PRODUCTION RATES AND SKIDDING COST OF THE FMC MODEL 210 CA HIGH-SPEED SKIDDER

(Second Draft)

by

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A PAPER

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Forestry

Completed March, 1977

Commencement June 1977

APPROVED:

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Date paper is presented: March 7, 1977

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INTRODUCTION

In recent years, inflation and a growing concern for soil compaction and environmental damage have affected both the forest manager and the logger. Balloons, helicopters, and skylines have been used to harvest timber and the results have been promising (Dykstra, 1975, 1976). However, the high cost of using these aerial systems is often prohibitive, particularly in areas of relatively low timber volumes.

Ground based logging systems have been limited to the familiar crawler-type tractor and the rubber-tired skidder. Few changes have been made in these systems to reduce compaction and environmental damage, and major improvements appear unlikely.

In 1974, FMC Corporation introduced a radically new design in logging equipment. Two models of a tracked skidder were introduced, the model 200 BG and the model 200 CA. The 200 BG was designed mainly to skid large quantities of small wood rapidly, and a study of its capabilities has been completed (Legault and Powell, 1975). The model 200 CA was designed to move larger timber at speeds equivalent to those of the rubber-tired skidder, but with reduced soil compaction.

Some maintenance problems were encountered with the suspension system of the model 200 CA and in July of 1976, the model 210 CA was introduced. The basic differences between the two models were a heavier suspension system and new design criteria on the road wheels.

The acceptance of this machine has been remarkable, with well over 200 now being used throughout the western and southern United States. In researching the literature, no evidence was found that production and cost studies have been conducted on this machine. This makes the acceptance of the FMC skidder even more remarkable.

Various studies have been conducted to determine factors that are important in explaining turn time and yarding costs for tractor skidding. Adams (1967), Aulerich, et al. (1974), McCraw (1964), and McDonald (1972) found skidding distance and number of logs per turn to be the most important variables in explaining turn time for tractors and skidders. McIntosh and Johnson (1974) found that for rubber-tired skidders, average tree size, stand and terrain characteristics, and the skidder operator's skill and motivation have the most effect on production rates. Suprisingly, skidding distance was not a significant variable in their study. Schillings (1969) devised a method of estimating skidding costs if skidding distance, terrain type, slope, and operating efficiency could be determined or estimated beforehand.

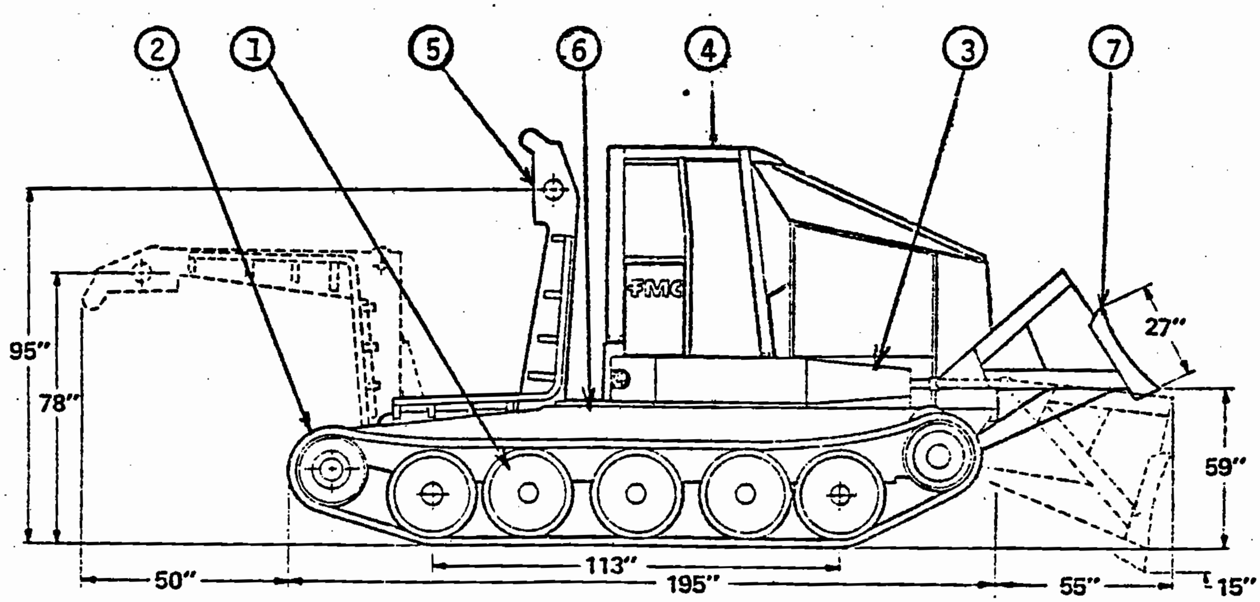
This paper investigates production rates and costs of the FMC model 210 CA skidder. Four variables have been identified that are considered important in affecting skidding production. Time study procedures, regression analysis, skidding costs, and up-hill skidding capabilities are described. It is hoped that more accurate cost allowances can be determined for skidding with the FMC by correct application of the information found in this paper.

BASIC MACHINE DESIGN

The FMC model 210 CA skidder is a tracked machine designed specifically as a logging vehicle. Two machines, a prototype model and a pre-production model, were designed, built, and tested over a period of four and one-half years before the skidder was marketed (Mulligan, 1976).

The main components of the machine, along with some dimensions, are shown in figure 1 and consist of:

1. Torsion bar suspension system.
2. 22 inch wide forged steel track.
3. 197-horsepower engine and 4-speed transmission.
4. Operator cab.
5. Pivotable arch.
6. Heavy duty winch.
7. Front blade.



The general arrangement consists of a running gear with forged steel track and torsion bar suspension, with the suspension mounted to a steel unitized lower chassis structure. The suspension consists of ten sets of dual road-wheels, five per side, mounted on rear facing roadarms. Each roadwheel and arm assembly is free to flex or move up and down using a torsion bar.

This torsion bar suspension provides several unique features for logging vehicle application:

1. The vehicle is able to maintain higher speeds over rough terrain and ground obstacles than equipment not equipped with a suspension system.
2. Shock loads to vehicle and operator are reduced.
3. The track tends to mold to uneven terrain and obstacles, thus maintaining continuous ground contact and traction and providing a lower average ground pressure.
4. Reduced vibration results in minimum energy release into the ground.

The track block itself is of forged steel, and is connected by steel pins working in rubber bushings. These rubber bushings allow the track to flex when operating over uneven terrain, eliminates metal-to-metal wear surfaces, and acts as a seal against entrance of abrasive material around the pin. It is also relatively easy to remove the pin when track repairs are necessary.

The 197-hp diesel engine and 4-speed power shift transmission are mounted as low as possible in the front of the vehicle. This feature reduces vehicle height and lowers and distributes the center of gravity more toward the center of the machine when the machine is loaded. Power is furnished to the tracks through a controlled steering differential and final drives.

Normal steering is accomplished using the controlled steering differential. Applying one steering lateral slows the track to that side while increasing the speed to the opposite track. Equal power is continuously provided to both tracks during a turn. On the model 200 CA, disk brakes were provided which allowed one track to be locked while full power was applied to the other track. This feature was discontinued on the model 210 CA because of maintenance and ground disturbance problems.

A walk-through operator cab is provided with roll-over-protective-equipment and screened window guards. The vehicle is also equipped with a pivotable arch, heavy duty winch of 40,000 pound pull capacity, and a front blade for road blading and decking logs. A detailed manufacturer's specification sheet has been included in Appendix A.

DESCRIPTION OF THE STUDY

The primary objective of this paper is to determine production rates and skidding costs of the FMC model 210 CA skidder. Secondary objectives are to analyze the FMC for uphill skidding capability and to observe and report soil and residual impacts.

To meet these objectives, a detailed time study was used to obtain data on skidding cycle time. This time study was conducted on the Bear Valley Ranger District of the Malheur National Forest located near John Day, Oregon. A map of the timber sale units of interest are shown in figure 2. While five units within the sale were yarded with the FMC skidder, data was collected from units 3 and 4 only.

The timber stand consisted of scattered mature ponderosa pine (Pinus ponderosa, Laws.) overstory, with a residual understory of white fir (Abies concolor, (Gord. & Glend.) Lendl.) and Douglas-fir (Psuedotsuga menziesii, (Mirb.) Franco var. glauca). The sale prescription called for removal of approximately 70 percent of the mature ponderosa pine and some scattered white fir ranging from 12 to 24 inch dbh. Estimated volume removed was from 7000 to 9000 board feet per acre.

The fir reproduction was very heavy in places, with trees of 2 to 12 inch dbh on an average spacing of 3 feet. One of the primary management objectives of this sale was to minimize damage to the residual stand. The criteria set forth in the timber sale contract was to keep the mortality of the residual below 15 percent. Forest Service personnel used transects to monitor this

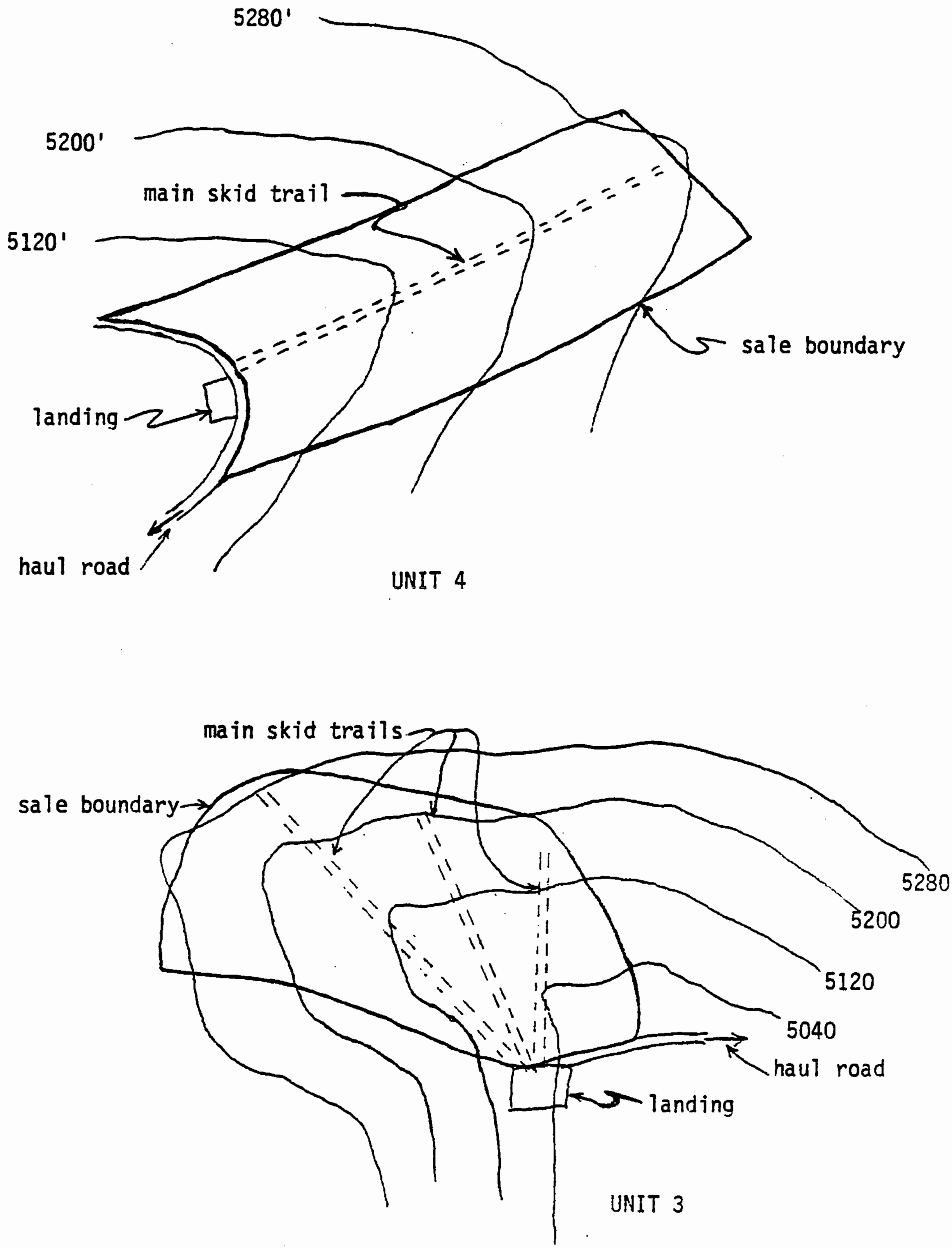


Figure 2. Map of units 3 and 4 of the sale area showing skid trail layout. (not to scale)

residual stand damage.

From my observations, it appeared that as much as 30 percent of the residual damage was a direct result of the felling operation. No real control was exercised to minimize the felling damage, although the logger tried to fall to the skid trails as much as possible. Skid trails were laid out prior to the felling by the logger and approved by the Forest Service. The distance between skid trails ranged from 100 to 150 feet.

