs over a distance of 150 feet with this homemade machine in 58 minutes.



Figure 8. A Skagit system used for high lead skidding.



Figure 9. A homemade high lead skidder.

SUMMARY

This chapter has been devoted to descriptions of non-crawler skidding machines in common use in the Rocky Mountain area.

After spending approximately three months in the field gathering data, this author has come to the following conclusions concerning non-crawler skidding machines:

1. None of the machines can be used without the aid of a crawler tractor for building roads.
2. Rubber-tired skidders should be investigated by loggers if they work primarily on level to moderate slopes.
3. Small contractors should investigate jammer skidders because of their versatility to be used as both a skidding and loading machine, thus lowering the initial investment in equipment and also utilizing the equipment more fully.
4. A lower priced high lead system is needed in areas where small loggers work so they can manage the initial investment.

CHAPTER IV

CRAWLER TRACTOR SKIDDING

Crawler tractors are the most versatile of all the skidding machines presently employed in the Rocky Mountain area. Because crawler tractors are so versatile, each logging contractor generally owns at least one crawler tractor even if he utilizes some other machine for skidding. Crawler tractors are commonly used for the following operations:

1. Skidding right-of-way for roads
2. Building roads
3. Skidding logs
4. Decking logs
5. Pulling trucks
6. Cleaning up the area after the logging operations are completed.

To minimize investment in equipment many small gyppo contractors own one or two crawlers to perform all of the above operations. Observations in the field indicated that crawler tractor skidding is the most popular method presently employed in the Rocky Mountain area. For this reason the remaining portion of this thesis will be devoted to crawler tractor skidding.

THE CRAWLER TRACTOR AND AUXILIARY EQUIPMENT

Crawler tractor skidding in the Rocky Mountain area is performed with all sizes of crawlers. In areas of small stems, such as lodgepole pine, small and medium size crawlers are most popular. Large crawlers are predominant in areas of larger stemmed trees, such as ponderosa pine and Douglas fir. A basic crawler tractor generally has a winch, dozer, and protective canopy mounted on it when used for skidding. Crawler tractors,

with their great weight and crawler tracks, offer a maximum traction effort for the various soil and terrain conditions that must be worked on.

Crawler tracks are designed in such a way that rutted surfaces and other ground irregularities can be driven over. Wide tracks reduce the ground loading per square inch thereby improving flotation. Greater flotation is needed on soft soil to keep the crawler from sinking in. After the logmaking operation there is considerable slash (i.e. branches, bark, tops, decayed logs, and broken or uprooted trees) lying on the ground which may cause track slippage. Because of the slash and soil condition, one generally finds crawlers with wide tracks in the forests. If an operator plans to be working in areas that are characterized by abrasive materials, such as rock and sand, he should be certain that the track shoes are heat treated. A special style track shoe is available for use in ice and snow.

Steering of crawler tractors is generally done by means of multiple disc clutches which stop the power to a track when disengaged. The tractor will turn in the direction of the stopped track. These steering clutches may be operated either mechanically or hydraulically, depending on the make and model of the tractor. A master clutch on a crawler tractor is used to connect the power from the engine to the transmission. All clutches are operated by hand levers instead of foot pedals. The speed of a crawler tractor is controlled with a throttle lever.

The winch is probably the most important piece of auxiliary equipment mounted on the crawler tractor. The winch allows the crawler to skid logs to the landing and also to retrieve logs from inaccessible spots.

Pulling trucks out of mud and removing stumps are two other jobs commonly performed by a winch. Fifty to one hundred feet of 3/4 or 7/8 inch diameter cable are attached to the winch. Chokers are attached to the end of the cable to be placed around the logs during the skidding process.

A canopy is required by law for crawler tractors used in the woods. A canopy is basically pipe, sheet steel, and heavy screen manufactured in such a way as to be mounted over the seat of a crawler to protect the operator from falling trees, limbs, and logs that get jackstrawed during skidding.

Most crawlers used for skidding have a dozer attached. Most dozers are hydraulically controlled although cable controlled dozers are available. An angle blade is preferred over a straight blade for the following reasons:

1. Sidecasting material while skidding road right-of-way
2. Decking logs with minimum damage to the logs.

A crawler tractor with auxiliary equipment used for skidding is shown in Figure 10.

Some crawlers are further equipped with an arch to lift the ends of the logs off the ground during the skidding process. An arch may be either mounted on the crawler or be pulled by the crawler as a separate unit. If mounted on the crawler it is known as an integral arch. An arch mounted on crawler tracks and pulled by the crawler is known merely as an arch. An arch mounted on steel or rubber wheels and pulled by the crawler is commonly called a sulky.

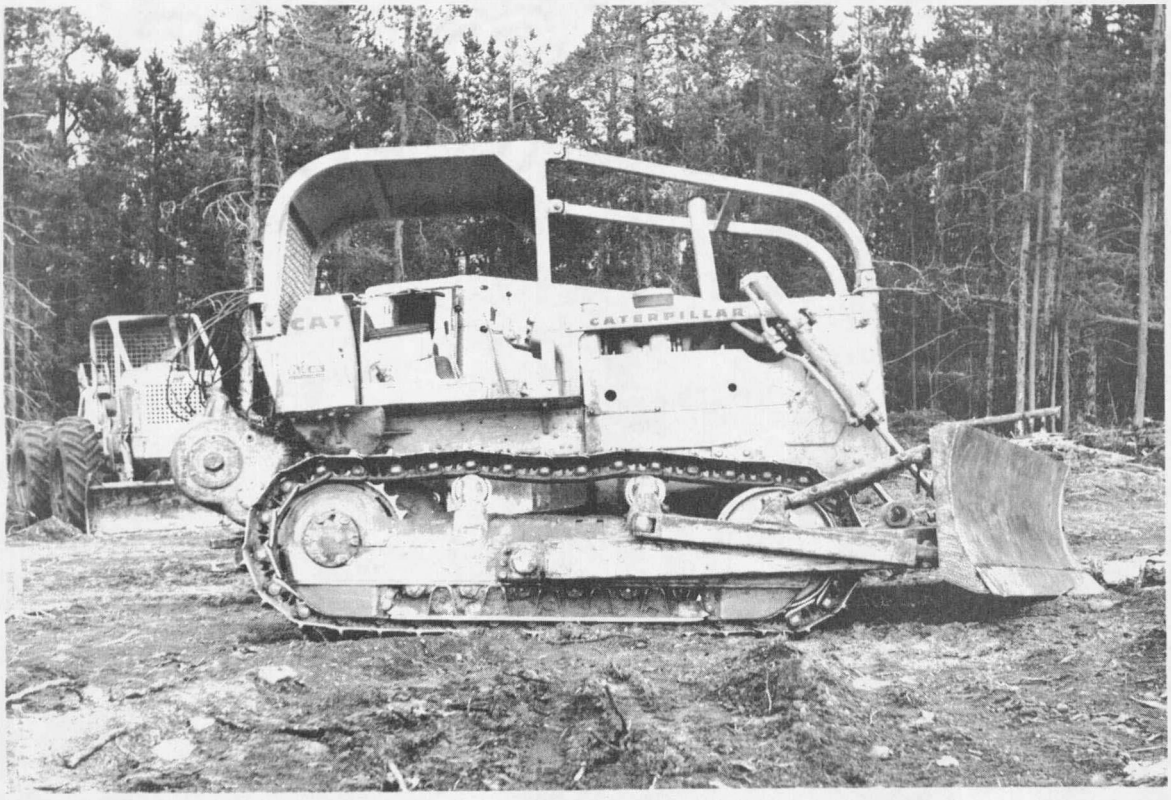

Figure 10. Crawler tractor with auxiliary equipment used for ground skidding.

The following list contains some of the advantages of an arch:

1. It keeps the ends of the logs off the ground, thereby increasing load capacity because of less log sliding resistance and eliminates the bulldozing effect of logs in the dirt.

2. Chokers are much easier to unhook at the landing because the logs have not been skidded on the ground packing the chokers full of dirt and foliage.

3. Maintenance cost and downtime at the sawmill are reduced because sand and rocks are not imbedded in the bark, as in the case of ground skidding, hence reducing saw sharpening at the sawmills.

Some of the disadvantages of an arch are:

1. Towed arches are slower to maneuver and require slightly longer to gather a load than regular ground skidding crawlers.

2. Integral arches put added weight on the back of the crawler and are said to cause excessive wear on the driving mechanisms, thereby increasing maintenance costs.

3. An arch costs about $1,200.00 installed.

Heavier loads and long skidding distances are particularly suited to skidding with a towed arch. Small crawlers can be used to bunch the logs in the woods for larger crawlers with towed arches which skid the logs to the landing. An integral arch mounted on a crawler is shown in Figure 11 and a picture of a rubber-tired arch (sulky) is shown in Figure 12.

Eleven turns studied on a small (about 31 drawbar horsepower) crawler with towed arch indicated that a small crawler with an arch skids approximately with the same number of board feet per turn as a medium size crawler (about 52 drawbar horsepower) without an arch. Studies showed that both crawlers skid about 450 board feet per turn.



Figure 11. An integral arch mounted on a crawler tractor.



Figure 12. A rubber-tired arch commonly known as a sulky.

DIFFERENT METHODS OF CRAWLER TRACTOR SKIDDING

Previous discussions show that there are variations in crawler tractor skidding. Use of an arch is one variation, the advantages and disadvantages of which have been previously stated.

Another variation in the method of skidding is tree-length logging versus saw log logging. This also was mentioned briefly before but will be discussed more thoroughly here. As previously stated most loggers in the Rocky Mountain area practice saw log logging. This means the feller cuts the stem into log lengths acceptable at the mills immediately after limbing the tree and before skidding. Occasionally loggers will skid the merchantable part of the stem from the woods in one piece. If the stem is not cut into acceptable log lengths before loading, it is known as tree-length logging. The major advantage of tree-length skidding is that fewer chokers have to be set and unhooked to skid the same amount of wood as in saw log logging. A major disadvantage of tree-length logging is that often more unmerchantable wood is sent to the mills. In areas of small stemmed trees, such as lodgepole pine, tree-length logging should probably be used more extensively because it often takes five or six trees to make a load for a crawler. As far as could be determined, the major reason that tree-length logging is not practiced to a greater degree in the small stemmed tree areas, is the mills' inability to process the longer stems. In areas of large diameter trees, tree-length logging would not be practical because often times the trees are so large that the crawler could not pull in a whole tree at a time, and even if it could,

the machine used for loading could not handle it.

Yet another variation in skidding is the use of a choker setter. A choker setter is an individual that hooks the chokers to the logs in the woods, rides to the landing on the crawler, and then unhooks the chokers at the landing. The savings or additional cost involved when a choker setter is used will be further discussed in Chapter VII.

Skidding right-of-way for roads is the fourth variation. Roads through the logging areas are generally marked by the owners of the land before logging begins. A feller fells the trees on the road right-of-way. Crawler tractors then skid the logs off and deck them along the edge of the right-of-way. Skidding right-of-way generally requires more time than regular skidding because the operator must clear all the brush, dead trees, and other slash from this area as he skids the logs.

Crawler tractor skidding is generally done on strips. It is this type of skidding that the parametric analysis is concerned with. Skidding from strips is the process of skidding all of the merchantable logs or trees from a certain area to a landing where loading takes place. The steps involved in one cycle of this type of skidding are shown in Figure 13.

DIFFERENT WAGE PAYMENT PLANS

After spending several weeks in the field gathering data for this thesis it became obvious that there is a large variation in the wage payment practices in different locations and among contractors.