TIME STUDY FIELD PRECEDURE

Production data were obtained from two units within the timber sale. Data from unit number 4 were collected in July, 1976, while the data from unit number 3 were collected in September, 1976. Stand characteristics were basically the same in the two units and both units were on north aspects. The skid trail slopes range from 10 to 35 percent on unit 4 and from 25 to 50 percent on unit 3. All data obtained were for downhill skidding. Uphill skidding on slopes as steep as 35 percent was accomplished on this sale, but unfortunately this activity did not occur during the time study.

All data were collected by a single observer. A continuous timing technique was used and separate times were recorded for travel empty, hook, travel loaded, unhook, deck, and delays. Times were recorded to an accuracy of one-tenth of a minute. In addition, the distance to each turn, the percent skidding slope, the number of logs per turn, small and large end diameters, and length of each log were recorded.

Due to the scattered, open character of the ponderosa pine stand, visual contact with the skidder was possible in practically all instances. This open condition permitted the use of a rangefinder to determine the skidding distance of each turn. The rangefinder used was a Rangematic manufactured by Ranging, Incorporated. This rangefinder measures distances between 150 feet and two miles. At distances of 1500 feet, the manufacturer claimed its accuracy was within five percent of the actual distance.

Most of the times were recorded while the observer was positioned at the landing. When observations were taken in the woods, it was difficult to determine accurate log lengths and diameters.

The yarding crew consisted of three men; a skidder operator, a choker setter who hooked the logs in the woods, and a chaser at the landing who unhooked the turns and "bumped" knots. At least 50 percent of the time the skidder operator would get off the machine and help the choker setter pull line and hook the logs. The choker setter appeared to be inefficient at spotting the next turn while waiting for the FMC to return. Consequently, some time was lost in making up a turn.

Five chokers were used on the machine, with the idea of filling these chokers on every turn. The bull line was 3/4 of an inch in diameter and a total of 100 feet was available on the winch drum. Chokers used were 5/8 of an inch in diameter and 14 feet in length. Slider hooks were used to fasten the chokers to the bull line.

ANALYSIS OF THE DATA

Regression equations for travel empty, hook, travel loaded, unhook, and total turn time have been developed for the two sale units separately and also for the combination of the two units. 104 turns were recorded in unit 3 and 47 turns were recorded in unit 4. The independent variables used in these regression equations are summarized in table 1.

The individual elements of the total turn cycle, including decking and delay times, are presented in tables 2, 3, and 4. These tables present the general characteristics of each element and, most importantly, the percentage of the total turn time occupied by each of these elements. Bar graphs are presented in figures 3 to 5 showing the percentage breakdown of the elements.

Frequency distributions of the dependent variable, independent variables, and volume per log are presented in figures 6 through 23.

A hypothesis was formed with independent variables thought to influence each element of the yarding cycle time. A regression analysis computer program, which is part of the Statistical Interactive Programming System (Guthrie, Avery, Avery, 1973) at Oregon State University, was used to test each hypothesis and to generate regression equations.

In the regression equations that follow,
*** indicates that the regression coefficient associated with an independent variable is significantly different from zero at the 0.01 probability level;

Table 1. REGRESSION VARIABLES

Variables	Mean	Standard Deviation	Range
Average skidding distance, feet			
(unit number 4)	504	239	150-950
(unit number 3)	772	453	100-1550
(combined units)	689	417	100-1550
Skid trail slope, percent			
(unit number 4)	20.1	8.4	10-35
(unit number 3)	37.5	5.1	25-50
(combined units)	32.1	10.2	10-50
Number of logs per turn			
(unit number 4)	4.3	1.1	1-6
(unit number 3)	3.4	1.0	1-6
(combined units)	3.7	1.1	1-6
Volume per turn, board feet			
(unit number 4)	1071	618	18-2602
(unit number 3)	1068	623	29-2673
(combined units)	1069	619	18-2673

Table 2. SUMMARY OF TIME FOR EACH ELEMENT OF TURN - (UNIT NUMBER 4)
All times are in minutes.

Time Element	Total	Mean	Standard Deviation	Range	% of Total Turn Time
Travel Unloaded	110.30	2.35	0.98	0.70-4.90	15.8
Hook	349.50	7.44	2.95	1.80-15.70	50.0
Travel Loaded	81.60	1.74	0.84	0.40-3.80	11.7
Unhook	48.70	1.04	0.49	0.20-2.40	7.0
Deck	88.70	1.89	1.88	0.00-6.80	12.7
Delay	19.80	0.42	1.20	0.00-5.00	2.8
Total Time	698.60	14.88	5.40	3.80-28.20	100

Table 3. SUMMARY OF TIME FOR EACH ELEMENT OF TURN - (UNIT NUMBER 3)
All times are in minutes.

Time Element	Total	Mean	Standard Deviation	Range	% of Total Turn Time
Travel Unloaded	334.40	3.22	1.43	0.50-6.30	23.5
Hook	632.20	6.08	2.41	0.50-12.00	44.5
Travel Loaded	192.00	1.85	0.73	0.20-3.50	13.5
Unhook	67.50	0.65	0.25	0.20-1.30	4.8
Deck	96.20	0.93	1.69	0.00-8.20	6.8
Delay	98.50	0.95	3.44	0.00-26.50	6.9
Total Time	1420.80	13.68	5.94	2.20-44.80	100

Table 4. SUMMARY OF TIME FOR EACH ELEMENT OF TURN - (COMBINED UNITS) All times are in minutes.

Time Element	Total	Mean	Standard Deviation	Range	% of Total Turn Time
Travel Unloaded	444.80	2.95	1.36	0.50-6.30	21.0
Hook	981.20	6.50	2.65	0.50-15.70	46.3
Travel Loaded	274.20	1.82	0.77	0.20-3.80	12.9
Unhook	116.00	0.77	0.38	0.20-2.40	5.5
Deck	184.90	1.22	1.80	0.00-8.30	8.7
Delay	118.30	0.78	2.94	0.00-26.50	5.6
Total Time	2119.40	14.04	5.79	2.20-44.80	100

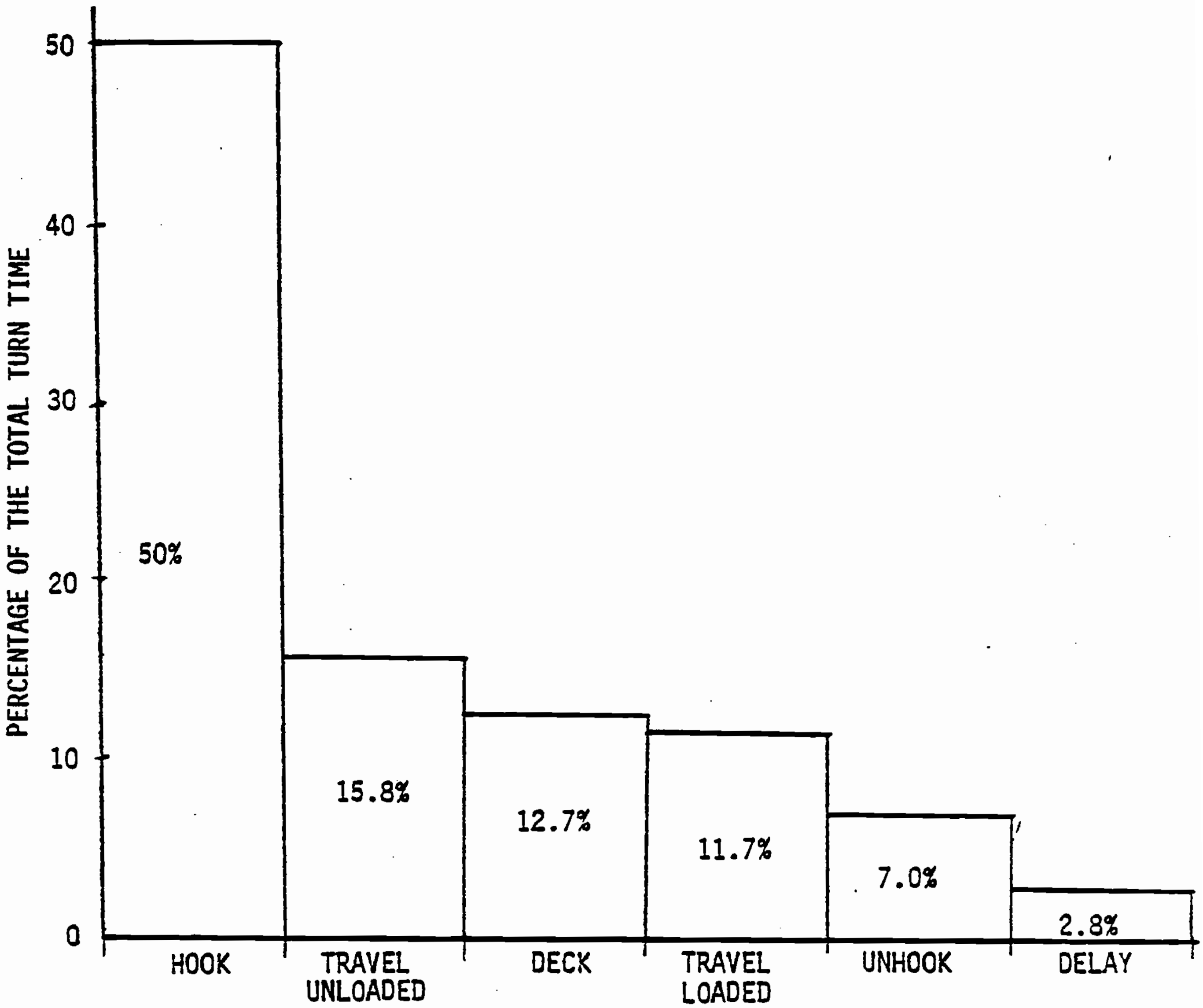


Figure 3. Bar graph of the individual elements of the turn shown as a percentage of the total turn time. (unit 4)

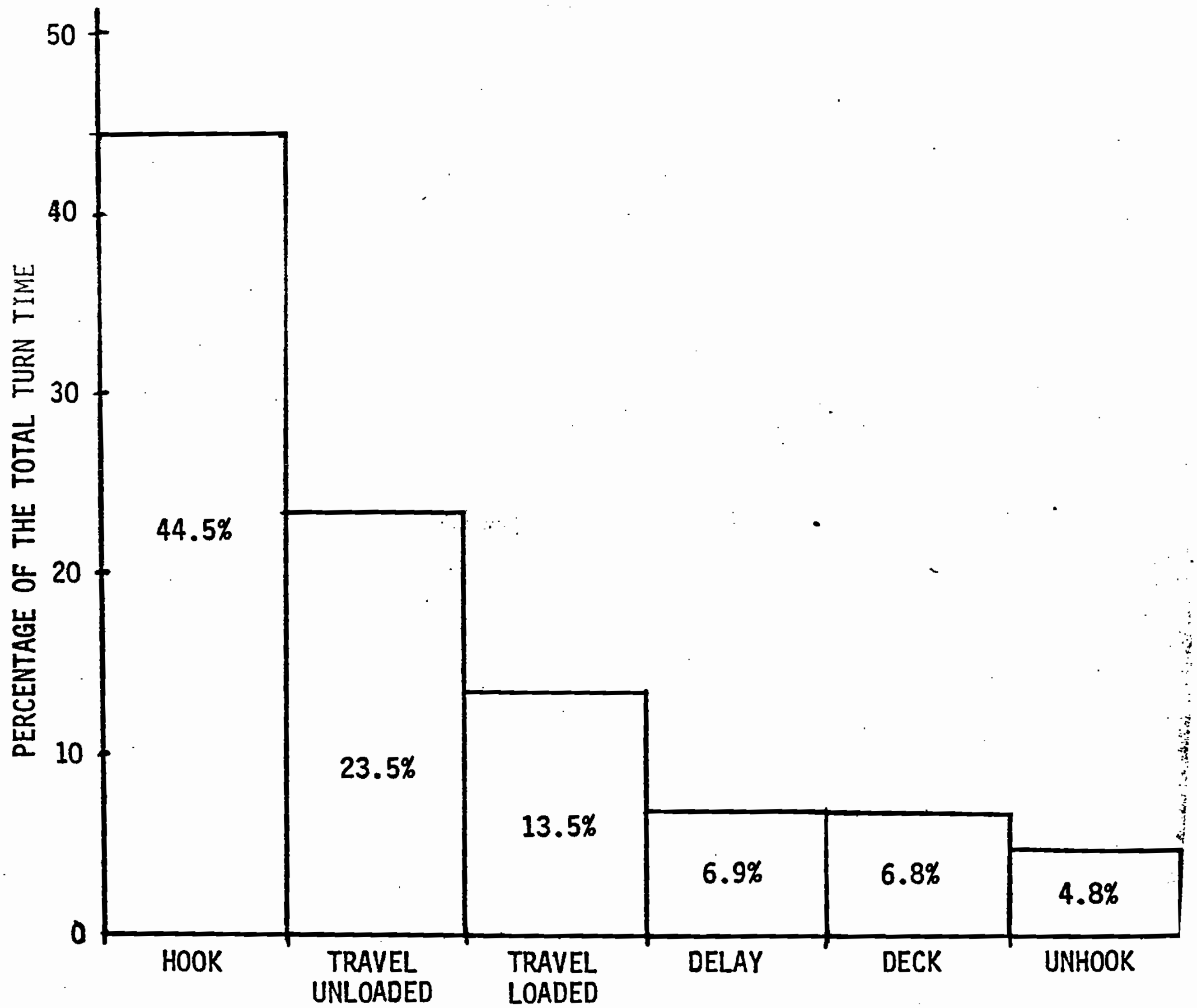


Figure 4. Bar graph of the individual elements of the turn shown as a percentage of the total turn time. (unit 3)