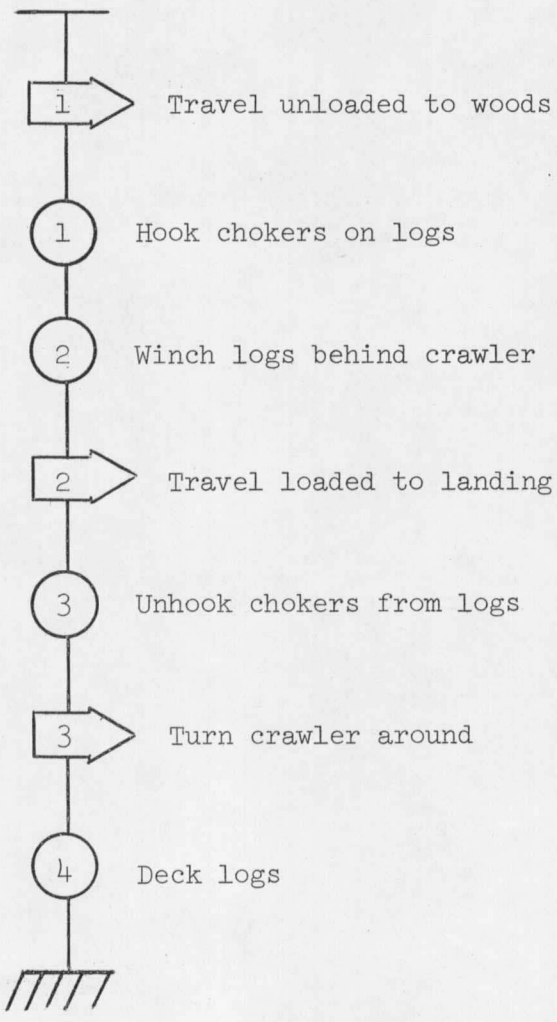

Figure 13. Flow process chart of steps included in one cycle of crawler tractor skidding.

Skidding wages are generally controlled by size of timber, steepness of terrain, depth of snow, who owns the equipment, and type of equipment used. The above factors are some of the controlling ones that determine the production level per unit. For example, one contractor may pay $4.00 per MBF for a production level of 12 MBF per day or $48.00 per day and another contractor may pay $3.00 per MBF for a production level of 16 MBF per day or $48.00 per day. The employee receives the same wage under both methods (i.e. $48.00 per day).

To gain a further understanding of the wage payment practices in the Rocky Mountain area, a survey was conducted by the Industrial Engineering Department at Montana State University. The survey is being continued but time permits including only preliminary results in this thesis. Questionnaires were sent to about 300 logging contractors in the Rocky Mountain area of which 70 were returned stating the wage payment practice followed. The questionnaires did not ask for information such as production level that the payment was based on. Further questionnaires will be mailed to the loggers to try to make the survey more meaningful. To indicate some of the variation in wage payment practices the reader is referred to Table III.

Loggers are covered by Workmen's Compensation. The logging contractor generally pays the expense for this coverage. In Montana, during 1965, the rate paid by the loggers was 15.7% of the gross pay. Besides paying for their employees Workmen's Compensation the logging contractors also pay 2.7% for unemployment insurance and 4.2% for Social Security starting in 1966. During 1987 and after the Social Security rate will be

TABLE III

SAMPLE OF WAGE PAYMENT PRACTICES FOR CRAWLER TRACTOR SKIDDING IN THE ROCKY MOUNTAIN AREA.

State	Who owns equipment	Payment for crawler operator	Payment for choker setter
Colorado	Operator	$6.00/MBF	$2.00/hour
	Operator	$6.50/MBF	
Idaho	Contractor	$ .20/piece	
	Contractor	$1.00/MBF	$2.50/hour
	Contractor	$ .60/MBF	$ .50/MBF
	Contractor	$1.48/MBF	
	Contractor	$1.65/MBF	$2.75/hour
	Contractor	$2.50/MBF	
	Contractor	$3.00/MBF	
	Operator	$ .06/100lbs.	
	Operator	$6.00/MBF	$2.25/hour
	Operator	$6.50/MBF	
	Operator	$7.00/MBF	
	Contractor	$2.25/hour	$2.00/hour
	Contractor	$2.50/hour	
	Contractor	$2.75/hour	$2.45/hour
	Contractor	$2.87/hour	$2.55/hour
	Contractor	$3.00/hour	
Montana	Operator	$6.50/MBF	$2.30/hour
	Operator	$7.00/MBF	
	Operator	$8.00/MBF	
	Contractor	$3.00/MBF	
	Contractor	$4.00/MBF	
	Contractor	$ .20/piece	
	Contractor	$1.50/hour	
	Contractor	$2.50/hour	$2.00/hour
	Contractor	$2.75/hour	$2.30/hour
	Contractor	$3.00/hour	$2.25/hour
New Mexico	Contractor	$2.50/hour	$2.00/hour
	Contractor	$4.00/MBF	
Utah	Contractor	$5.00/MBF	$1.75/hour
Wyoming	Contractor	$1.50/hour	$1.25/hour
	Contractor	$2.50/hour	
	Operator	$6.00/MBF	
	Operator	$10.00/hour	$2.50/hour

5.65%. From the above figures it can be seen that logging contractors are presently paying 22.6% of their employees gross pay into governmental agencies for insurance and Social Security. This amount is in addition to what he pays the employee. For example, if a contractor pays an employee $3.00 per hour he must pay an additional $.678 per hour for insurance and Social Security. To be relieved from paying the Workmen's Compensation fee, small logging contractors often form partnerships and each of the partners do some of the work. As owners, they are not required to pay the fee for Workmen's Compensation. (10, p. 2)

As stated previously the independent contractors are paid on a thousand board foot basis for delivering the logs to the mills.

Board foot volume measurement is an attempt to predict how much usable product will be obtained from the log. There are over 40 different log measuring methods in the United States, each resulting in a different board foot measurement for the same log. No single rule has been adopted as a standard. The rule which is used the most by the United States Forest Service is the Scribner Decimal C Log Rule. (9, p. 81)

The time involved to scale (i.e. measure) a load of logs is so great that neither the mills nor the contractors can afford to scale every load. All of the three mills visited during the data collection period practiced weight scaling. Estimation of board feet volume by the weight method follows these steps:

1. A weight factor (i.e. so many pounds per board foot) is agreed to by the mill's management and the contractor before logging begins.

2. Each load of logs is weighed by taking the gross weight

of the truck and the logs and then subtracting the weight of the truck.

3. The net weight of the logs is then divided by the weight factor to determine the estimated number of board feet in the load.

4. A certain percentage of the loads are scaled periodically to check the weight factor. The weight factor may be adjusted depending on the outcome of these periodic checks.

Obviously, the derivation of the weight factor depends on one of the board foot rules. Therefore, the same estimate of usable product per load should result whether a board foot rule is used or the weight method is used.

Loggers generally disapprove of the weight method of estimating board foot volume. They maintain that the weight of the wood varies with the type of wood and the moisture content of the wood, which in turn depends upon length of time between felling the tree and delivery to the mill.

CLASSIFICATION OF PRINCIPAL VARIABLES AFFECTING CRAWLER TRACTOR SKIDDING

Each of the principal variables affecting crawler tractor skidding will be defined and classified in this section. The method of gathering data and working it into a parametric analysis will be explained in Chapters V and VI.

The principal variables affecting crawler tractor skidding were listed on page 4, but will be listed here again for convenience. These variables are:

1. Tractor size
2. Soil (includes brush density, soil moisture content, and rockiness of the soil)
3. Slope
4. Number of logs per turn
5. Distance
6. Operator efficiency
7. Number of men
8. Log type
9. Size of logs
10. Altitude.

For the purpose of this study the crawler tractors were classified according to drawbar horsepower. Drawbar horsepower is that power available to do productive work. For example, a crawler may have an engine horsepower of 65 and a drawbar horsepower of 52. The difference between these two horsepowers is the power loss between the engine and the tracks.

Crawler tractors used for the analysis were classified as either small, medium, or large, depending on the drawbar horsepower. Time permitted gathering sufficient data on only one crawler of each size. Pictures of each crawler size studied are shown in Figures 14 through 17. Specifications for the three crawler sizes are presented in Table IV.

It should be noted that crawlers much larger than 75 drawbar horsepower are used for skidding in areas of large diameter trees. Many crawlers have drawbar horsepowers exceeding 200. A maximum of 75 drawbar horsepower was used for the analysis because this was the largest crawler studied.

When data collection started, soil was divided into twelve classifications. After approximately three weeks of collecting data, it became obvious that the original classification was too fine for this type of study. Therefore, the soil classification was modified so only three

distinct classifications were used. These classifications were:

Soil 1 - Good skidding soil (firm dry earth, very little slash, and few rocks to hinder travel)

Soil 2 - Average skidding soil (may be wet with some slash and/or a few small rocks)

Soil 3 - Poor skidding soil (may be muddy and/or very rocky and/or with a lot of slash).

This classification may be further clarified by saying that generally in areas of lodgepole pine with 150 to 200 trees per acre the amount of slash remaining after the logmaking operation would necessitate classifying the soil as number 2.

TABLE IV

SPECIFICATIONS FOR CRAWLER TRACTORS STUDIED

Crawler Size	Manufacturers and Models	Drawbar Horsepower	Approximate Weight With Aux. Equip.	Approximate Cost New
Small	A-C - HD5 Cat - D2 I-H - TD6	25-40 (40 used for analysis)	11,000 pounds	$11,800.00
Medium	A-C - HD6 Cat - D4D I-H - TD9	41-60 (52 used for analysis)	15,500 pounds	$17,450.00
Large	A-C - HD11 Cat - D6B I-H - TD15	61-80 (75 used for analysis)	24,300 pounds	$24,600.00



Figure 14. A small crawler tractor.



Figure 15. A medium crawler tractor.



Figure 16. A large crawler tractor.

Altitudes above 3,000 feet have an appreciable effect on crawler tractors. Above 3,000 feet a 3% loss of horsepower is encountered for each 1,000 feet. For example, at 13,000 feet altitude a crawler tractor has only 70% of the power available that it has from sea level to 3,000 feet. (3, p. 21) Most of the data for this thesis was collected at an altitude of 8,000 feet. Therefore, the horsepowers had to be derated by 15%. These adjusted horsepowers were used for classifying slopes. The altitudes for various areas were obtained from maps.

Slope was classified as minus if skidding downhill and as plus if skidding uphill. It was further classified according to steepness by using elementary dynamics.

Most skidding is done downhill. Therefore, the major problem is to determine at what slopes must a crawler tractor operator shift gears while traveling uphill unloaded. A crawler tractor moving uphill has several forces acting on it, the main one shown in Figure 17.

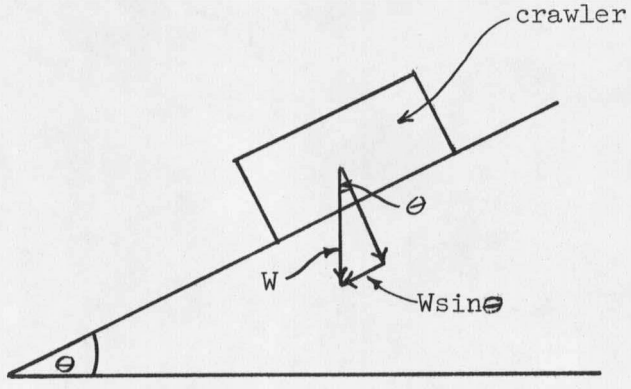

Figure 17. Schematic showing the main force acting on a crawler moving uphill.

Tables are available that give the pull available for different crawler sizes operating in various gears at sea level. (2, pp. 16-21) These pull values were all multiplied by .85 because the data was collected primarily in areas of 8,000 feet altitude.

The biggest force, known as grade resistance, that a crawler tractor must overcome is denoted as $W\sin\theta$ in Figure 17. "W" is the weight of the crawler. Therefore, by taking a ratio of the pounds pull available for each gear over the weight of the crawler one can determine the angle and hence, the percent slope at which a crawler operator must shift gears. For example, a medium sized crawler that weighs 15,500 pounds has 3,400 pounds pull available at 8,000 feet altitude in fourth gear. Therefore, the maximum value of the angle θ is the angle whose sine $= \frac{3,400}{15,500} = .2194$. This angle is 12°41', or when converted to slope (i.e. rise over run), is 23%. Table V shows the maximum slopes over which different size crawlers move in the various gears.