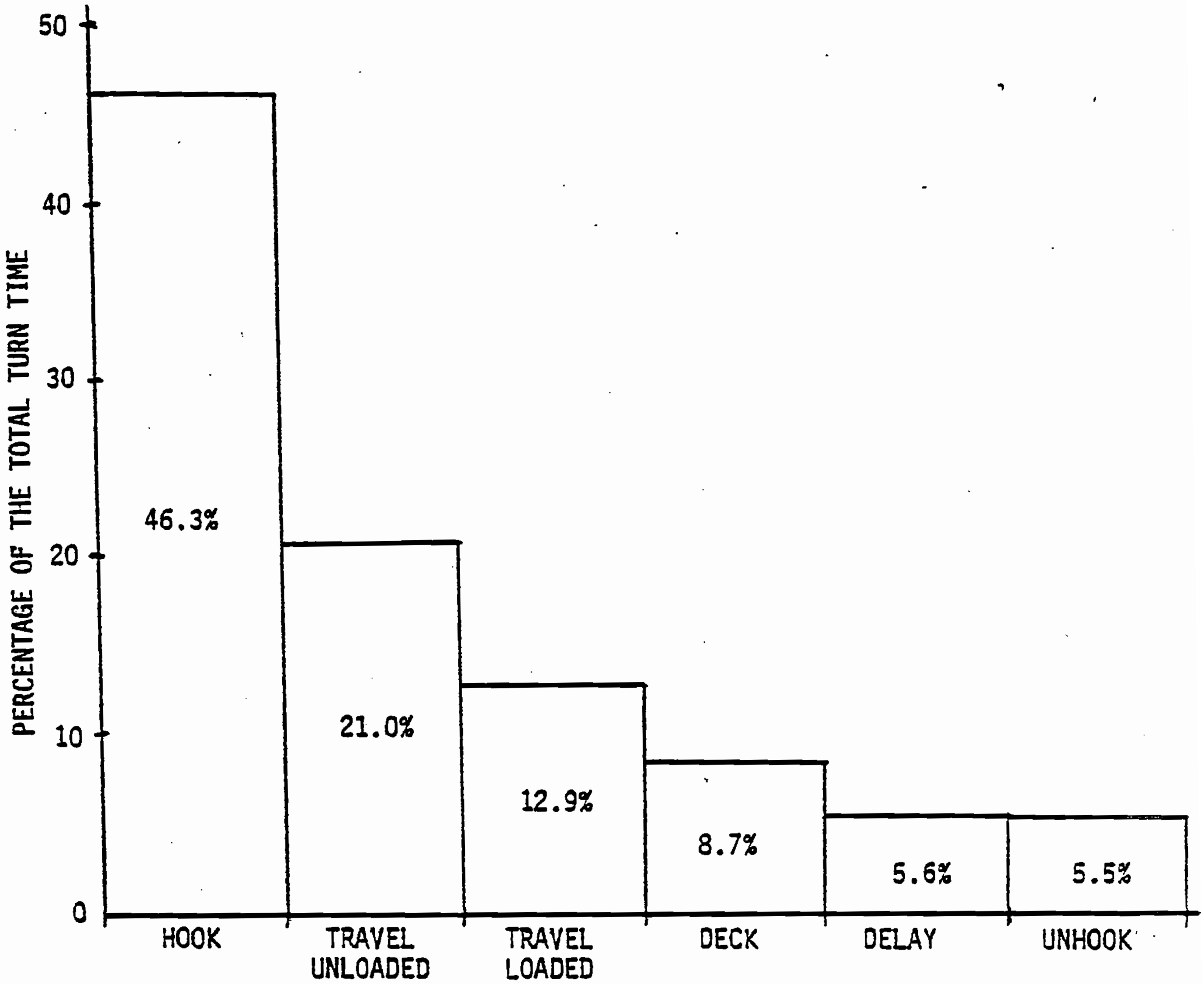


Figure 5. Bar graph of the individual elements of the turn shown as a percentage of the total turn time. (combined units)

** indicates that the regression coefficient is significant at the 0.05 probability level;

* indicates that the regression coefficient is significant at the 0.10 probability level.

n.s. indicates that the variable is not significant at the 0.10 probability level.

R^2 is the coefficient of determination which measures the proportion of change in the dependent variable which is accounted for by the linear relationship between that variable and the independent variables.

n is the number of observations in the sample.

All times estimated by the regression equations are in minutes.

From previous studies (Aulerich, et al., 1974, McDonald, 1972, Adams, 1967, McCraw, 1964) skidding distance and number of logs per turn have been important variables in estimating turn time. Additional variables that have been considered include ground slope, volume per turn, volume per acre, brush conditions, ground conditions, and number of men on the crew.

In this study, four variables were chosen to predict turn time. It was felt that most of the variation in turn time could be explained by these variables and that accurate measurements could be obtained with relative ease.

The description of the variables used in the regression equations are:

DIST = slope skidding distance, in feet.

SLOPE = average slope of the skid trail, in percent.

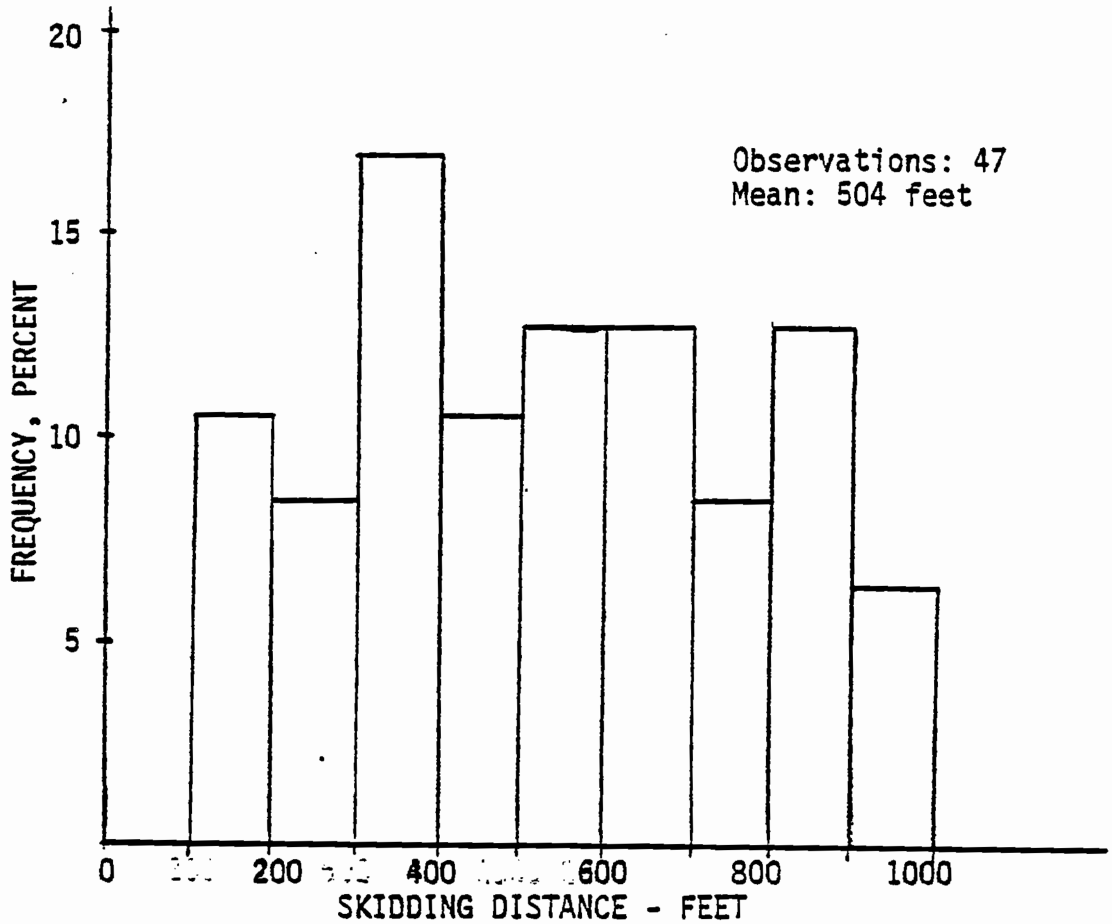


Figure 6. Frequency distribution of skidding distance (unit number 4).

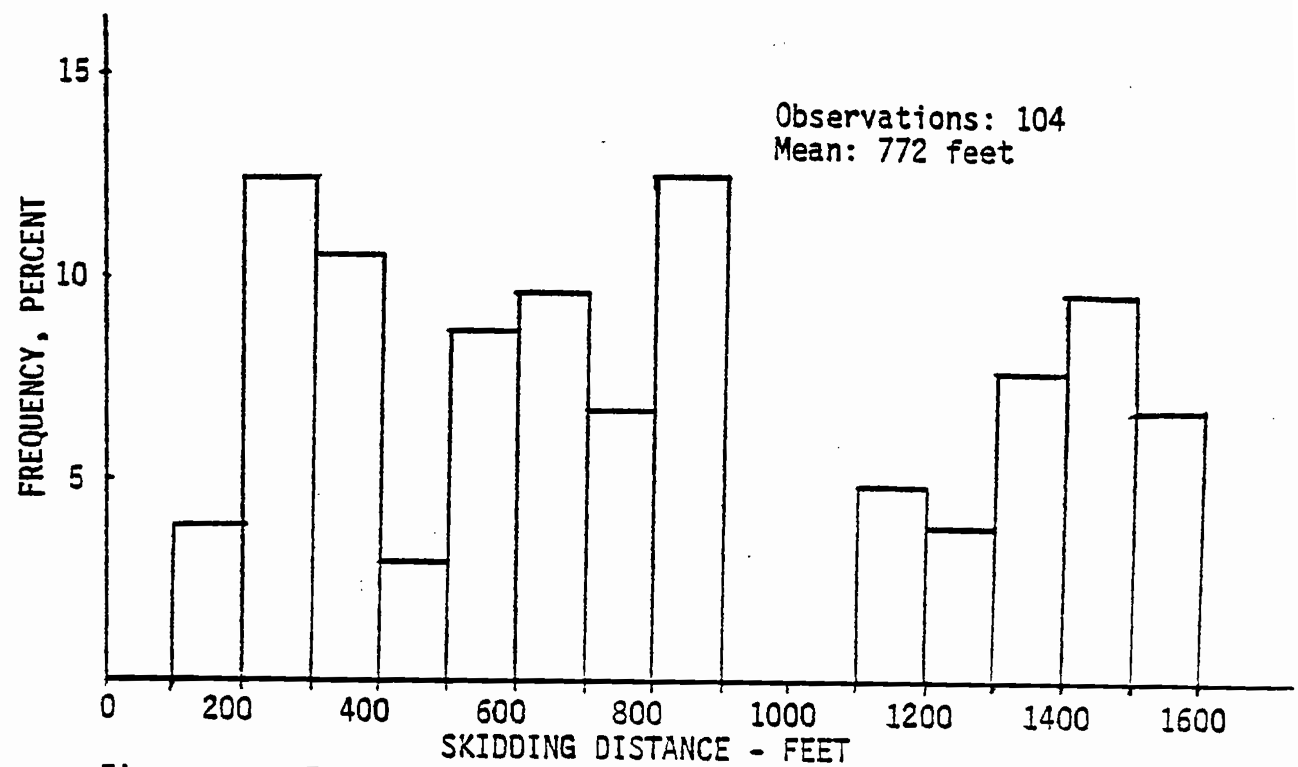


Figure 7. Frequency distribution of skidding distance (unit number 3).