TABLE V

MAXIMUM SLOPES OVER WHICH DIFFERENT SIZE CRAWLERS CAN MOVE IN VARIOUS GEARS

Gear / Crawler Size	5th	4th	3rd	2nd
Large	13%	18%	27%	41%
Medium	14%	23%	30%	41%
Small	17%	26%	33%	44%
Average	15%	22%	30%	42%

The slopes were averaged so that all crawlers could be compared on the same basis. From the above table, slopes were classified as follows for the analysis:

Slope A - 0 through 15%, level to moderately gentle
Slope B - 16 through 22%, gentle to moderate
Slope C - 23 through 30%, steep to very steep
Slope D - 31 through 42%, extremely steep.

A turn in skidding is defined as one complete cycle. In other words, a turn starts when the crawler tractor starts for the woods and is completed after decking (i.e. pushing the logs into a pile at the landing) is complete.

The variable, number of logs per turn, is then merely the number of logs that the crawler pulls into the landing and decks each cycle.

The variable, distance, is the number of feet that the crawler tractor moves during the skidding cycle. Distance traveled unloaded and distance traveled loaded were recorded separately during data collection because often the operator would travel unloaded to the woods, hook one or two chokers, move the crawler several feet, hook more chokers, and then travel to the landing. Many operators do this because they need not pay out excessive cable while hooking chokers if they can drive close to the ends of the logs.

Operator efficiency is probably the most important variable in crawler tractor skidding. Many factors have a bearing on operator efficiency. Among these factors the most important are skill, experience, motivation, and physical characteristics.

To make a meaningful analysis with operator efficiency as a variable,

the operators must be rated. "Rating is a technique for equitably determining the time required to perform a task by a normal operator after the observed values of the operation have been recorded." A normal operator is a qualified, thoroughly experienced operator, working under conditions as they customarily prevail at a pace that is neither too fast nor too slow, but representative of average. (12, p. 275) (12, p. 269)

Presently there is no strictly quantitative method of performance rating available. Time study experience and training is about the only way an individual can apply a performance rating. The author has had formal training and about two years experience in time study. Therefore, all operators were rated, as the author feels an educated estimate is much better than ignoring the variable althogether.

An 100% operator is considered normal. If an operator is rated at 110%, he is considered 10% above normal; and if rated at 90%, he is considered 10% below normal. An operator can theoretically be rated at any level, but generally only operators between about 85% and 115% should be studied.

As an example of performance rating usage, assume operator A took .91 hour for a particular operation and was rated at 110%. The normal time allowed to do the operation in this example would be .91 x 1.10 = 1.00 hour. Operator B may take 1.11 hours for the same operation but be rated at 90%. The normal time allowed for the operation would still be 1.00 hour (i.e. 1.11 x .90 = 1.00). If a third operator was rated at 100%, he should take 1.00 hour to do the same operation.

The variable, number of men, is simply the number of people that are hooking or unhooking chokers. If the crawler tractor operator hooks and unhooks his own chokers, the number of men is one. If an extra man is employed to hook and unhook chokers, the number of men is two.

Often an extra man is employed to hook chokers in the woods but the crawler operator unhooks them at the landing. If this was the case, during data collection a note was made saying two hooking and one unhooking.

The variable, log type, refers to the kind of trees in the logging area. Lodgepole pine was the predominant species in most of the areas that data were gathered in. Douglas fir and spruce were also found during the data collection period.

Log type is important because different types of trees have different weights per board foot. All of the turn volumes (i.e. number of board feet per turn) had to be converted into pounds so that all of the crawlers could be compared on the same basis. The number of pounds per board foot for the trees encountered during the data collection period are: (11, p.14)

1. Lodgepole pine - 10.8 pounds per board foot
2. Douglas fir - 9.7 pounds per board foot
3. Spruce - 9.1 pounds per board foot.

The variable, log size, is a measure of the number of board feet in each log. The number of board feet in each log is required to determine the number of board feet per turn.

By multiplying the number of board feet per turn (computed by adding the individual log sizes per turn together) by the proper weight factor for log type, one arrives at the number of pounds skidded per turn.

CHAPTER V

METHOD OF GATHERING DATA AND PUTTING IT INTO USABLE FORM FOR THE PARAMETRIC ANALYSIS

Data for this thesis were collected during the summer months of 1965. Logging areas within a 75 mile radius of Bozeman, Montana, were generally chosen as areas of study, as they were within driving distance of Montana State University. A 75 mile radius of Bozeman includes such areas as Hyalite Canyon, Squaw Creek, and Maudlow, Montana. National forests included in this area are the Gallatin, the Beaverhead, and the Helena.

GATHERING DATA IN THE FIELD

Continuous decimal hour stop watch studies were chosen as the method of gathering data in the field. This method allows the analyst to break the skidding operation into elements or constituent parts.

The skidding operation was broken into the following elements:

1. Time to travel unloaded to the woods
2. Time for hooking chokers
3. Time for freeing logs
4. Time to travel loaded to the landing
5. Time for unhooking chokers
6. Time to deck the logs
7. Time for foreign elements (i.e. those elements other than 1-6).

The time for each element was determined by subtracting the termination point for the previous element from the termination point for the element in question and then subtracting the time taken by foreign elements if there were any. The termination point is the instant that one element ends and another element begins. In the field, termination points were recorded for each element per turn or cycle.

To determine the time to travel unloaded to the woods, assume that the stop watch reading for the termination point of the element, decking logs, is 10 or .0010 hour and the termination point of the element, travel unloaded to the woods, is 440 or .0440 hour. The time to travel unloaded to the woods is then equal to .0440 hour - .0010 hour or .0430 hour. For data collection purposes, only the termination points were listed in the field books. The actual time for each element was determined in the office while putting the field data into usable form. The termination points for elements one through six were:

1. Time arrived in woods - operator gets off the crawler
2. Time chokers hooked - operator gets on the crawler
3. Time left woods - crawler starts moving towards the landing
4. Time arrived at landing - operator gets off the crawler
5. Time unhooking completed - operator gets on the crawler
6. Time decking completed - crawler starts moving towards the woods.

Foreign elements are used to account for all of the time during the period studied. A foreign element is an element that does not occur during every cycle or turn. Examples of foreign elements that may occur during the skidding operation are choker breaks, talk to gyppo, and clear brush.

A foreign element may occur in the middle of a regular element or between regular elements. An example of a foreign element that may occur in the middle of a regular element and the procedure for handling it follows:

Assumptions:

1. Time arrived in woods = .0560 hour
2. Time operator started talking to gyppo = .0640 hour

3. Time operator finished talking to the gyppo = .0930 hour
4. Time chokers hooked = .1170 hour.

Time for hooking chokers = time chokers hooked - time arrived in woods - time taken for the foreign element
= .1170 hour - .0560 hour - (.0930 hour - .0640 hour)
= .0610 hour - .0290 hour = .0320 hour.

Rather than going into a lengthy discussion of time study in this thesis, the reader is referred to any time and motion study text for details other than those given so far in this chapter.

Slope in the field was measured with a clinometer. The person measuring slope merely holds the instrument up to one eye and aligns a line inside the instrument with some point at the same height above the ground as the user's eye. The slope is read directly from the instrument in either degrees or percent. The author found that the top of the seat of most crawler tractors is about eye level, so generally when measuring slope, this is the point that was aligned with the instrument.

As mentioned in Chapter IV, if logs were being skidded downhill, the slope was recorded as minus, and if logs were being skidded uphill, the slope was recorded as plus.

Soil conditions as observed in the field were recorded as either one, two, or three. The reader is referred to the section on classification of the principal variables affecting crawler tractor skidding in Chapter IV for a more comprehensive discussion concerning soil classification.

The make and model of the crawler tractor being studied was recorded in the field. The drawbar horsepower used for classification of tractor

sizes was determined by referring to manufacturers' specifications in the office.

The number of logs per turn was recorded at the landing while chokers were being unhooked.

Distances had to be paced while gathering data as no instrument could be found that would measure long distances over varying terrain. The distance from the deck to where the first choker was hooked was paced and recorded as distance unloaded. The distance from where the last choker was hooked to where the operator got off the crawler to unhook the chokers was paced and recorded as distance loaded. All distances were recorded to the nearest 50 foot increment.

If the crawler tractor operator hooked and unhooked his own chokers, one was recorded as the number of men. If a choker setter was used, the numbers of men hooking and unhooking were recorded separately. For example, if the choker setter only helped to set chokers in the woods, and the operator of the crawler had to unhook his own chokers at the landing, the numbers of men would be recorded as two hooking and one unhooking.

The log type for each turn was recorded as either lodgepole pine, Douglas fir, or spruce. The type of logs could generally be determined by merely looking at the logs as each type of log has bark different from the other two. Douglas fir is characterized by thick gray bark while lodgepole pine has a light colored, scaly bark, and spruce has a red scaly bark.

Log size was determined by scaling the logs by the Scribner Decimal C Log Rule method. The most common log lengths found in the woods are 16,

25, and 32 feet. The different logs were scaled and recorded as follows:

1. Logs 16 feet long - recorded the log length and diameter of the small end

2. Logs 25 feet long - recorded the log length and diameters at the small end and at the $12\frac{1}{2}$ foot mark

3. Logs 32 feet long - recorded the log length and diameters at the small end and at the 16 foot mark.

Lengths could generally be determined by observation, although a 100 foot tape was carried to measure the length of logs when in doubt. Diameters were generally measured with a tape measure. When measuring diameters, one should be careful to measure only the diameter of the usable wood. This means that the bark should be excluded. Only the log lengths and required diameters of the logs were recorded in the field. The actual board foot volume and corresponding weight were determined in the office by using a log scale book and proper weight factor for type of log.

Other items recorded while in the field include:

1. Operator efficiency

2. The location where the data were being collected

3. The name of the gyppo contractor or the foreman if the logging was being done by mill personnel

4. The wage payment practice used for the payment of the crawler operator and choker setter

5. The amount of fuel and oil used by the crawler tractor

6. The depreciation period allowed for the crawler tractor.

The amounts of fuel and oil used by the crawler tractor were estimated by either the gyppo or the crawler operator.

Data were recorded in surveyors' field books. These small hard-covered books are easy to carry and to write in while in the field.

For long skidding distances (i.e. those distances over 300 feet) two men were used to gather data. Stop watches were synchronized, one man was stationed at the deck or landing, and the other man was stationed in the woods where chokers were being hooked.

If the skidding distance was short, one man could generally gather all of the data for a particular turn, as he could see where the chokers were being hooked from his station at the landing.

The field data collection books were always set up under the assumption that two men would be collecting data on one crawler. This means that one book was set up for the man at the landing, and another book was set up for the man in the woods. The man at the landing was responsible for the following information:

1. Time that the crawler departed from the deck which was generally the same as the time that decking was completed.
2. Time that the crawler arrived at the deck or landing
3. Time that unhooking was completed
4. Time that decking was completed
5. The number of logs per turn
6. The type of logs
7. The number of men unhooking chokers at the landing
8. The length and required diameters of the logs for scaling purposes
9. Any foreign elements that occurred while the crawler tractor could be seen from the landing

10. Operator efficiency

11. Date of the study

12. Wrist watch starting and ending times of the study to be compared with stop watch times

13. Any other comments that he felt were pertinent.

If a man was stationed in the woods, he was responsible for the following information:

1. Time that the crawler arrived in the woods
2. Time that the chokers were all hooked
3. Time that the crawler departed from the woods
4. Distances both unloaded and loaded
5. Slope
6. Number of men hooking chokers in the woods
7. Soil classification
8. Any foreign elements that occurred while the crawler tractor could be seen from the woods
9. Location where data were being collected
10. Name of the gyppo or foreman
11. Wage payment practice followed
12. Crawler's estimated fuel and oil consumption
13. Depreciation period
14. Crawler make and model
15. Any other comments that he felt were pertinent.

Information for items 9 through 14 was generally obtained during the lunch period. The way that the field books were set up and actual data recorded at the landing for six turns or cycles is shown in Table VI. Table VII shows the way that the field books were set up and actual data recorded by the man in the woods.

If the skidding distances were such that one man could gather all of the required data, he was responsible for all of the information, and the other man was assigned to study another crawler.

Standard safety practices were followed in the field while gathering

TABLE VI

SAMPLE OF ACTUAL DATA GATHERED IN THE FIELD BY THE MAN STATIONED AT THE LANDING

(Page 1)

Turn No.	Time Depart Deck	Time Arrived Deck	Time Unhooking Completed	Time Decking Completed	Foreign Elements	Comments
1	1040	1790	1970	2090		Date of study - 8/26/65
2	2090	(1) 80	230	330		Wrist watch start time - 9:05 A.M.
3	330	1490	1600	1690		Wrist watch end time - 11:53 A.M.
4	1690	2650	2760	2950		
5	2950	(2) 990	1190	1330		
6	1330	2150	2310	2390		

(Page 2)

Turn No.	No. of Logs	Type of Logs	No. of Men	Comments	Lengths and Diameters			
1	5	DF	2	Operator eff. = 110%	25-12, 14 16-14	16-8	32,10,12	25-12,15
2	5	DF	2		25-12, 13 16-4	25-10,12	16-15	25-10,13
3	5	DF	2		32-11, 13 16-8	16-16	25-13,15	32-12,14
4	5	DF	2		32-12, 13 25-11, 13	32-14,15	16-9	32-11,13
5	5	DF	2		25-6, 8 25-10, 11	25-14,15	25-9,10	25-10,12
6	5	DF	2		37-9, 11 25-9, 10	25-10,12	25-13,14	32-8,10

TABLE VII

SAMPLE OF ACTUAL DATA GATHERED IN THE FIELD BY THE MAN STATIONED IN THE WOODS

(Page 1)

Turn No.	Time Arrived Woods	Time Chokers Hooked	Time Departed Woods	Foreign Elements	Comments
1	1270	1630	1640		Gyppo owns the crawler
2	2430	2740	2750		Crawler make and model - AC-HD6
3	(1)660	1200A	1290	750A / 660 Talk to gyppo	
4	2050	2460	2470		
5	(2)200	790	800		
6	1620	1930	1940		

(Page 2)

Turn No.	Distance	Slope	No. of Men	Soil	Comments
1	300 UL 300 L	-15%	2	1	Location - Maudlow, Montana
2	300 UL 300 L	-15%	2	1	Gyppo - George Elder
3	400 UL 400 L	-15%	2	1	Wage payment practice - $3.00/MBF
4	400 UL 300 L	-15%	2	1	Estimated fuel consumption/day - 15 gal./10 hr.
5	450 UL 350 L	-11%	2	1	Estimated oil consumption - 3 gals./100 hr.
6	450 UL 350 L	-11%	2	1	Depreciation period - 5 years @ 10 mo./yr.

data. Hard hats, first aid kits, and safety instructions were issued by the U. S. Forestry Sciences Laboratory personnel before data collection began.

PUTTING THE FIELD DATA INTO USABLE FORM FOR THE PARAMETRIC ANALYSIS

After the field data were collected, it was transferred to columnar sheets. The times for each element were then determined and various indices, such as average time per log to hook chokers, were calculated. . . . An example of data in usable form for the parametric analysis is shown in Table VIII. The reader should note that turns one through six utilize the field data from Tables VI and VII.

For convenience, the sheets that have the data in usable form for the parametric analysis will be referred to as office data sheets throughout the remaining portion of this thesis.

Columns lettered a, b, d, f, h, j, and l on the office data sheet are merely the stop watch readings that were recorded in the field. The elemental times for the various elements were determined by subtracting the reading for the previous element from the reading for the element in question and deducting the time for foreign elements, if any. For example, the time for hooking chokers during the third turn was determined by the following computation:

.1200 hour - .0660 hour - (.0750 hour - .0660 hour) =
.1200 hour - .0660 hour - .0090 hour = .0450 hour.

The elemental times are given in columns c, e, g, i, k, and m.

Column "n" contains the number of logs per turn and column "q" con-

tains the distance. If the distance unloaded was the same as the distance loaded, only one number was put into this column per turn. The numbers in both column "n" and column "q" were transferred from the field books.

The board foot volume was determined by using the lengths and diameters that were recorded in the field and a scale book. From Table VI one can see that the log lengths and diameters for the first turn were 25' - 12" and 14", 16' - 8", 32' - 10" and 12", 25' - 12" and 15", 16' - 14". By referring to a Scribner Decimal C Log Rule scale book, one finds that the corresponding board foot volumes are 150, 30, 140, 170, and 110. These board foot volumes are summed and recorded in column "t".

The weight for each turn was determined by multiplying the board foot volume per turn by the proper weight factor for type of log. Because the log type for turn one was Douglas fir, the board foot volume was multiplied by 9.7 pounds per board foot. The weight was recorded in column "u".

The percent slope for each turn was transferred from the field data books into column "v".

The soil classification for each turn was transferred to column "w", and the number of men hooking and unhooking chokers was transferred to column "x". Foreign elements and comments were transferred to the office data sheets from the field books.

The average times per log to hook and unhook chokers were calculated and recorded in columns "o" and "p" respectively. Note that the average times are determined by multiplying the elemental times by the number of men and then dividing by the number of logs. For example, the average time per log to hook chokers for turn one is determined by the computation

TABLE VIII

EXAMPLE OF DATA THAT IS IN USABLE FORM FOR THE PARAMETRIC ANALYSIS

ALLIS CHALMERS - MODEL HD6

DRAWBAR H. P. = 52

	a	b	c=b-a	d	e=d-b	f	g=f-d	h	i=h-f	j	k=j-h	l	m=l-j	n	o=ex/n	p=kx/n	q	r=50c/q	s=50/q	t	u=9.7t	v	w	x		
Turn No.	Time Depart Deck	Time Arrive Woods	Time To Travel Unloaded In Hours	Time Chokers Hooked	Time For Hooking Chokers In Hours	Time Depart Woods	Time For Freeing Logs In Hours	Time Arrive Deck	Time To Travel Loaded In Hours	Time Unhooking Complete	Time To Unhook Chokers In Hours	Time Decking Complete	Time To Deck In Hours	No. of Logs	Average Time/Log To Hook	Average Time / Log To unhook	Distance In Feet	Average Time/50' Unloaded Interval	Average Time/50' Loaded Interval	Board Foot Volume	Weight In Pounds	Slope In Percent	Soil Class	Number Of Men	Foreign Elements	Comments
8/26 1 11:53 9:05	1040	1270	.0230	1630	.0360	1640	.0010	1790	.0150	1970	.0180	2090	.0120	5	.0144	.0072	300'	.0038	.0025	600	5,820	-15	1	2 h 2 uh		Location — Maudlow
2	2090	2430	.0340	2740	.0310	2750	.0010	① 80	.0330	230	.0150	330	.0100	5	.0124	.0060	300'	.0057	.0055	570	5,529	-15	1	2 h 2 uh		Gyppo— Geo. Elder
3	330	660	.0330	A 1200	.0450	1290	.0090	1490	.0200	1600	.0110	1690	.0090	5	.0180	.0044	400'	.0041	.0025	790	7,663	-15	1	2 h 2 uh	750 A 660 Talk to gyppo	Wage Payment — $3.00/MBF
4	1690	2050	.0360	2460	.0410	2470	.0010	2650	.0180	2760	.0110	2950	.0190	5	.0164	.0044	400 ul 300 l	.0045	.0030	750	7,275	-15	1	2 h 2 uh		Est. Fuel Consumption = 15 gals. / 10 hr. day
5	2950	② 200	.0250	790	.0590	800	.0010	990	.0190	1190	.0200	1330	.0140	5	.0236	.0080	450 ul 350 l	.0028	.0027	450	4,365	-11	1	2 h 2 uh		Est. Oil Consumption = 3 gals. every 100 hr.
6	1330	1620	.0290	1930	.0310	1940	.0010	2150	.0210	2310	.0160	2390	.0080	5	.0124	.0064	450 ul 350 l	.0032	.0030	510	4,947	-11	1	2 h 2 uh		Depreciation — 5 years @ 10 months / year
7	③ 650 B	940	.0290	1520	.0580	1540	.0020	1720	.0180	1790	.0070	1890	.0100	4	.0290	.0035	350 ul 300 l	.0041	.0030	490	4,753	-11	1	2 h 2 uh	③ 650/2390 B Coffee Break	Gyppo owns crawler
8	1890	2300	.0410	2630	.0330	2640	.0010	2980	.0340	④ 80	.0100	—	—	5	.0132	.0040	500'	.0041	.0034	430	4,171	-11	1	2 h 2 uh		Operator efficiency = 110 %
9	80	420	.0340	820	.0400	840	.0020	1130	.0290	1260	.0130	1370	.0110	5	.0160	.0052	500'	.0034	.0029	610	5,917	-11	1	2 h 2 uh		

$\frac{(.0360 \text{ hours})\ (2)}{5 \text{ logs}} = .0144$ hour per log.

These two average times per log were determined to see if it takes longer per log to hook and/or unhook with a choker setter, and also to see if the average time per log to hook and/or unhook varies as the number of logs per turn increases. These comparisons are made in Chapter VI.

The average times to travel 50 foot unloaded and loaded intervals were calculated and recorded in columns "r" and "s" respectively. Note that the average times are determined by multiplying the elemental times by 50 and then dividing by the number of feet traveled. For example, the average time per 50 foot unloaded interval for turn one was determined by the computation $\frac{(.0230 \text{ hour})\ (50)}{300} = .0038$ hour.

These average times to travel 50 foot loaded and unloaded intervals are used in Chapter VI to determine the effect of different conditions of soil and various slopes.

AMOUNT OF DATA AVAILABLE FOR THE PARAMETRIC ANALYSIS

When data collection started, the policy was to gather data for 25 turns on as many crawlers as possible. After gathering data for about four weeks, it became obvious that this was not a good policy to follow for two primary reasons. First, too much time was lost looking for different logging operations. The second reason was that often after a logging operation was found, either skidding was not being done consistently or the crawler tractor operator was so inexperienced that useful data could not be gathered. Therefore, the four best logging locations that had been studied during the first four weeks were chosen as areas of

concentration for the rest of the data collection period.

The data for the parametric analysis was taken primarily from studies of four crawler tractors. A summary of the data used is presented in Table IX.

TABLE IX

SUMMARY OF DATA USED FOR THE PARAMETRIC ANALYSIS

No.	Drawbar Horsepower	Range of Distances	Range of Slopes	Range of BF Volumes Per Turn	Number of Turns Studied
1.	40	50' to 700'	-33% to +25%	90 to 1,640	52
2.	52	50' to 550'	-32% to -11%	240 to 1,090	26
3.	52	50' to 450'	-31% to +20%	170 to 1,410	69
4.	75	50' to 500'	-33% to +15%	250 to 1,550	78

CHAPTER VI

PARAMETRIC ANALYSIS OF CRAWLER TRACTOR SKIDDING DATA

This chapter is devoted to determining how the principal variables affect crawler tractor skidding. The author wishes to emphasize that the times, factors, and costs presented in this and remaining chapters are representative of average times, factors, and costs in the area that data was collected. He also wishes to re-emphasize that this was an exploratory study and that more data is required to substantiate some of the information presented.

LOAD WEIGHT

The first hypothesis that was tested was that load weight and time to travel 50 foot loaded intervals were related. To test this hypothesis, time per 50 foot loaded interval versus weight per turn was plotted in Figure 18. Crawler size was held constant (large crawler), soil was held constant at class "2", slopes were all classified as "A", and the operator was working at 100 percent efficiency. From this graph it is obvious that there was no correlation between time per 50 foot loaded interval and weight per turn.

Because there was no correlation between time per 50 foot loaded interval and weight per turn, the average load weight as observed in the field for each crawler was plotted against crawler weight and the regression equation, (average load weight = 2,249 + .19 crawler weight) determined. This graph is shown in Figure 19. The correlation coefficient was about .99.