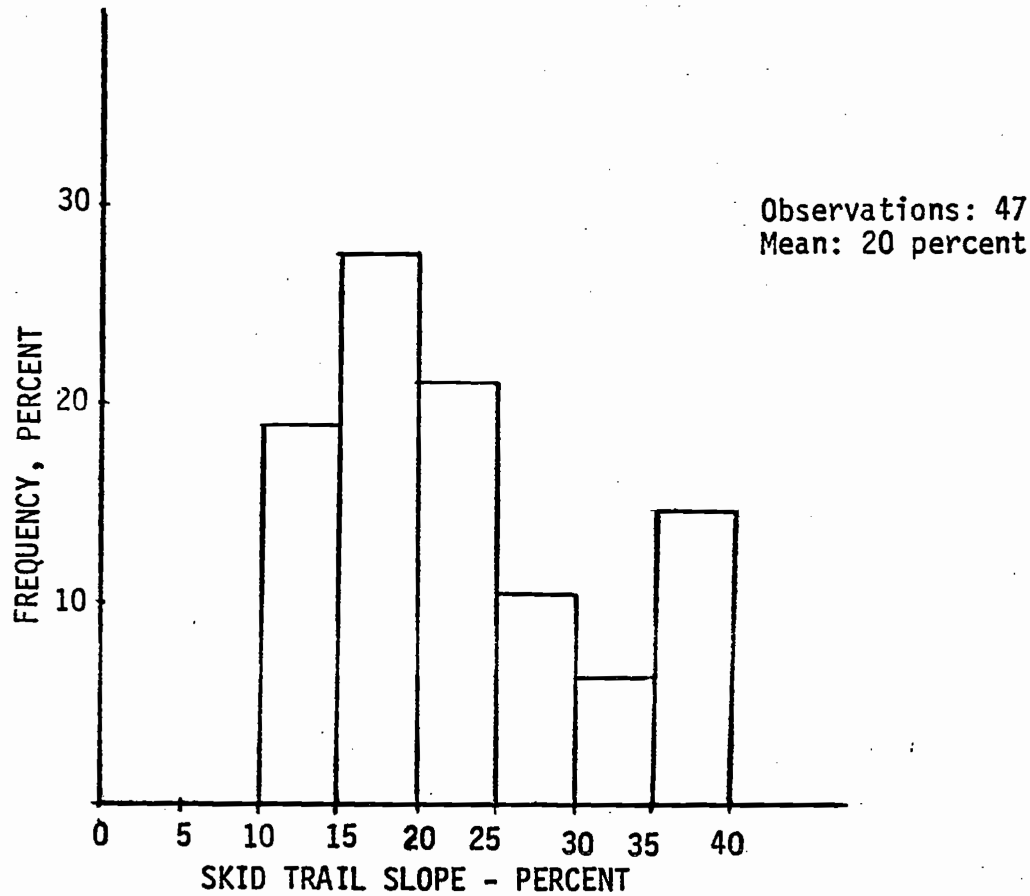


Figure 8. Frequency distribution of skid trail slope (unit number 4).

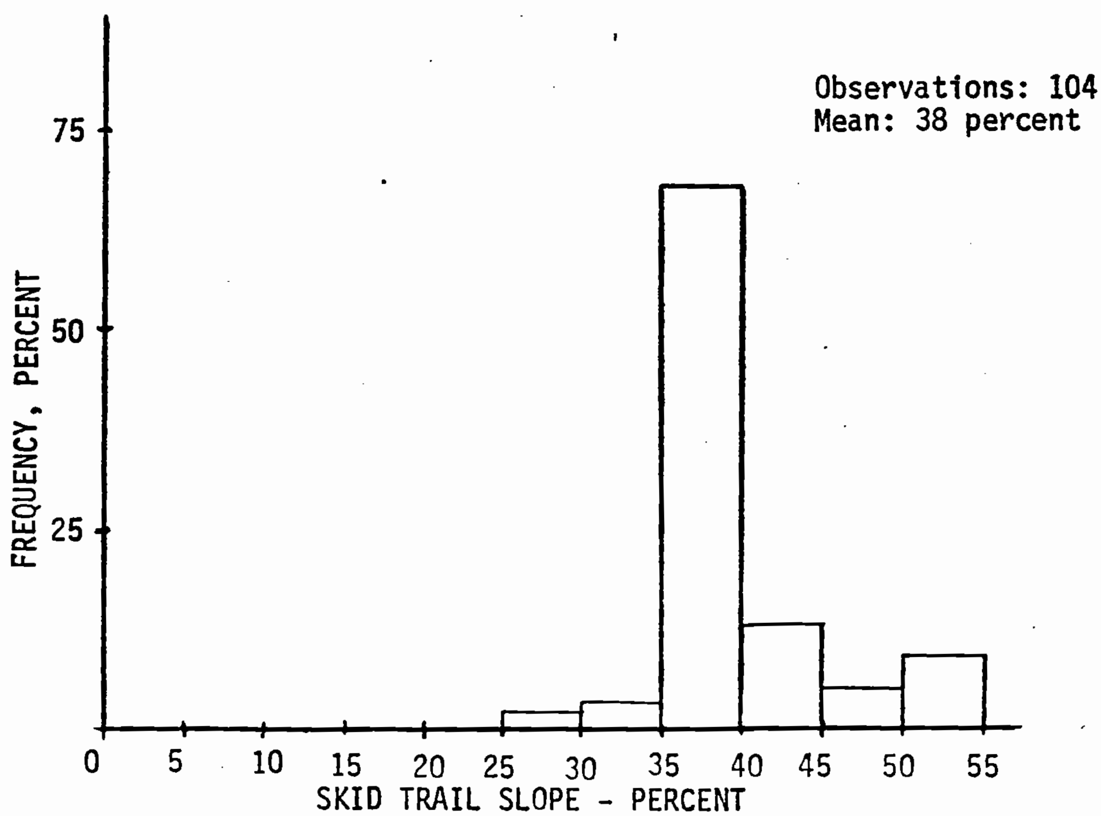


Figure 9. Frequency distribution of skid trail slope (unit number 3).

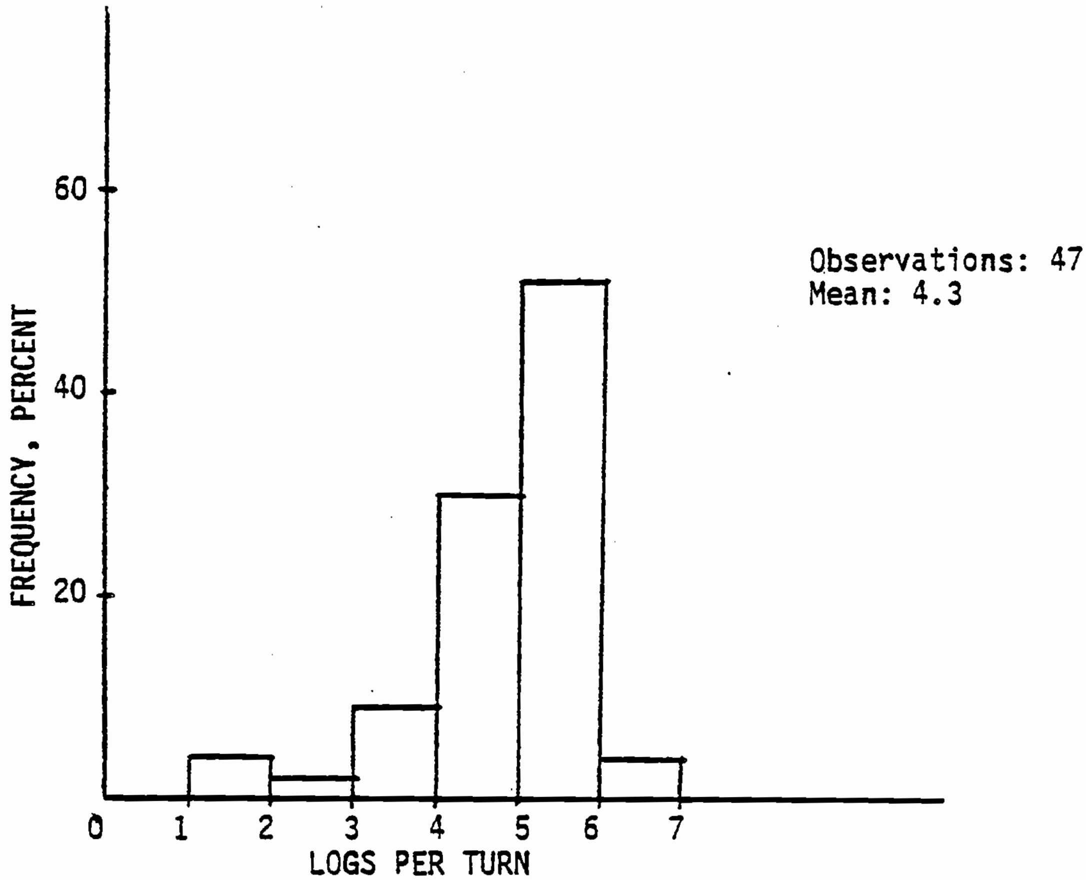


Figure 10. Frequency distribution of number of logs per turn (unit number 4).

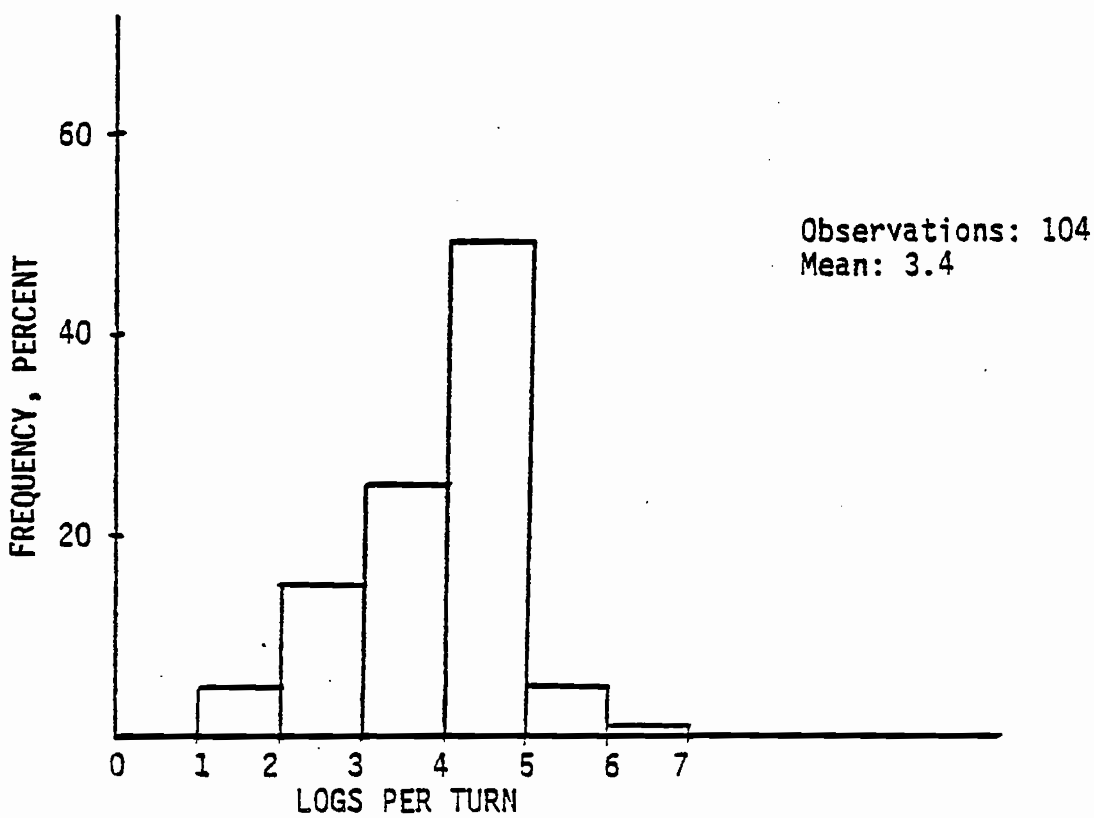


Figure 11. Frequency distribution of number of logs per turn (unit number 3).