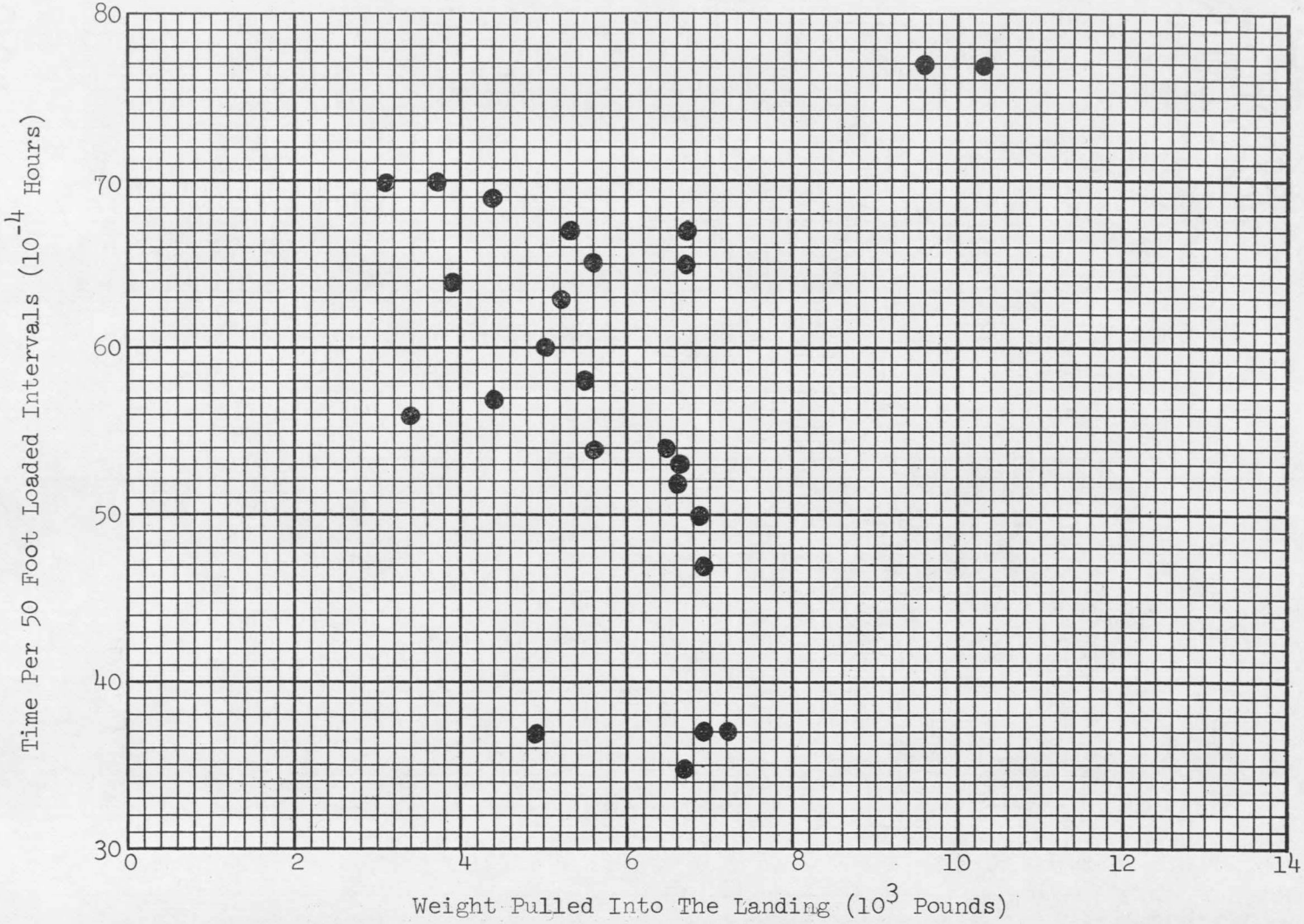

Figure 18. Time per 50 foot loaded intervals vs. weight pulled into the landing.

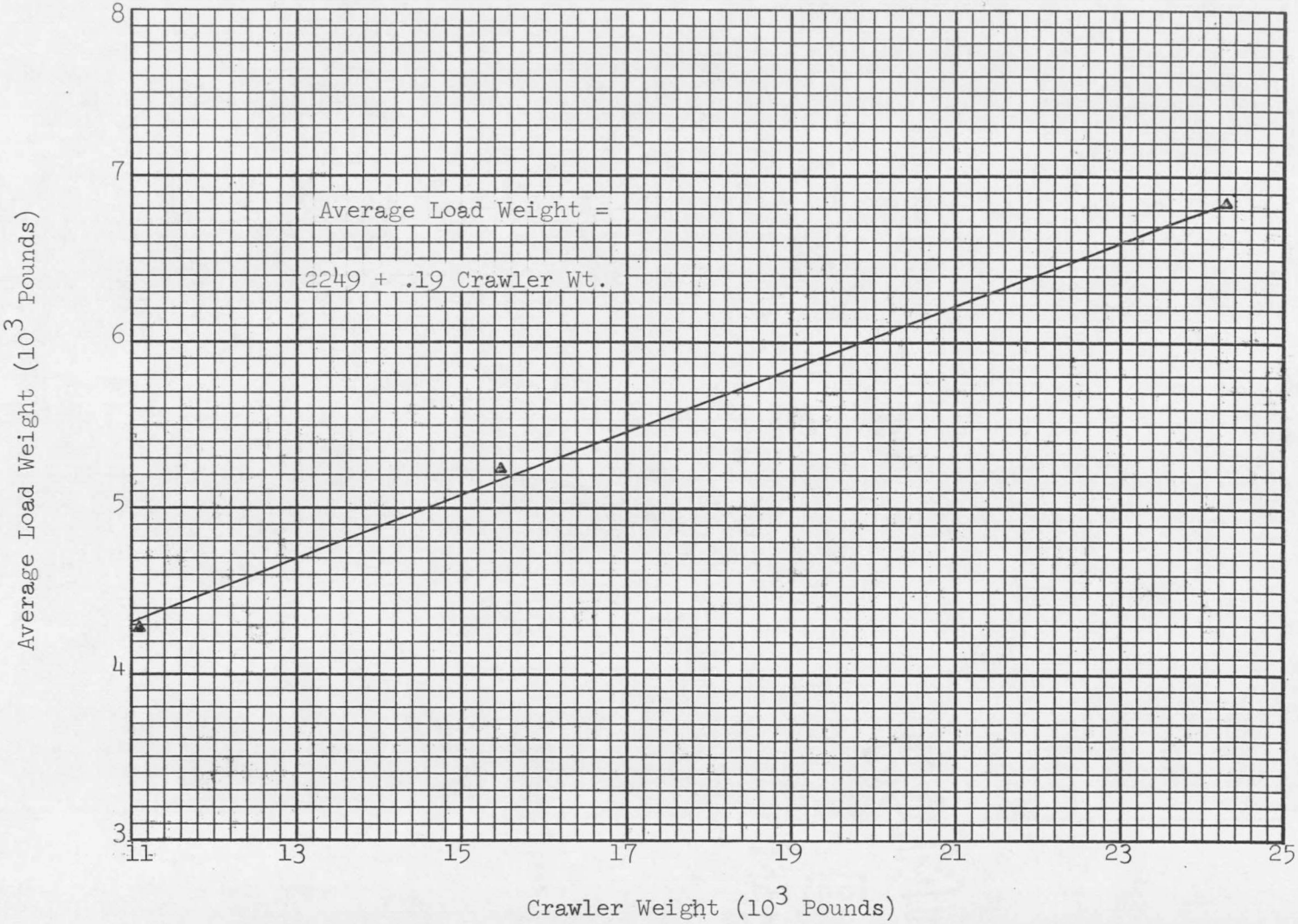

Figure 19. Average load weight vs. crawler weight.

The following average load weights per turn will be used:

Small crawler - 4,287 lbs. per turn
Medium crawler - 5,256 lbs. per turn
Large crawler - 6,855 lbs. per turn.

SOILS

The second hypothesis tested was that the times per 50 foot intervals varies with soil condition. In statistical terms this means the times per 50 foot intervals were different for the various soil conditions or $\mu_1 \neq \mu_2 \neq \mu_3$.

This hypothesis was tested twice by using the analysis of variance technique. For the first test, the average times per 50 foot unloaded intervals for a large crawler working on slope classified as "A" were compared. For the second test, the average times per 50 foot loaded intervals for a medium crawler working on slope classified as "A" were compared. The operators were both working at 100% efficiency. A summary of these two tests is presented in Table X. For these tests and all remaining tests a five percent significance level was used.

Because there was a difference in the times that it took a crawler to travel under different conditions of soil, a method had to be devised to determine the effect of soil. The method used was to compare the means of the times to travel 50 foot intervals holding operator, crawler size, and slope constant. The means of the times for 50 foot loaded intervals and 50 foot unloaded intervals were compared separately because one time the crawler is pulling a load and the other time it is not.

TABLE X

ANALYSIS OF VARIANCE SHOWING THERE IS A DIFFERENCE IN TRAVEL TIMES FOR DIFFERENT SOILS

H_0: $\mu_1 = \mu_2 = \mu_3$
H_A: $\mu_1 \neq \mu_2 \neq \mu_3$

Test	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Conclusion
1	Treatment	2	2,880	1,440	10.44	Reject H_0
	Error	30	4,126	137.8		Accept H_A
	Total	32	7,006			
2	Treatment	2	6,541	3,270.5	18.8	Reject H_0
	Error	31	5,380	173.5		Accept H_A
	Total	33	11,921			

Soil classified as number "1" was used as the base for comparison. The factors for the other soil classifications were determined by dividing the mean time for soil number "1" by the mean time for soil number "2" or "3". For example, if the average time to travel 50 foot loaded intervals on soil "1" was one minute and the average time to travel 50 foot loaded intervals on soil number "2" was two minutes, the factor for soil "1" was one and the factor for soil "2" was $\frac{1 \text{ minute}}{2 \text{ minute}} = .5$. This could also be stated by saying that the times to travel 50 foot loaded intervals on soil "2" had to be multiplied by .5 to obtain the times to travel 50 foot loaded intervals on soil "1". A summary of the loaded and unloaded soil factors is given in Table XI.

TABLE XI

SOIL FACTORS FOR DIFFERENT CLASSIFICATIONS OF SOIL

	Soil 1	Soil 2	Soil 3
Unloaded	1.00	.62	.55
Loaded	1.00	.56	.56

The reader should note that the factors for soils "2" and "3" are the same when loaded. This should be expected because the crawler operator will generally clear the rocks and brush off the trail when traveling unloaded as well as looking for the best trail to return to the landing.

SLOPES

The third hypothesis tested was that there was no difference in the times to travel 50 foot loaded or unloaded intervals within a slope class. This hypothesis was tested to justify the slope classification. It should be noted that this thesis deals only with skidding downhill.

Again the analysis of a variance technique was used. A summary of three tests is presented in Table XII. The null hypothesis, $\mu_1 = \mu_2 = \ldots = \mu_k$, implies, for example, that the mean time for 0% slope = mean time for -1% slope = ... = mean time for -15% slope. Soil, operator, and crawler size were held constant while performing the analysis of variance for each test.

TABLE XII

ANALYSIS OF VARIANCE SHOWING THERE IS NO DIFFERENCE IN TRAVEL TIMES WITHIN A SLOPE CLASS

H_0: $\mu_1 = \mu_2 = \ldots = \mu_k$

H_A: $\mu_1 \neq \mu_2 \neq \ldots \neq \mu_k$

Slope Classification	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Conclusion
A	Treatment	5	984	196.8	.77	Accept H_0
	Error	25	6,350	254		
	Total	30	7,334			
B	Treatment	3	483	161	.24	Accept H_0
	Error	16	10,715	670		
	Total	19	11,198			
C	Treatment	3	1,221	470	.77	Accept H_0
	Error	8	4,223	527.8		
	Total	11	5,444			

Since there was no difference between the times within a slope class, the next hypothesis tested was that there was no difference in times over the range of slopes. In other words, the null hypothesis that was tested was $\mu_A = \mu_B = \mu_C = \mu_D$. A summary of two tests is presented in Table XIII.

TABLE XIII

ANALYSIS OF VARIANCE SHOWING THERE IS A DIFFERENCE IN TRAVEL TIMES OVER THE RANGE OF SLOPES

H_0: $\mu_A = \mu_B = \mu_C = \mu_D$
H_A: $\mu_A \neq \mu_B \neq \mu_C \neq \mu_D$

Test	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Conclusion
1	Treatment	3	6,926	2,308	29.13	Reject H_0
	Error	60	4,755	79		Accept H_A
	Total	63	11,681			
2	Treatment	2	7,452	3,726	14.93	Reject H_0
	Error	23	5,741	250		Accept H_A
	Total	25	13,193			

Because there was a difference in times over the range of slopes, the means were compared to derive slope factors. A summary of these slope factors is presented in Table XIV.

The .84 from Table XIV for slope "B" unloaded implies that the times must be multiplied by .84 to obtain the times for slope "A". The 1.07 for slopes "C" and "D" loaded implies that the crawler moves faster down a steep slope than on a level to moderate slope and that the times for slopes "C" and "D" have to be multiplied by 1.07 to obtain times for slopes "A" and "B".

TABLE XIV

SLOPE FACTORS FOR DIFFERENT CLASSIFICATIONS OF SLOPE

	Slope A	Slope B	Slope C
Unloaded	1.00	.84	.68
Loaded	1.00	1.00	1.07

TIMES TO TRAVEL 50 FOOT INTERVALS

Basic times to travel 50 foot intervals, loaded and unloaded, were determined from the office data sheets for each size crawler traveling on soil classified as one and slope classified as "A". These basic times per 50 foot intervals are shown in Table XV.

TABLE XV

BASIC TIMES TO TRAVEL 50 FOOT UNLOADED AND LOADED INTERVALS ON SOIL "1" AND SLOPE "A"

Crawler Size	Unloaded	Loaded
Small	.0045 hour	.0060 hour
Medium	.0042 hour	.0037 hour
Large	.0041 hour	.0036 hour

To determine the time to travel on conditions of soil and slope other than one and "A" respectively, the basic times in Table XV were multiplied by the reciprocals of the proper soil and slope factors. If one wants to know the time for a medium crawler to travel 50 feet unloaded on soil three and slope "B", .0042 hour is multiplied by $\frac{1}{.55}$ for soil and then by $\frac{1}{.84}$ for slope. In this example the time would be (.0042 hour)$(\frac{1}{.55})(\frac{1}{.84})$ or .0091 hour.

HOOKING AND UNHOOKING TIMES

Hooking and unhooking times refer to the times to hook chokers in the woods and to unhook chokers at the landing. Average times per choke when a choker setter was not used to aid in hooking and unhooking are presented in Table XVI. The average number of logs per turn is also presented in this table.

TABLE XVI

AVERAGE TIMES PER CHOKE TO HOOK AND UNHOOK WHEN A CHOKER SETTER IS NOT USED AND THE AVERAGE NUMBER OF LOGS PER TURN

Crawler Size	Hooking	Unhooking	Average Number of Logs per Turn
Small	.0216 hour	.0066 hour	3.54
Medium	.0190 hour	.0059 hour	5.16
Large	.0138 hour	.0045 hour	6.16

The reader should note that as the crawler size and number of logs per turn increase, the average times to hook and unhook chokers decrease. This should be expected because the time to get off the crawler and also to get back on the crawler after hooking or unhooking was completed, was included in the elemental times and therefore, included in the average times. Also, once several logs are located, it generally does not take as long to place the second choker on a log as it does for the first choker. Thus, part of the elemental times for hooking and unhooking chokers is taken up by looking for logs to be skidded.

If a choker setter was used to aid in hooking and/or unhooking chokers, the elemental times for hooking and/or unhooking chokers were multiplied by the number of men and then divided by the number of logs. One would probably expect that the elemental times (i.e. those times taken by subtracting stop watch readings) for two men would be one half the elemental times for one man. Then, after multiplying by two and dividing by the number of logs, the average time per choke would be the same for two men as for one man.

This assumption was false as can be seen from the average times to hook and unhook chokers when a choker setter was used. Table XVII presents these average times. This table indicated that it actually takes more man hours per choker to hook or unhook when a choker setter is used. The values in Table XVII were divided by two when determining how long the crawler sets idle while chokers were being hooked or unhooked. This was done because the actual clock times or elapsed times were only half the times in Table XVII because two men were doing the work.

TABLE XVII

AVERAGE TIMES PER CHOKE TO HOOK AND UNHOOK
WHEN A CHOKER SETTER IS USED

Crawler Size	Hooking	Unhooking
Small	.0343 hour	.0087 hour
Medium	.0302 hour	.0077 hour
Large	.0219 hour	.0059 hour

A more comprehensive analysis of the advantages and disadvantages of using a choker setter was developed by Mr. John Heaney of the Industrial Engineering Department at Montana State University.

DECKING

Decking is the operation of pushing the logs into a pile at the landing. The hypothesis that the number of logs per turn does not affect decking time was tested to see if a constant time per turn for decking could be used for each crawler size. A summary of an analysis of variance with null hypothesis, that the times for decking does not vary as the number of logs increase, is presented in Table XVIII. Crawler size was held constant while performing the analysis of variance.

TABLE XVIII

ANALYSIS OF VARIANCE SHOWING THERE IS NO DIFFERENCE IN THE TIMES TO DECK LOGS AS THE NUMBER OF LOGS INCREASE

H_0: $\mu_1 = \mu_2 = \cdots = \mu_k$
H_A: $\mu_1 \neq \mu_2 \neq \cdots \neq \mu_k$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Conclusion
Treatment	4	12,548	3,137	.78	Accept H_0
Error	34	136,097	4,003		
Total	38	148,645			

Because the number of logs per turn did not affect the decking time when the crawler size was held constant, only the mean decking time for each size crawler studied was used. The mean decking times per turn are presented in Table XIX.

TABLE XIX

MEAN DECKING TIMES PER TURN

Crawler Size	Decking Time Per Hour
Small	.0200 hour
Medium	.0166 hour
Large	.0161 hour

FREEING

The element, freeing logs, was included in the study because often the logs were jackstrawed behind the crawler. It took time to get the logs behind the crawler so it could start moving towards the landing. This elemental time is the time that it took to winch the logs behind the crawler.

The time for this element varied so much that only a mean for each turn was used. This mean was .0101 hour, regardless of the crawler size or soil condition. It should be noted that this elemental time varied from .0005 hour to .0680 hour.

FOREIGN ELEMENTS

The only foreign element that was considered productive was clearing trail. This was the time taken to clear slash and rocks off of the skidding trail while moving unloaded to the woods.

A constant time per turn for each soil condition was calculated in the following manner:

1. The amount of time required for clearing brush on each type soil per study was determined.
2. The above time was divided by the number of turns on the study for that soil type to arrive at an average time per turn for a particular soil classification.
3. The average times for each crawler were then weighted by the number of turns and a weighted average for all crawlers determined.

The weighted average times per turn for clearing trail are presented in Table XX.

TABLE XX

AVERAGE TIMES PER TURN FOR CLEARING TRAIL

Soil Classification	Average Times Per Turn
1	.0057 hour
2	.0113 hour
3	.0330 hour

All of the times presented in this chapter were adjusted to an 100% operator. This was accomplished by multiplying the times on the office data sheets by the decimal equivalents of the operators' efficiencies in percent. If the time for other than an 100% operator was desired, the times given in the tables were multiplied by the reciprocal of the operator efficiency in decimal form.

SUMMARY

By utilizing the times and factors developed in the preceding part of this chapter, a generalized equation for time per turn for any crawler size was developed. The generalized equation may be written as:

$$T = (TU + CT + HC + FL + TL + UH + DL)\left(\frac{1}{OE}\right).$$

The symbols, activities represented by the symbols, controlling variables, and the tables where the basic times and factors for each activity can be found are summarized in Table XXI.

An example should help to clarify the method of determining the time per turn to skid logs with a crawler tractor if certain conditions are

TABLE XXI

SKIDDING TIME ACTIVITIES AND CONTROLLING VARIABLES

Symbol	Activity	Controlling Factors	Tables Where Basic Times Can Be Found
T	Time /turn for a given crawler size	Crawler size, soil, slope distance, number of logs, number of men, operator efficiency	
T U	Travel unloaded to the woods	Crawler size, soil, slope distance, operator efficiency	XI, XIV, XV
C T	Clear slash and rocks off trail	Soil, operator efficiency	XX
H C	Hook chokers	Crawler size, number logs, number of men, operator efficiency	XVI, XVII
F L	Free logs	Operator efficiency	Time = .0101 hour per turn for an 100% operator
T L	Travel loaded to the landing	Crawler size, soil, slope, distance, operator efficiency	XI, XIV, XV
U H	Unhook chokers	Crawler size, number of logs, number of men, operator efficiency	XVI, XVII
D L	Deck Logs	Crawler size, operator efficiency	XIX
O E	Operator efficiency	Skill, experience, motivation, physical characteristics	Estimated

given. Assume the following conditions:

1. A Caterpillar D6B is used for skidding-a large crawler.
2. The soil is classified as number two.
3. The slope is -25% or Slope "C".
4. The distance unloaded is 450 feet.
5. The distance loaded is 400 feet; the operator moved the crawler 50 feet while hooking chokers.
6. The number of logs is six.
7. Two men hook chokers in the woods.
8. One man unhooks chokers at the landing.
9. The operators are rated at 100%.

The time for this turn would be:

$$T = \left[(.0041 \text{ hour}/50 \cancel{\text{ft.}})\left(\frac{1}{.62}\right)\left(\frac{1}{.79}\right)(450 \cancel{\text{ft.}})\right.$$

$$+ .0113 \text{ hour}$$

$$+ (.0219 \text{ hour}/\cancel{\text{choke}})\left(\tfrac{1}{2}\right)(6 \cancel{\text{chokes}})$$

$$+ .0101 \text{ hour}$$

$$+ (.0036 \text{ hour}/50 \cancel{\text{ft.}})\left(\frac{1}{.56}\right)\left(\frac{1}{1.07}\right)(400 \cancel{\text{ft.}})$$

$$+ (.0045 \text{ hour}/\cancel{\text{choke}})(6 \cancel{\text{chokes}})$$

$$\left. + .0161 \text{ hour}\right]\left[\frac{1}{1.00}\right]$$

$$= .0753 \text{ hour} + .0113 \text{ hour} + .0657 \text{ hour} + .0101 \text{ hour} + .0481 \text{ hour} +$$

$$.0270 \text{ hour} + .0161 \text{ hour} = \underline{.2536 \text{ hour.}}$$

CHAPTER VII

THE EFFECT OF THE PRINCIPAL VARIABLES ON THE ECONOMIC SKIDDING CAPABILITIES OF SOME CRAWLER TRACTORS IN THE ROCKY MOUNTAIN AREA

The purpose of this chapter is to determine the cost per thousand board feet to skid logs, given different combinations of variables. To accomplish this aim the costs involved in operating the different crawler sizes were determined. These costs were related to the times developed in Chapter VI to develop cost curves for different combinations of variables.

COSTS INVOLVED IN OPERATING VARIOUS CRAWLERS

Costs can be classified as owning and operating costs. (3, p. 51) Owning costs are also often called fixed costs. Items included in this category are depreciation, interest, insurance, and taxes. Operating costs are also commonly known as variable costs. Included in this category of cost are fuel, lubricants, maintenance, operator wage, and choker setter wage if a choker setter is used.

Depreciation cost was figured by dividing the new cost by the number of hours in the depreciation period. Generally a five year period is allowed for depreciating the equipment. Most of the loggers in the Rocky Mountain area work about 40 weeks per year. During the logging season these loggers generally work about 50 hours per week. Therefore, the depreciation period in the Rocky Mountain area is generally 5 years x 40 weeks per year x 50 hours per week = 10,000 hours.

No resale or salvage value of the equipment is used because used

equipment value cannot be considered stable. If one does desire to consider resale or salvage value, the hourly depreciation cost is determined by the equation: hourly depreciation cost = $\frac{\text{new cost - resale value}}{\text{10,000 hours}}$. (3, p. 52)

"Interest, insurance, and taxes average about 10% of the average yearly investment divided by the estimated number of operating hours each year. Since both of these factors vary on a year-to-year basis, a rule of thumb has been developed that accurately estimates the cost of interest, insurance, and taxes to be $.03 per $1,000.00 of the new cost per hour." (3, p. 53)

Fixed costs per hour for a medium crawler were determined as follows:

Hourly depreciation cost = $17,450.00/10,000 hours = $1.74

Hourly interest, insurance, and taxes cost = $17,450.00 x $.03/$1,000.00 = $.52.