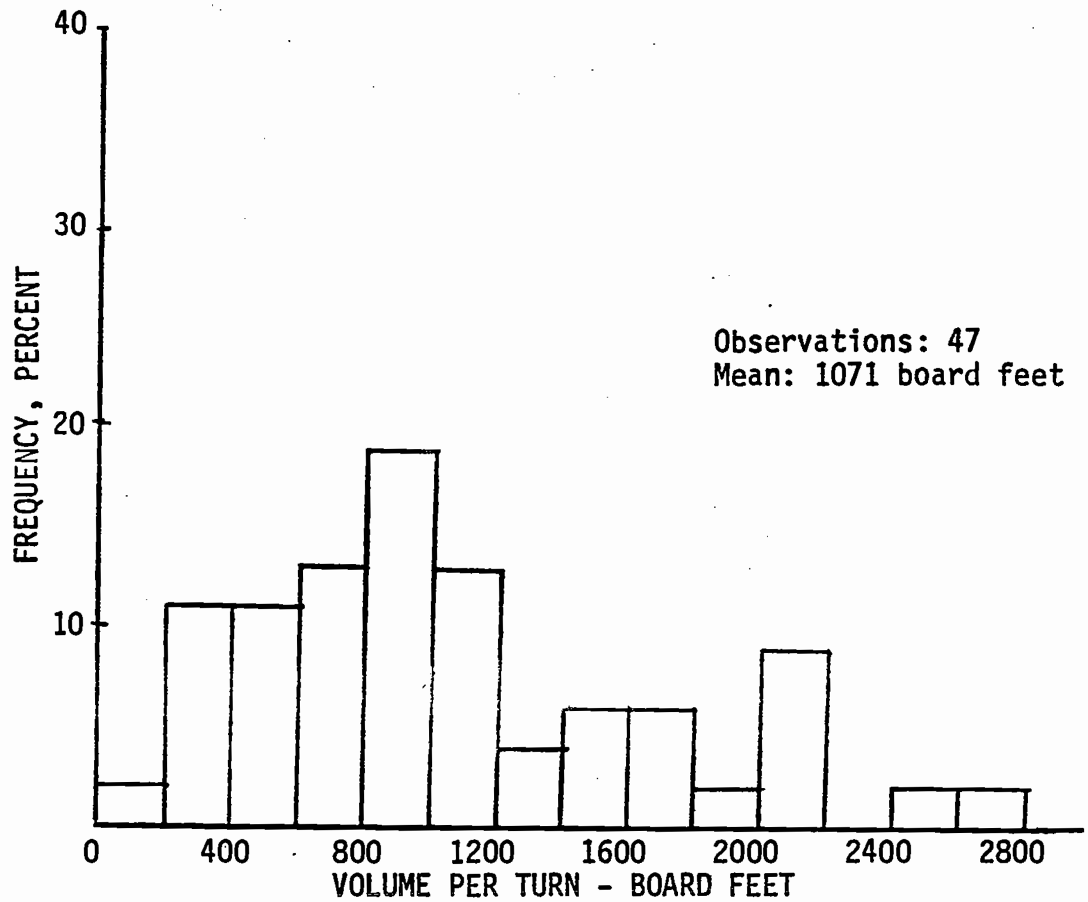


Figure 12. Frequency distribution of volume per turn (unit number 4).

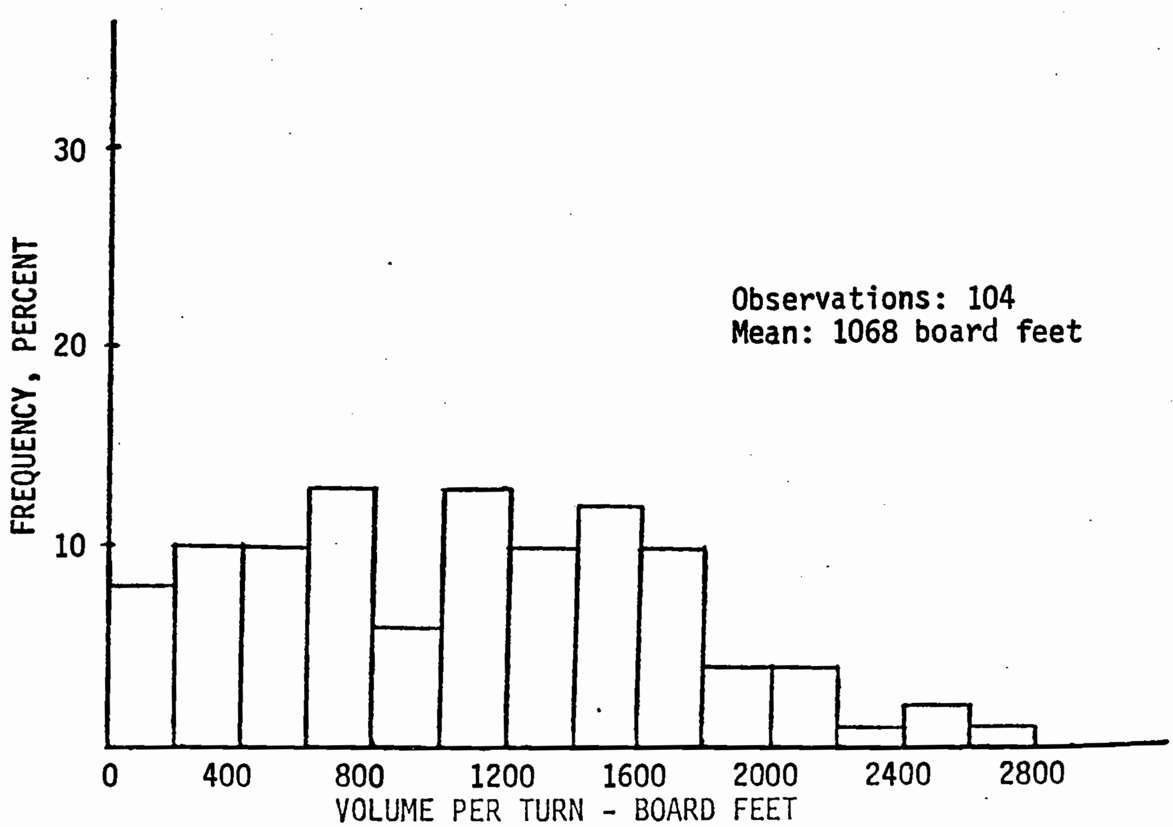


Figure 13. Frequency distribution of volume per turn (unit number 3).

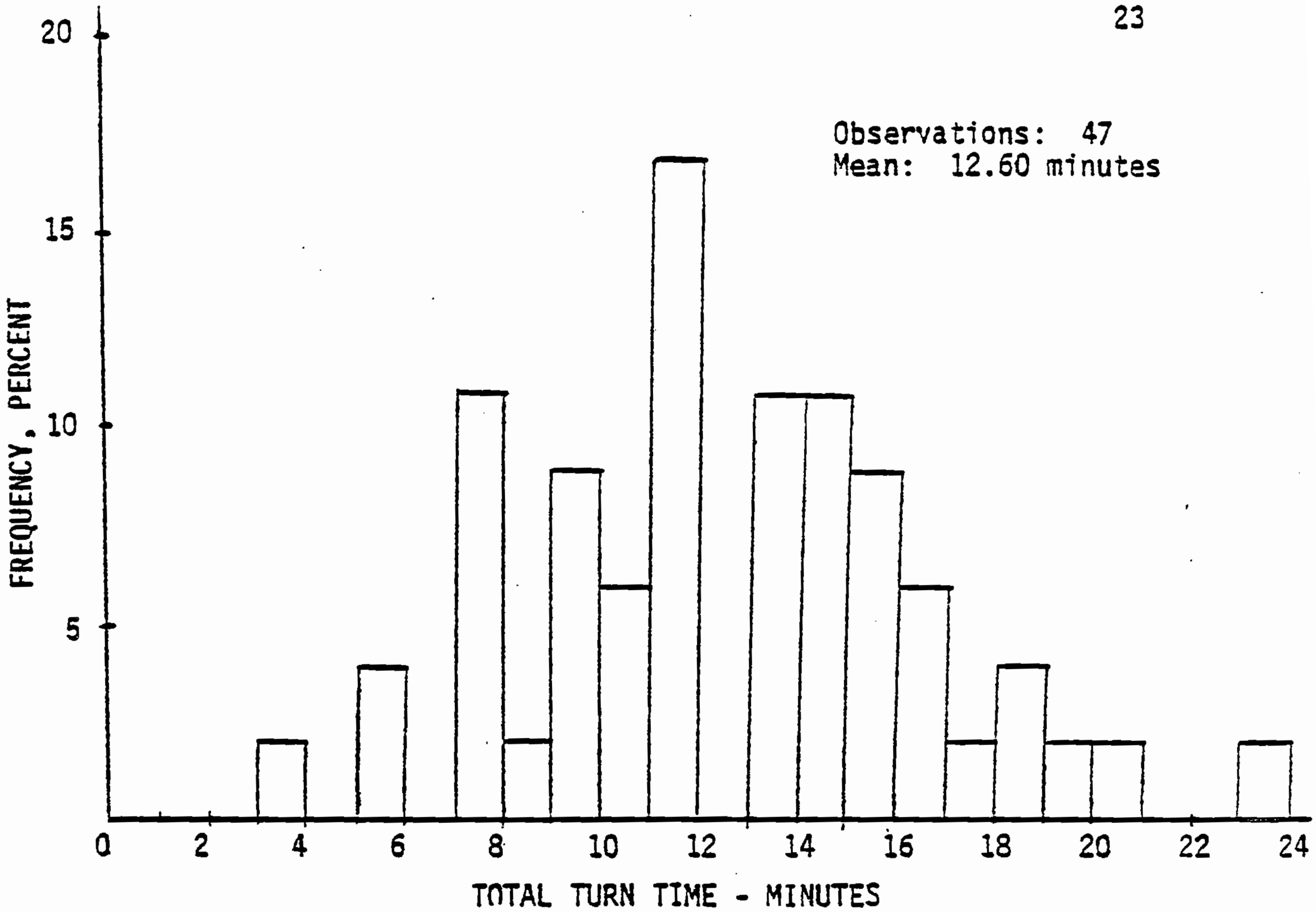


Figure 14. Frequency distribution of total turn time, minus decking time and delays. (unit number 4)

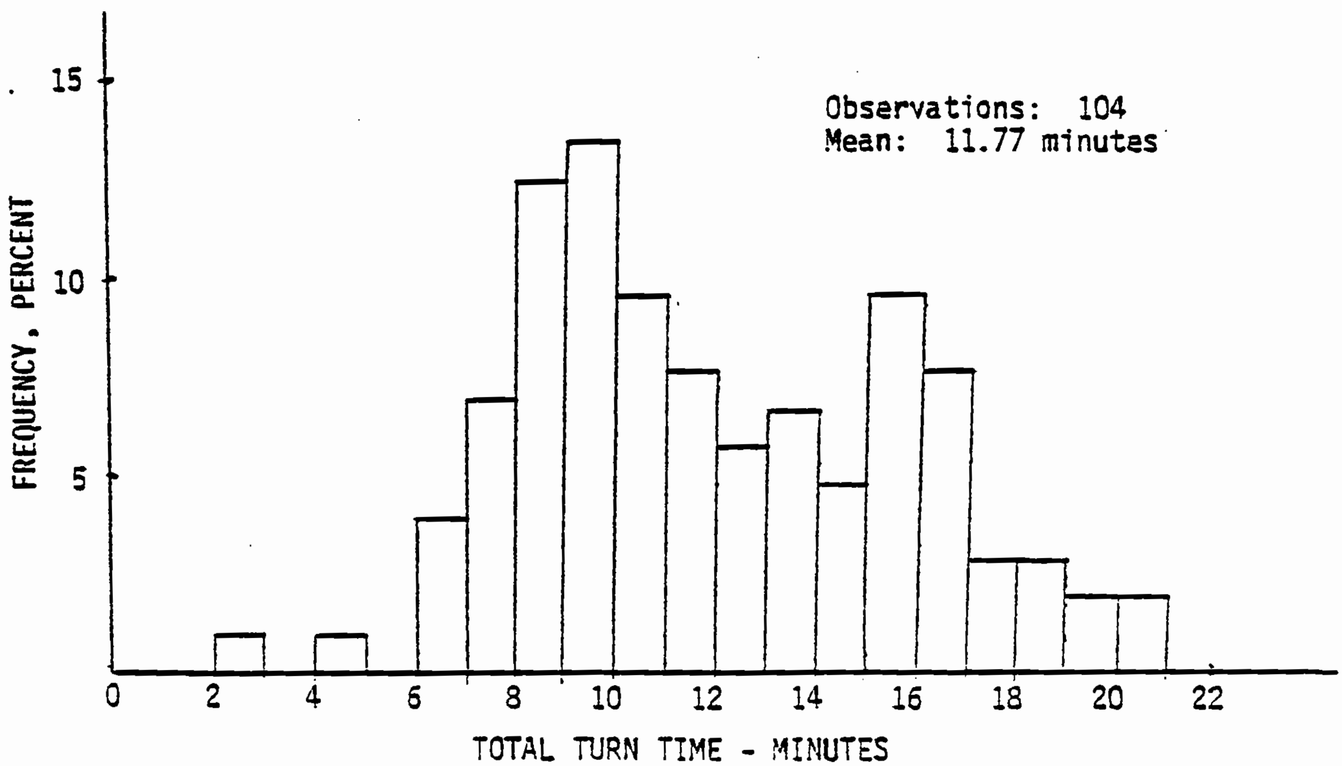


Figure 15. Frequency distribution of total turn time, minus decking time and delays. (unit number 3)

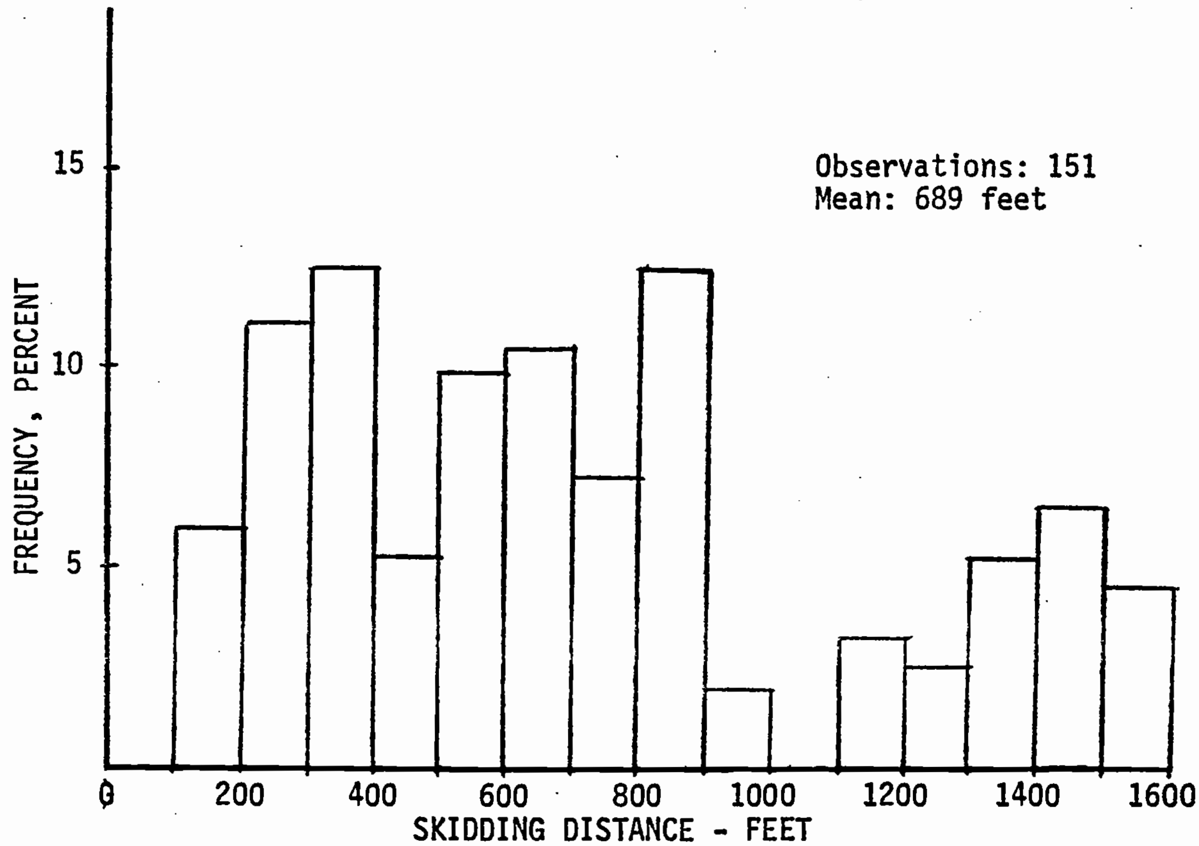


Figure 16. Frequency distribution of skidding distance (combined units).

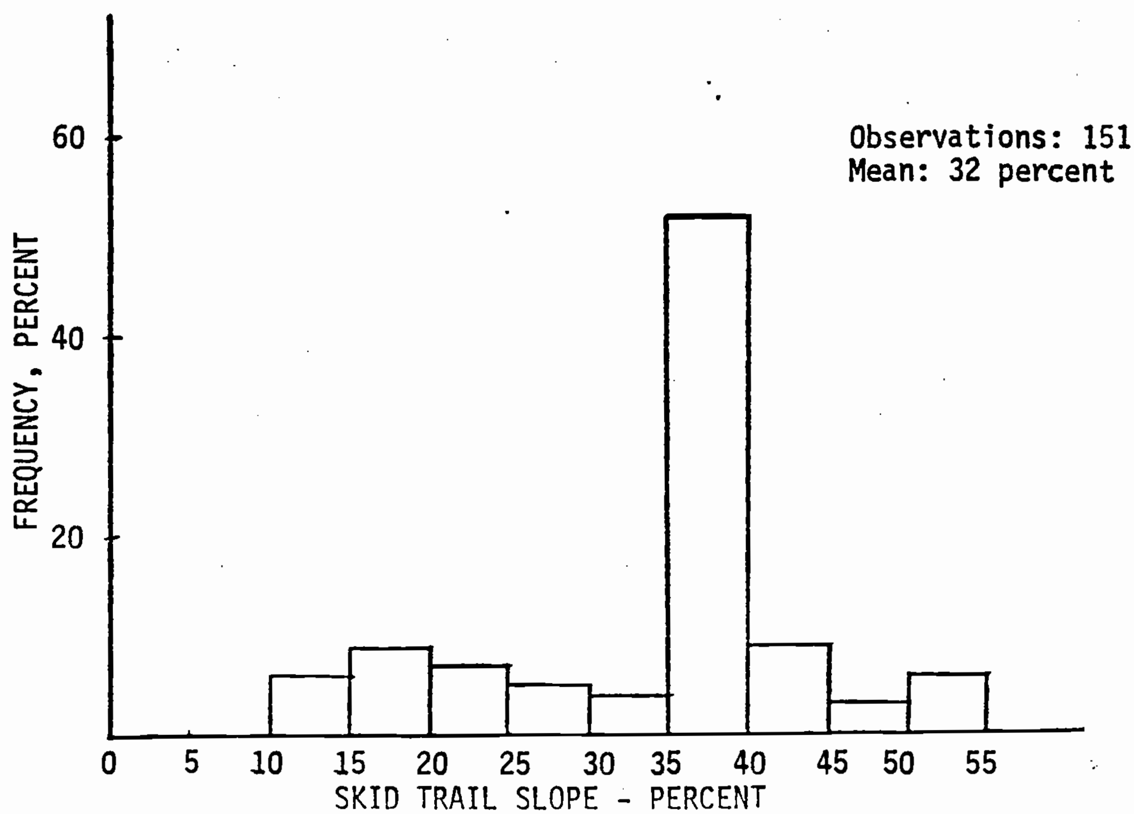


Figure 17. Frequency distribution of skid trail slope (combined units).

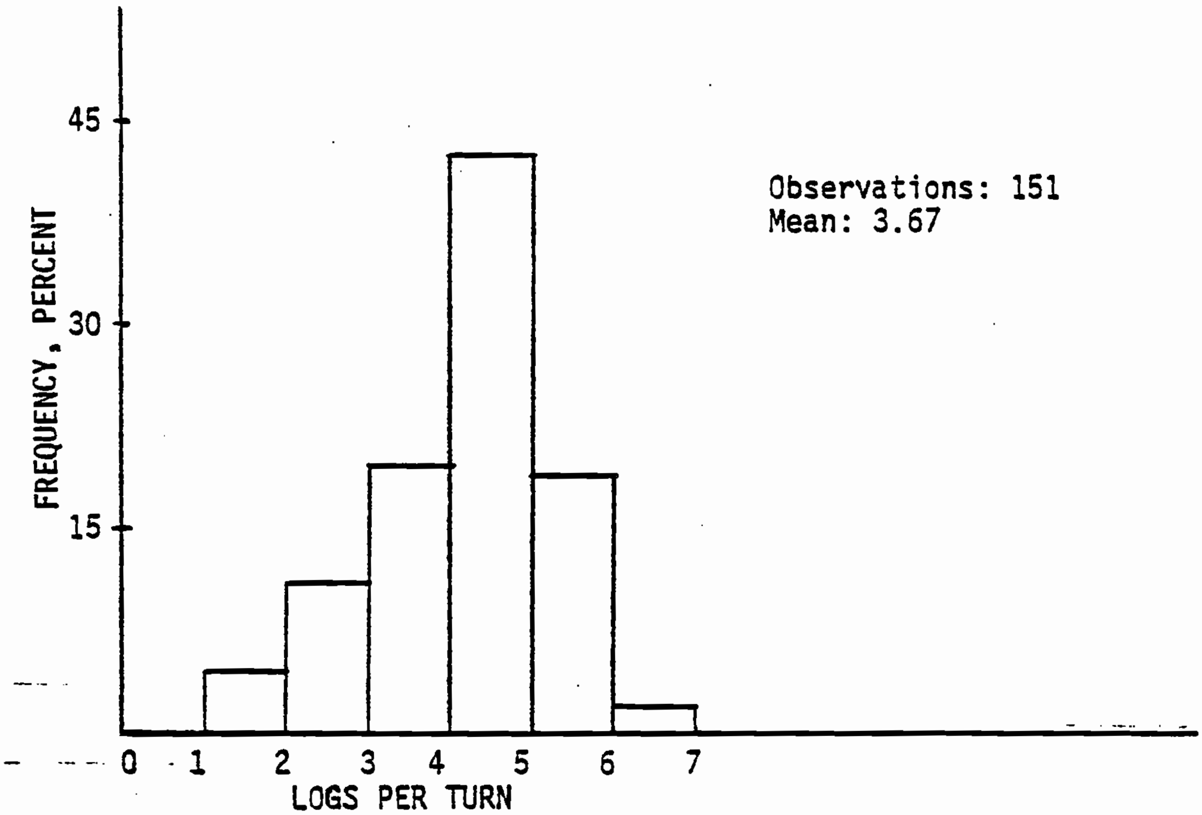


Figure 18. Frequency distribution of number of logs per turn (combined units)

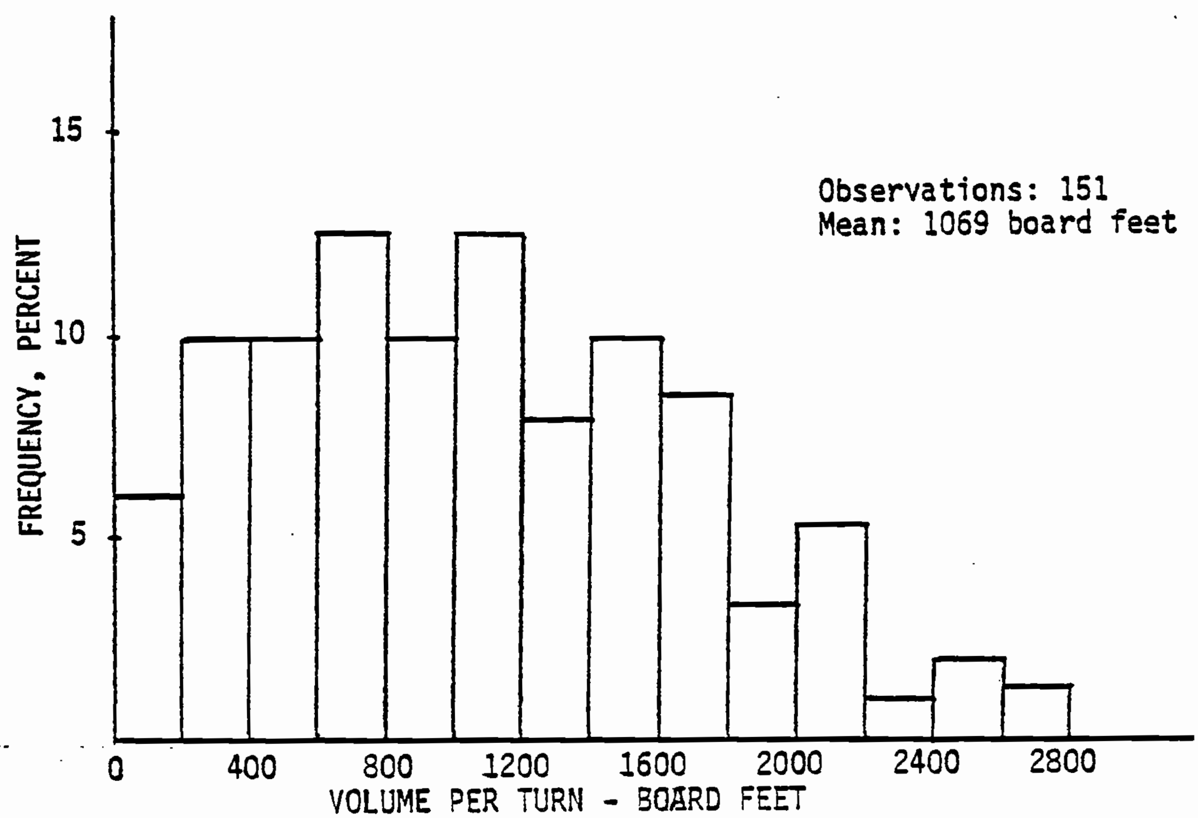


Figure 19. Frequency distribution of volume per turn (combined units).