The amount of fuel consumed by the crawler while skidding was estimated by the gyppo or crawler operator. The estimated amounts were the following:

1. Small crawlers - 1.0 gallons per hour
2. Medium crawlers - 1.5 gallons per hour
3. Large crawlers - 2.5 gallons per hour.

Diesel fuel used for crawlers engaged in logging can be purchased for about $.17 per gallon. Therefore, the cost for fuel per hour would be the estimated consumption multiplied by $.17. For example, the hourly fuel cost for a medium crawler would be 1.5 gallons per hour x $.17 per gallon = $.26 per hour.

Included in the category of lubricants are gasoline for the starting engine, oil, filters, and grease. The hourly cost for lubricants for the

different crawler sizes were estimated to be the following: (3, p. 54-55)

1. Small crawlers - $.10 per hour
2. Medium crawlers - $.12 per hour
3. Large crawlers - $.14 per hour.

Maintenance costs include the necessary parts and labor to keep a crawler tractor properly maintained. Included in this category are cable for the winch, chokers, track maintenance, periodic overhauls when necessary, or in general, anything required to keep the crawler tractor in good running condition.

The hourly cost for maintenance was determined by multiplying the hourly depreciation cost by .90. (3, p. 56) It should be noted that during the first part of a crawler's service life the maintenance cost will probably be less than during the latter part of its service life.

The crawler tractor industry has found through actual record keeping that 90% of the hourly depreciation cost is a good estimate of maintenance cost if the crawler works primarily under average conditions. This figure can vary depending on how well the operator takes care of the equipment and whether or not the owner does much of the repair work himself.

The operator's wage varies among contractors as was shown in Table III. For this study, a wage of $2.50 per hour for the crawler tractor operator was assumed. If a choker setter was used, his assumed wage was $2.00 per hour. These wages are representative of the wages paid in the data collection area.

The costs involved in operating the various crawlers are summarized in Table XXII.

TABLE XXII

HOURLY COSTS INVOLVED IN OPERATING VARIOUS CRAWLERS

Cost \ Crawler Size	Small	Medium	Large
Depreciation	$1.18	$1.74	$2.46
Interest, Insurance, & Taxes	.35	.52	.74
Fuel	.17	.26	.42
Lubricants	.10	.12	.14
Maintenance	1.06	1.57	2.21
Operator Wage	2.50	2.50	2.50
Total cost per hour if a choker setter is not used	$5.36	$6.71	$8.47
Choker Setter Wage	$2.00	$2.00	$2.00
Total cost per hour if a choker setter is used	$7.36	$8.71	$10.47

It should be emphasized that the hourly costs presented in Table XXII vary depending on depreciation period assumed, resale or salvage values, maintenance estimates, and operator and choker setter wages.

If the person using this thesis to estimate skidding costs does not agree with the costs presented in this table, he should make the necessary adjustments before proceeding to the next section of this chapter.

COST CURVES FOR VARIOUS COMBINATIONS OF VARIABLES

Curves may now be developed that will give the skidding cost per thousand board feet for different combinations of variables. Many of these curves can be developed by merely varying the variables.

In Chapter VI it was shown that the time per turn to skid logs with a certain crawler size is:

$$T = \left[(\text{Basic time to travel 50 ft. unloaded int.})\left(\frac{1}{\text{soil fact.}}\right)\left(\frac{1}{\text{slope fact.}}\right)\left(\frac{\text{dist.}}{50}\right)\right.$$

$$+ \text{ Time for clearing trail}$$

$$+ (\text{Average time per choke to hook})\left(\frac{1}{\text{number of men}}\right)(\text{number of chokers})$$

$$+ \text{ Time for freeing the logs}$$

$$+ (\text{Basic time to travel 50 ft. loaded int.})\left(\frac{1}{\text{soil fact.}}\right)\left(\frac{1}{\text{slope fact.}}\right)\left(\frac{\text{dist.}}{50}\right)$$

$$+ (\text{Average time per choke to unhook})\left(\frac{1}{\text{number of men}}\right)(\text{number of chokers})$$

$$\left. + \text{ Time to deck the logs}\right]\left[\frac{1}{\text{operator efficiency}}\right].$$

If the time per turn is multiplied by the hourly cost, the cost per turn can be determined. If the cost per turn is divided by the number of board feet per turn and then multiplied by 1,000, the cost per thousand board feet is obtained.

The reader is now referred to the example on page 86, in which the time was calculated to be .2536 hours. A choker setter was used with a large crawler so the hourly operating cost from Table XXII was $10.47. It was assumed that the log type was lodgepole pine. Therefore, the number of board feet per turn was the average load weight for large crawlers, or 6,855 pounds, divided by 10.8 pounds per board foot, or 635 board feet.

The cost for skidding 1,000 board feet was determined by the following equation:

$$\text{Cost/MBF} = \frac{(.2536 \text{ hour})(\$10.47/\text{hour})}{635 \text{ board feet}} \times 1{,}000 = \$4.17.$$

Figures 20, 21, and 22 are presented to show how skidding cost per thousand board feet varies given different combinations of variables.

Distance loaded was assumed to be 50 feet less than distance unloaded. This is considered a good assumption because the operators generally moved

the crawlers about 50 feet while hooking chokers. Operator efficiency was assumed to be 100%.

Lodgepole pine, weighing 10.8 pounds per board foot, was used as the log type in developing the cost curves. The average load weights per turn, given on page 73, were divided by 10.8 to give the following board foot volumes per turn:

1. Small crawlers - 397 board feet per turn
2. Medium crawlers - 487 board feet per turn
3. Large crawlers - 635 board feet per turn.

Figure 20 presents skidding costs for crawlers working on soil "1" and slope "A". Figure 21 presents skidding costs for crawlers working on soil "2" and slope "A". These two figures, showing skidding costs, are representative of the most common conditions in the woods in the data collection area. The average number of logs per turn, used in developing skidding costs for Figures 20 and 21, were those presented in Table XVI or:

1. Small crawlers - 3.54 logs per turn
2. Medium crawlers - 5.16 logs per turn
3. Large crawlers - 6.16 logs per turn.

Six cost lines are presented in each figure. For Figures 20 and 21 the curves are labeled as follows:

1. Small crawler without a choker setter to aid in hooking and unhooking chokers
2. Small crawler with a choker setter to aid in hooking and unhooking chokers
3. Medium crawler without a choker setter to aid in hooking and unhooking chokers
4. Medium crawler with a choker setter to aid in hooking and unhooking chokers

5. Large crawler without a choker setter to aid in hooking and unhooking chokers

6. Large crawler with a choker setter to aid in hooking and unhooking chokers.

Figure 22 is presented to show how the skidding cost per thousand board feet varies if the crawler size and soil are held constant but the number of logs per turn and slope changes. Figure 22 assumes the crawler size is medium and the soil is class "2". The number of board feet per turn is still assumed to be 487.

The following six curves are presented in Figure 22:

1. Medium crawler without a choker setter, soil 2, slope A, 5.16 logs per turn

2. Medium crawler with a choker setter, soil 2, slope A, 5.16 logs per turn.

3. Medium crawler without a choker setter, soil 2, slope B, 3 logs per turn.

4. Medium crawler with a choker setter, soil 2, slope B, 3 logs per turn.

5. Medium crawler without a choker setter, soil 2, slope D, 3 logs per turn.

6. Medium crawler with a choker setter, soil 2, slope D, 3 logs per turn.

Cost lines three through six would be representative of large diameter tree areas where fewer logs are required to yield the same average load weight as in areas of small diameter trees.

It should be emphasized that the cost per thousand board feet for skidding logs given any set of conditions can be determined.

The reader is encouraged to develop other cost curves from the information given in this thesis to fit his particular situation.

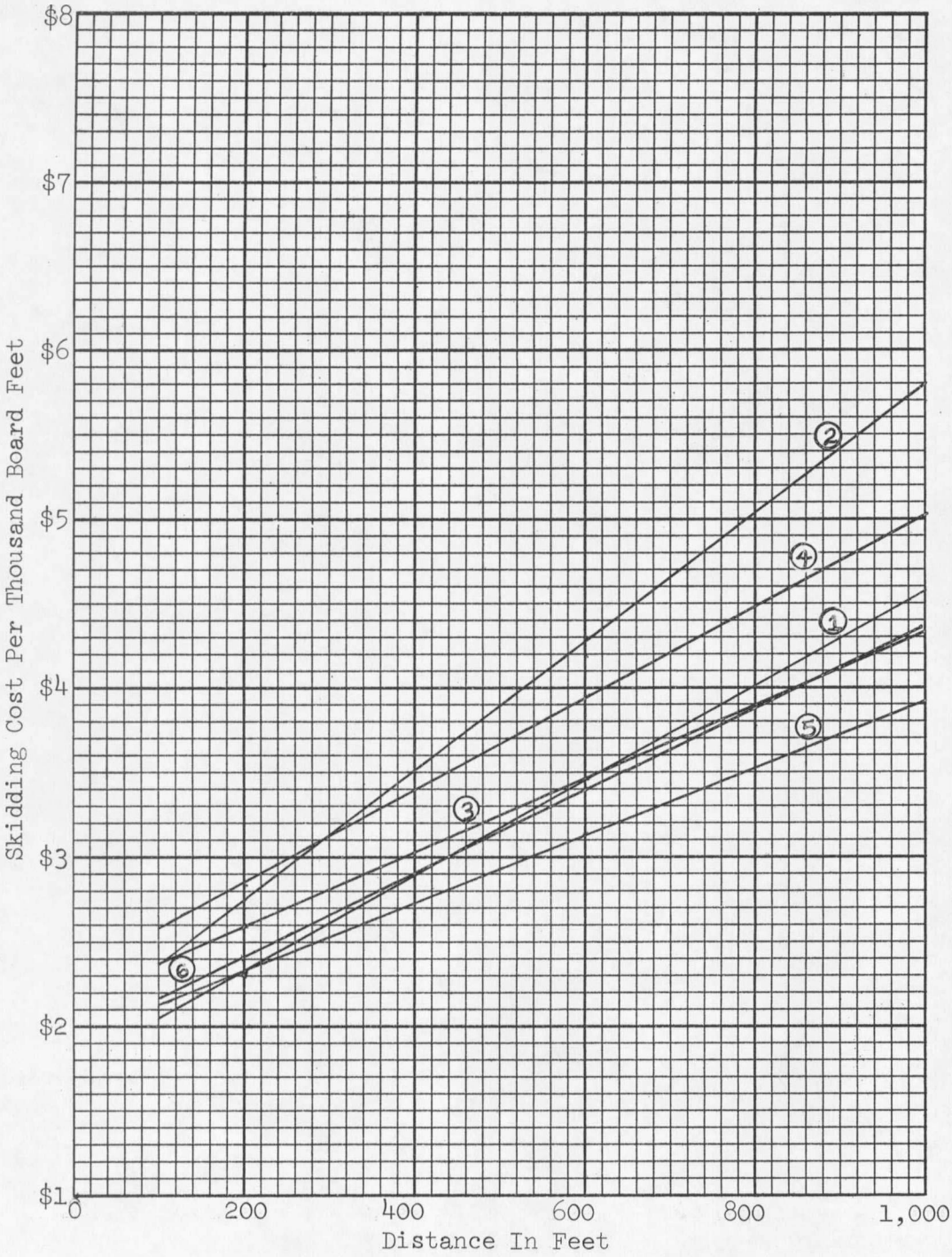

Figure 20. Comparison of skidding costs for soil class "1" and slope "A".