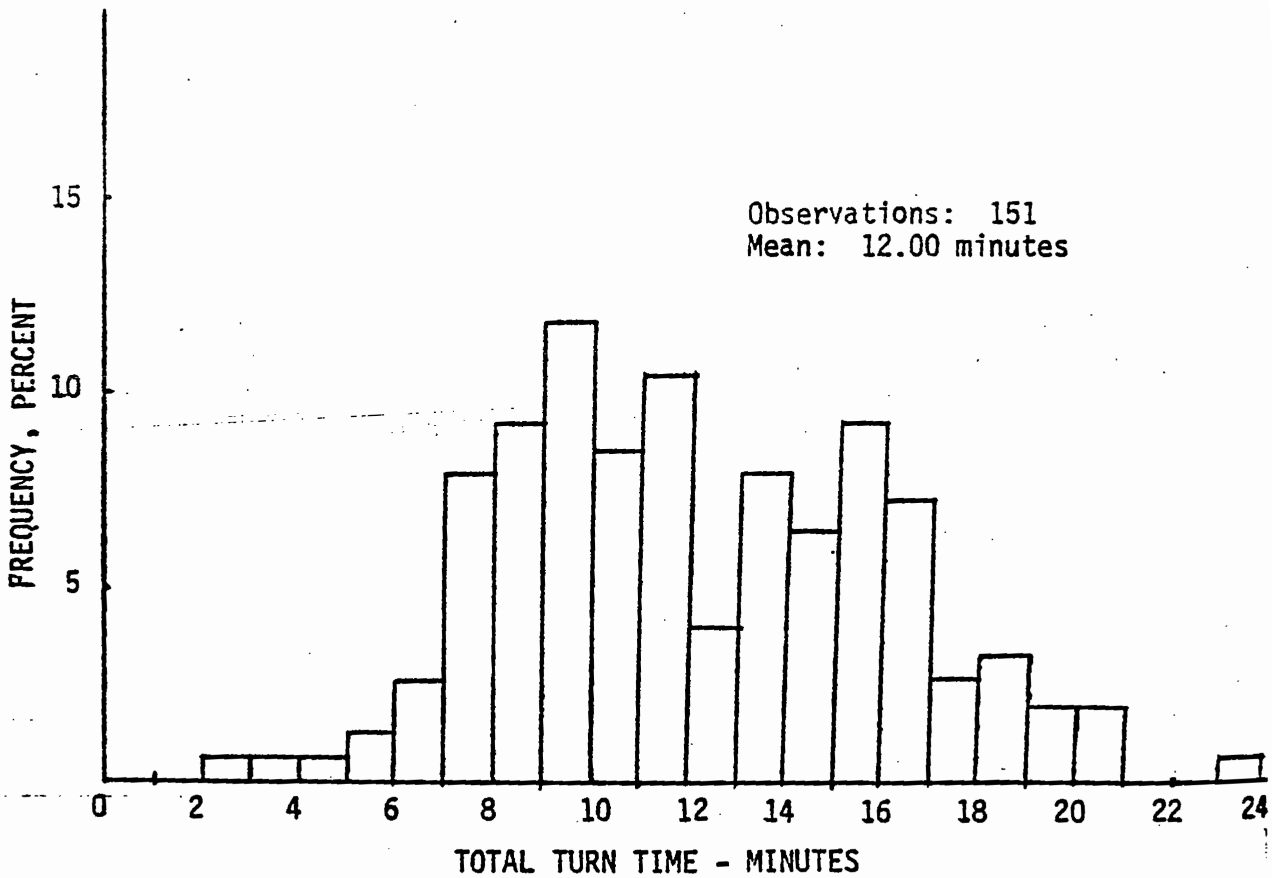


Figure 20. Frequency distribution of total turn time, minus decking time and delays. (combined units)

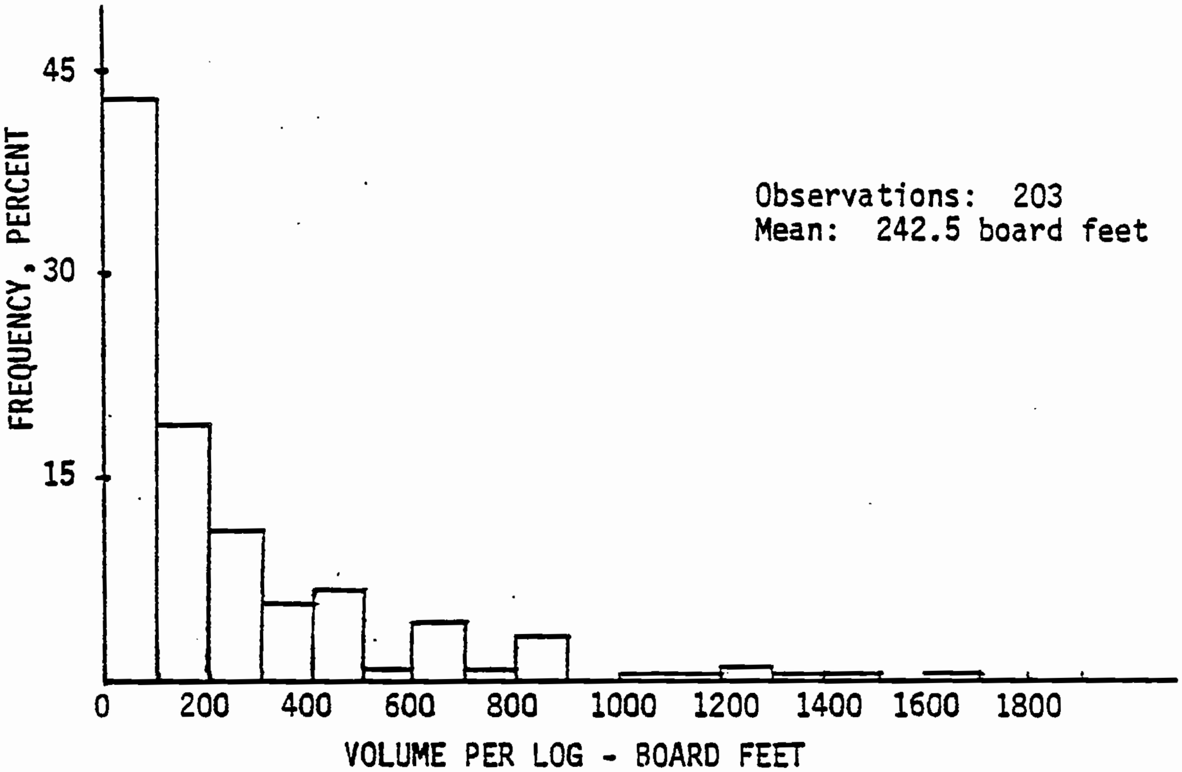


Figure 21. Frequency distribution of volume per log (unit number 4)

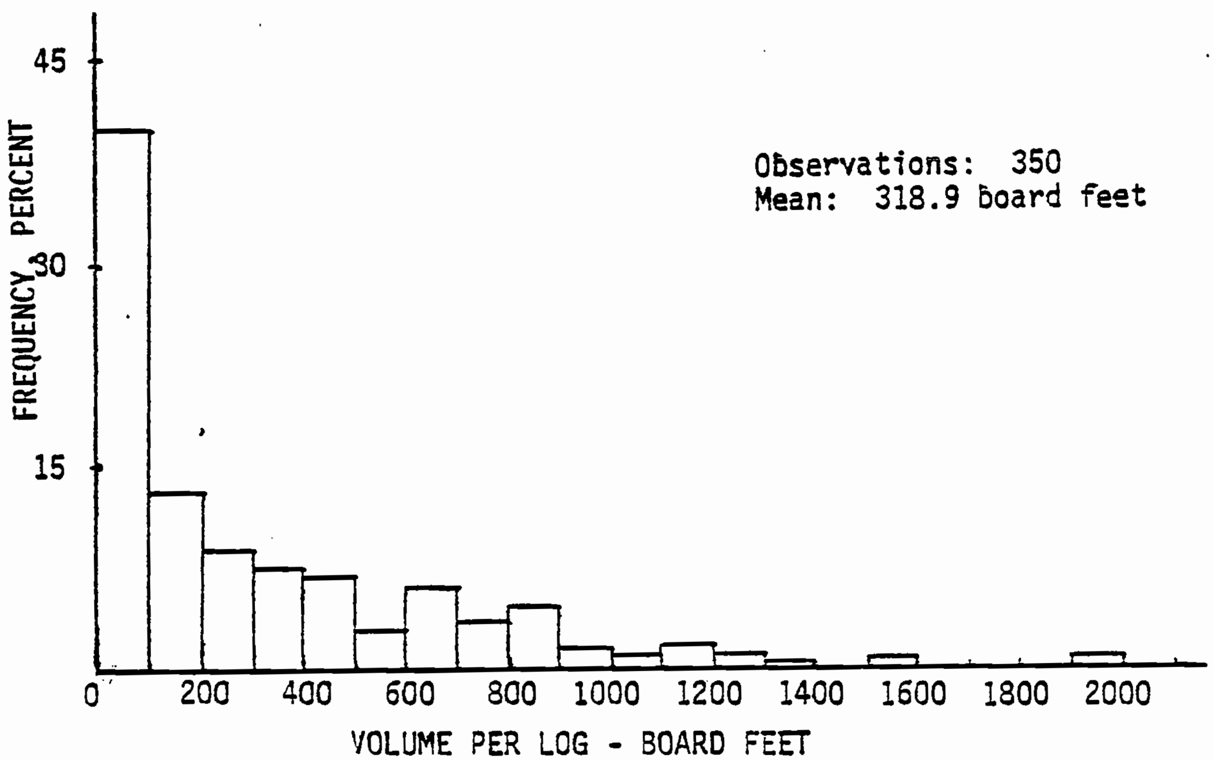


Figure 22. Frequency distribution of volume per log (unit number 3).

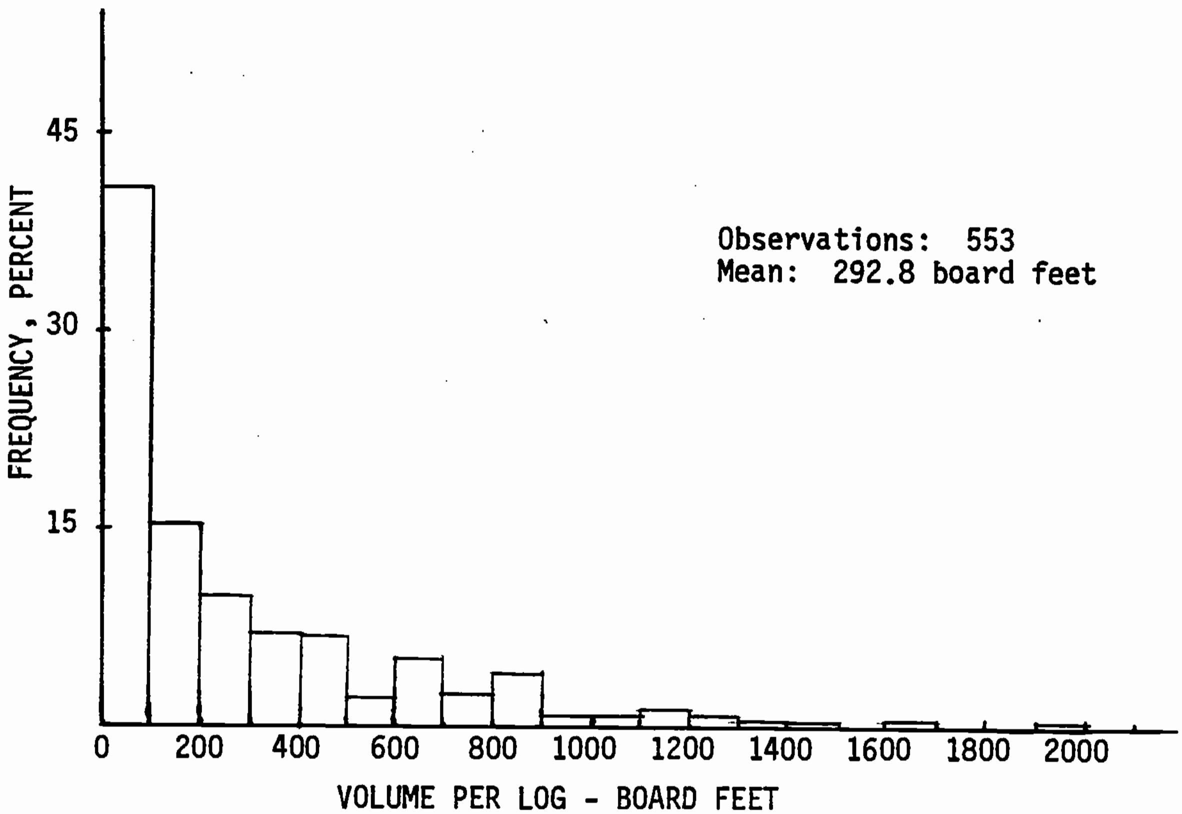


Figure 23. Frequency distribution of volume per log (combined units)

NOLOGS = number of logs per turn.

VOL = log volume per turn, in board feet.

TRAVEL UNLOADED

H_0: Unloaded Travel Time = f(DIST, SLOPE)

unit 4

Unloaded Travel Time = 0.62595 R^2 = 0.689
+0.0033909(DIST)*** n = 47

unit 3

Unloaded Travel Time = -1.2244 R^2 = 0.813
+0.0029498(DIST)*** n = 104
+0.057514(SLOPE)***

combined units

Unloaded Travel Time = 0.54102 R^2 = 0.787
+0.0028387(DIST)*** n = 151
+0.013737(SLOPE)***

In unit 4, where the average slope ranged from 10 percent to 35 percent, the variable SLOPE was not significant. In unit 3 and the combined units, where slopes of 50 percent were measured and the average slope was greater than in unit 4, SLOPE was a significant predictor of travel time.