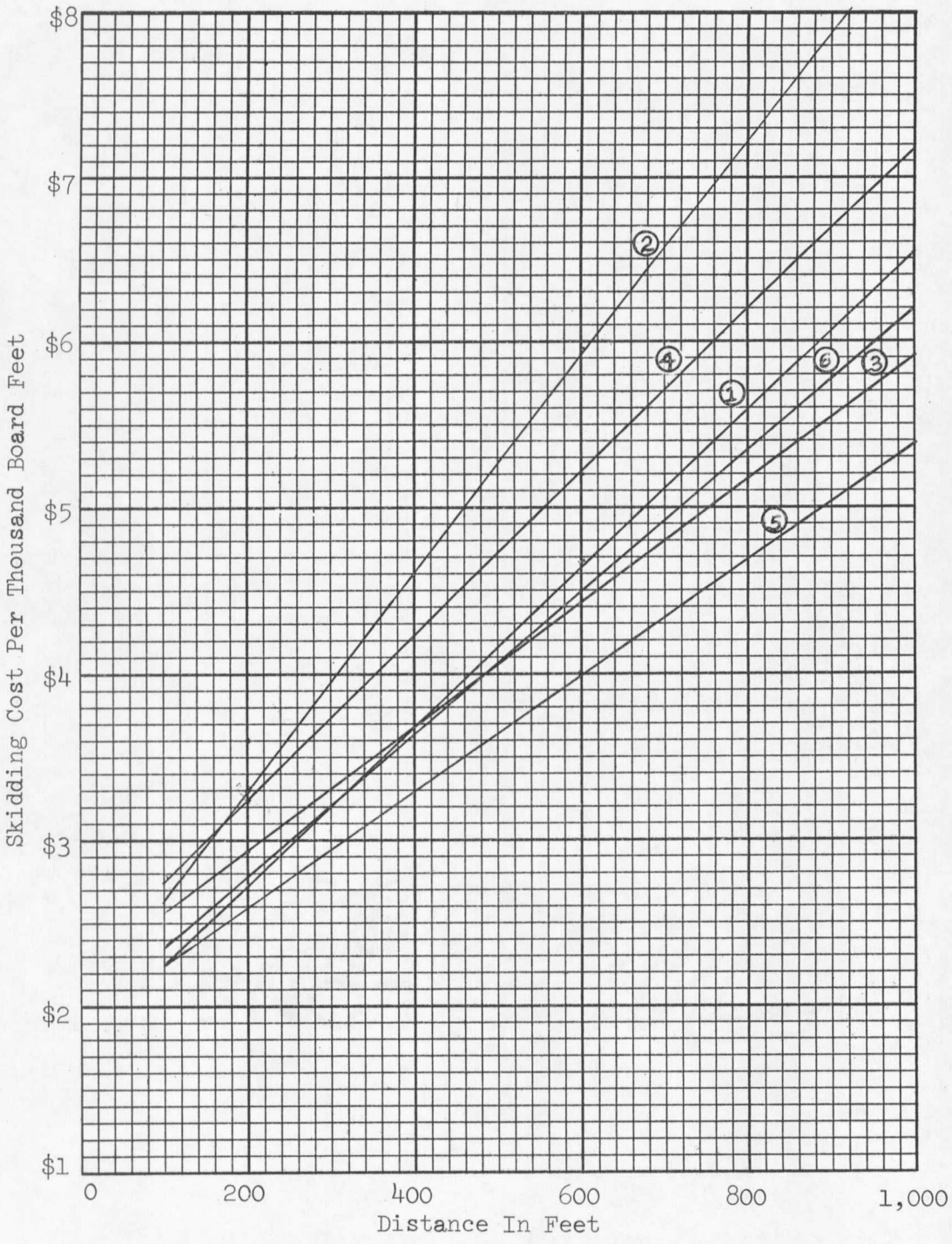

Figure 21. Comparison of skidding costs for soil class "2" and slope "A".

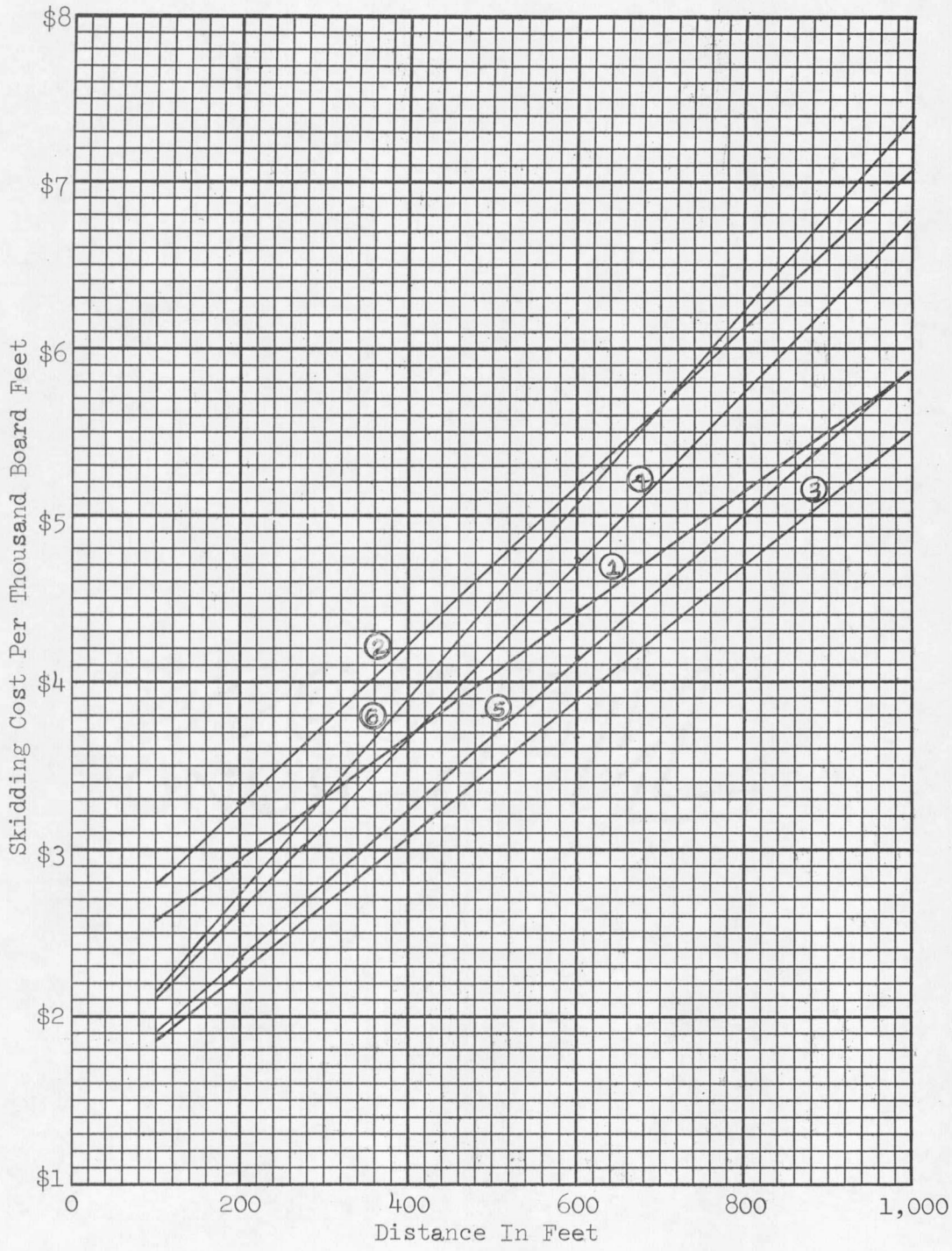

Figure 22. Comparison of skidding costs for a medium crawler on soil "2".

CHAPTER VIII

SUMMARY

The purpose of this chapter is three-fold. First, some conclusions will be discussed. Second, some refinements will be discussed and then recommendations for further study will be made.

CONCLUSIONS

The reader may recall that there were two major objectives of this thesis. They were the following:

1. To present preliminary data and conclusions reached concerning non-crawler tractor skidding.

2. To present an exploratory analysis of the effect of the principal variables affecting some crawler tractor skidding in the Rocky Mountain area.

Non-crawler tractor skidding

Non-crawler tractor skidding machines in common use in the Rocky Mountain area were discussed in Chapter III. The author set forth the following conclusions concerning non-crawler tractor skidding machines:

1. None of these machines (i.e. rubber-tired skidders, jammer skidders, or high lead skidders) can be used without the aid of a crawler tractor for building roads.

2. Rubber-tired skidders should be investigated by loggers working primarily on level to moderate slopes.

3. Small contractors should investigate jammer skidders because of their versatility to be used as both a skidding and a loading machine, thus

lowering the initial investment in equipment and also utilizing the equipment more fully.

4. A lower priced high lead system is needed in areas where small logging contractors work so they can manage the initial investment.

The conclusions were based primarily on conversations with the loggers, a literature search, and some actual data collected in the field.

Crawler tractor skidding

The major part of this thesis was devoted to the exploratory analysis of the effect of the principal variables affecting some crawler tractor skidding in the Rocky Mountain area. Approximately 800 man hours were spent gathering data and about 150 man hours were spent analyzing the data before the author started writing this thesis.

Before this analysis could be made, a system of classifying the principal variables and a method of gathering data had to be devised. The classification of variables is given in Chapter IV, and the method of gathering data and putting it into usable form is presented in Chapter V.

Several conclusions can be drawn from the exploratory analysis of crawler tractor skidding. These conclusions are as follows:

1. Continuous stop watch study. Continuous stop watch time study is probably the best method of gathering data for this type of analysis because this method appears to be the least costly and most accurate method of obtaining all the pertinent information needed for the analysis.

2. Average load weight per turn versus crawler weight. There is a relationship between average load weight per turn and crawler weight as given by the equation, average load weight = 2,249 pounds + .19 crawler

weight, between crawler weights of 11,800 pounds and 24,300 pounds.

3. Soil. Soil affects the ability of a crawler to move. In Chapter VI it was shown that the times for soil "2" have to be multiplied by .62 to attain the same times for soil "1" when traveling unloaded. More time on the average is taken to clear trail for soil "2" than soil "1". If everything but soil is assumed constant, it costs $3.04 per thousand board feet to skid with a medium crawler for 400 feet on soil "1" and $3.68 for the same crawler skidding 400 feet on soil "2".

4. Large crawlers. It is generally cheaper to skid with a large crawler than with a small or medium crawler.

5. Choker setters. If a choker setter is used, the skidding time is less, but the cost per thousand board feet for skidding is generally higher.

6. Number of logs. The cost per thousand board feet for skidding decreases as the number of logs decrease, but load weight stays the same.

REFINEMENTS

Suggestions for refinements to this thesis will be confined to the parametric analysis portion as this is where the major emphasis has been directed. Suggested refinements are:

1. For soils and slopes other than "1" and "A" respectively it was difficult to find crawlers working. The author suggests that before additional data is collected the logging areas be surveyed to determine the soil and slope generally found in the area. After this is accomplished, data collection should be stressed in areas where soil and slope are not "1" and "A" respectively.

2. While collecting data, only three crawlers (one of each size) should be studied. This is necessary to get a large enough sample without a large amount of variation caused by operator efficiencies.

3. A major refinement would be to look at the possibility of applying operations research to the skidding problem by using Monte Carlo simulation. The author feels the simulation approach will be more practical after more data is collected.

4. Another suggested refinement would be to compare the cost involved in building more roads and landings versus skidding longer distances. Besides the obvious cost of the crawler tractor and operator for building roads, the silvicultural requirements will have to be considered.

RECOMMENDATIONS FOR FURTHER STUDY

1. The author recommends that more time be spent analyzing the non-crawler tractor skidding machines. It is his opinion that all of these machines have potential in particular situations as given in Chapter III.

2. In accordance with recommendation "1", the feasibility of several gyppo contractors with different types of skidding equipment forming partnerships to better utilize their equipment should be studied. As the logging industry becomes more competitive, the forming of partnerships by the independent gyppo contractors seems to be the only solution to obtain profitable operations.

3. A lower priced high lead skidder is needed in many areas. This is primarily a design problem needing considerable study in the future.

4. The effect of logmaking practices on skidding, and of decking on loading requires further study. If logs are jackstrawed during logmaking, skidding takes longer. If a poor deck is made, loading takes longer. Costs should be obtained for different conditions of logmaking, skidding, decking, and loading and then be analyzed to see what level of care should be taken when felling trees and making decks.

5. As a final area for further study, the author feels some standard or relatively standard wage payment practice should be established. The term, wage payment practice, is used here to mean both the way that the contractors are paid by the mill and the way that the employees are paid by the contractors. If some type of system could be established, the author feels there would be less tendency to move around by contractors and employees, therefore, helping to make the logging profession more stable.

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