There will be very little increase in the unloaded travel time if the skid trail slope is below 35 percent. This feature can be attributed to the higher speed and track laying design of the FMC as compared to conventional tracked skidders.

HOOK

H_0: Hook Time = f(NOLOGS, VOL).

unit 4

Hook Time = 2.8938 R^2 = 0.142
+1.0377(NOLOGS)** n = 47

<u>unit 3</u>

Hook Time = 2.3625 R^2 = 0.207

+1.1027(NOLOGS)*** n = 104

<u>combined units</u>

Hook Time = 2.3521 R^2 = 0.223

+1.1267(NOLOGS)*** n = 151

The number of logs that were choked was the only variable that influenced hook time in this study. The volume(i.e., size of logs) was not a significant variable in determining hook time.

Other variables that could have an influence on hook time, but were not measured, are ground surface conditions, brush and slash conditions, and slope of the ground at the hooking site. Except for ground slope, these types of variables are subjective and therefore difficult to measure.

It was obvious from field observations that a variable which definitely influences hook time is the distribution of logs on the ground. If the logs were bunched together and the turn could be made up without pulling extra line or maneuvering the tractor to pick up scattered logs, then the hook time was reduced. Also important was the direction that the trees were felled. Trees that were felled upslope and in a radial line from the landing were easier to hook and skid to the main trails than trees that were felled cross-slope or downslope and not in a radial line from the landing.

A preliminary method has been developed by which tree distribution and felling patterns can be determined prior to logging. (Ohmstede, 1976) A Kelsh plotter has been used to locate trees from an aerial photograph and a desk-top calculator has been used to cut these trees into logs and distribute them in a radial pattern from a chosen landing. With this information, more accurate production costs can be determined and a better job of logging obtained.

TRAVEL LOADED

H_0: Loaded Travel Time = f(DIST, SLOPE, VOL)

<u>unit 4</u>

Loaded Travel Time = 0.13292		R^2 = 0.665
	+0.0027208(DIST)***	n = 47
	+0.00020732(VOL)*	

<u>unit 3</u>

Loaded Travel Time = 0.64643		R^2 = 0.643
	+0.0012534(DIST)***	n = 104
	+0.00021673(VOL)***	

<u>combined units</u>

Loaded Travel Time = 0.63481		R^2 = 0.575
	+0.0013267(DIST)***	n = 151
	+0.00024316(VOL)***	

As with virtually all logging production studies, skidding distance was found to be the most significant variable in explaining loaded travel time. In my hypothesis, loaded travel time was thought to be a function of slope. For unit number 3 and the combined units, it was a significant variable at the 0.05 probability level. However, for the combined units, the coefficient of the slope variable had a negative sign. Additional testing by the use of scatter diagrams indicated no linear relation between the dependent variable, Loaded Travel Time, and the independent variable, SLOPE. It was therefore felt that a better prediction of loaded travel time could be obtained by eliminating the variable, SLOPE, from the regression equation.

From field observations of the skidding operation, steep slopes did tend to push or accelerate the skidder due to the extra weight of the logs being carried by the machine. On the 50 percent slope, the logs had a tendency to slide to the side and past the skidder. This was especially true when slash between the log and the ground reduced the coefficient of friction.

UNHOOK

H_0: Unhook Time = f(NOLOGS)

unit 4

Unhook Time = 0.37206 +0.15202(NOLOGS)** R^2 = 0.110, n = 47

unit 3

Unhook Time = 0.19524 +0.13470(NOLOGS)*** R^2 = 0.287, n = 104

combined units

Unhook Time = 0.09830 +0.18250(NOLOGS)*** R^2 = 0.280, n = 151

The time required to unhook the logs was a small percentage of the total turn time and was fairly consistent. As a turn was dropped at the landing, one of the logs would occasionally be trapped underneath the other logs. This would mean that the inaccessible log would have to be pulled free before it could be unhooked. The result would be an increase in unhook time, with no change in the independent variable.

TOTAL TURN TIME

H_0: Total Turn Time = f(DIST, SLOPE, NOLOGS, VOL) unit 4

Total Turn Time = 2.4925 $\qquad R^2 = 0.543$

+0.0095248(DIST)*** $\qquad n = 47$

+0.77360(NOLOGS)*

+0.0018200(VOL)**

unit 3

Total Turn Time = 4.2829 $\qquad R^2 = 0.751$

+0.0065865(DIST)*** $\qquad n = 104$

+0.71497(NOLOGS)***

combined units

Total Turn Time = 2.7584 $\qquad R^2 = 0.620$

+0.0060951(DIST)*** $\qquad n = 151$

+1.16930(NOLOGS)***

+0.00073449(VOL)**

The predicted total turn time was greater as distance and number of logs increased for all three regression equations. The variable SLOPE was not significant for the individual units, but was significant for the combined units. As in the regression equation for the loaded travel time, the coefficient of this slope variable had a negative sign. Again using a scatter diagram of dependent variable, total turn time, against the independent variable SLOPE, no linear relation between the two variables was noted. It was therefore concluded that slope be eliminated from the final regression equation.

In using these regression equations for purposes of determining total turn times for other units, it is recommended that values used be within the range of the variables used in developing these equations. Values outside these ranges could give unreliable results.

DECK AND DELAY TIMES

The regression equations that have been developed did not include either the time spent decking logs at the landing or delay time. Decking and delay time must be added to the total turn time so that production rates and skidding costs can be determined.

In tables 2 through 4, average time per turn for decking and delays are shown. By using these values, total time can be determined as follows:

<u>unit 4</u>
Average Total Turn Time (from regression equation) = 12.57 min.
Average decking and delay time per turn (table 2) = 2.31 min.
Average Total Time per Turn = 14.88 minutes.

<u>unit 3</u>
Average Total Turn Time (from regression equation) = 11.80 min.
Average decking and delay time per turn (table 3) = 1.88 min.
Average Total Time per Turn = 13.68 minutes.

<u>combined units</u>
Average Total Turn Time (from regression equation) = 12.04 min.
Average decking and delay time per turn (table 4) = 2.00 min.
Average Total Time per Turn = 14.04 minutes.

Decking time was not included in the regression equation because it was felt that this was a poor way to utilize a fast, expensive skidder. As seen in tables 2 through 4, between 7 percent and 13 percent of the total yarding cycle time was used in decking logs. A small landing cat or rubber-tired skidder could have been used for decking logs and thus increased production of the FMC.

The size of the landing had a direct influence on the amount of time spent decking logs. Landing size in unit 4 was limited to an area of approximately 40 feet by 70 feet and 13 percent of the cycle time was spent decking. In unit 3, where a large landing area of 200 feet by 200 feet was available and several turns could be unhooked before decking was necessary, only about 7 percent of the cycle time was spent decking.

Recorded delays consisted of all times that were considered non-productive. The types of delays varied, consisting of such things as talking to the cutters, replacing chokers, repairing the bull line, and running over a chain saw.

The delay caused by repairing the bull line was a result of using slider hooks to fasten the chokers to the bull line. As the turn was winched onto the skidder bunk for transport to the landing, the slider hooks were pulled through the fairleads on the skidder arch. This would cause the hooks to cut into the cable and eventually cause the line to part. At least twice a week, a new knot would have to be tied in the bull line.

The percentage of total turn time for delays ranged from 3 percent to 7 percent. This is a very minor portion of the total cycle time.

The FMC skidder operating on this study area was remarkably maintenance-free. The only downtime observed was when the operator tried to skid a turn across a 50 percent slope and threw the downhill track. The crew had no tools available in the field and a total of four hours were lost because the machine was idle. When the proper tools were obtained, one and one-half hours were required to replace the track on this steep slope.

Because this was an unusual occurrence and was the result of improper vehicle operation, this delay was not included in the calculation of total turn time. No other problems were encountered with tracks coming off. The machine had been operating continuously since July and the redesigned suspension system seems to be working quite well.

SKIDDING COST

Total skidding costs have been calculated for an hourly rate and converted to a cost per thousand board feet by using the actual volume of production. Table 5 shows the actual hourly and daily production rates while table 6 presents the hourly labor and equipment costs.

The equipment costs and labor rates for Eastern Oregon have been obtained from the Region 6 Cost Guide (Forest Service 1976) and BLM Schedule 19 (Bureau of Land Management 1974).

By dividing the total cost per hour by the production per hour, the following cost per thousand board feet($/mbf) is obtained:

unit 4
Total Skidding Cost = $10.16/ mbf.

unit 3
Total Skidding Cost = $9.33 / mbf.

combined units
Total Skidding Cost = $9.56 / mbf.

These skidding costs are for gross volume production. To convert to net volume cost, it is necessary to know the net-to-gross volume ratio. From cruise data of the sale obtained from the Malheur National Forest, this ratio averaged 0.80. By dividing the gross yarding cost per mbf by this ratio, we can obtain the net skidding cost per mbf as follows:

unit 4
Net Skidding Cost = $10.16/ 0.80 = $12.70 / mbf.

unit 3
Net Skidding Cost = $9.33 / 0.80 = $11.66 / mbf.

Table 5. HOURLY AND DAILY PRODUCTION (average conditions)

Item	unit 4	unit 3	combined units
Time per Turn (minutes)	14.88	13.68	14.04
Logs per Turn	4.3	3.4	3.67
Turns per Hour	4.02	4.39	4.28
Logs per Hour	17.29	14.93	15.71
Volume per Turn (board feet)	1071	1068	1069
Volume per Hour (board feet/hr.)	4305	4689	4575
Turns per Day[1]	32.16	35.12	34.24
Logs per Day	132.32	119.44	125.68
Volume per Day (board feet/day)	34,440	37,512	36,600

[1]Based on an eight productive machine hour day.

Table 6. MACHINE AND LABOR COSTS PER HOUR

Equipment Cost	Cost/hr. dollars
Machine Depreciation (straight line depreciation method)	7.92
initial cost = $95,000[1]	
residual value = 20 percent of initial cost	
life = 6 yrs. X 1600 hrs. per yr. = 9600 hrs.	
Winch Line Cost[2]	0.35
Choker Cost[2]	0.84
Maintenance and Repair	3.96
Estimated at 50 percent of depreciation cost	
Fuel and Lubrication[3]	1.94
Insurance, taxes, and Interest	1.39
3.5 percent of average annual investment	
average annual investment = $63,333	
Total Machine Cost	= 16.40
Labor Cost	
Skidder Operator (wages plus benefits)[3]	10.04
Choker Setter (wages plus benefits)[3]	8.15
Chaser (wages plus benefits)[3]	9.15
Total Labor Cost =	27.34
TOTAL COST PER HOUR =	43.74

[1]Mulligan, P. J., 1976

[2]Bureau of Land Management, 1974

[3]Forest Service, 1976

<u>combined units</u>

Net Skidding Cost = \$9.56 / 0.80 = \$11.95 / mbf.

Skidding costs for a conventional tracked skidder (D-7 Cat) using the average conditions of the combined units of this study showed a net skidding cost of \$11.20 per mbf. If the additional benefits of less ground compaction and less soil disturbance could also be converted to a cost savings, then the investment in an FMC skidder could be profitable.

COMPACTION AND DAMAGE

This study did not specifically consider soil compaction. However, a study currently being conducted by Oregon State University (Froehlich, 1976) in conjuction with the United States Forest Service has involved soil compaction in the same sale area. Preliminary results indicate that most of the compaction generally occurs by the first or second pass of the FMC and is usually restricted to the upper four inches of the soil.

As mentioned previously, the Malheur National Forest monitored the entire sale area to determine soil exposure and residual damage. The sale contract was written as an end result contract in which soil exposure would be limited to 7 percent of the sale area and residual damage would be limited to 15 percent of the total residual of the sale area.

Results are not available for the entire sale due to early snow cover. Data collected from transects located within units 3 and 4 indicate that the soil exposure and residual damage is well within the allowable limits of the sale contract.

UPHILL SKIDDING CAPABILITIES

It was unfortunate that data for uphill skidding were not available from this study. A comparison between uphill and downhill skidding would have been interesting.

The general rule of thumb for conventional tracked skidders is that they cannot skid uphill on slopes greater than 30 percent. Due to the unique design of the FMC skidder in which a portion of the turn weight is transferred to the machine, uphill skidding on slopes greater than 30 percent is definitely feasible.

Neither the conventional tracked skidder nor the FMC skidder is limited by horsepower on 30 percent slopes. Rather, the tractive coefficient is the limiting factor. The tractive coefficient is defined as a measure of the amount of normal force available for any given machine to enable this machine to move. It is expressed as a decimal and values range from 0.12 to 0.90 for tracked vehicles, depending on ground conditions(Caterpillar Tractor Co., 1976).

The FMC experiences a greater normal force than conventional skidders due to the transfer of weight from the turn of logs to the skidder. This increase in normal force enables the FMC to climb steeper slopes.

In figures 24 and 25, graphs have been prepared which show the tractive coefficient as a function of slope and log weight for a conventional skidder and an FMC skidder. The operating weight used for the FMC was 26,500 pounds and the operating weight used for the conventional skidder was 36,000 pounds (D-7 Cat).

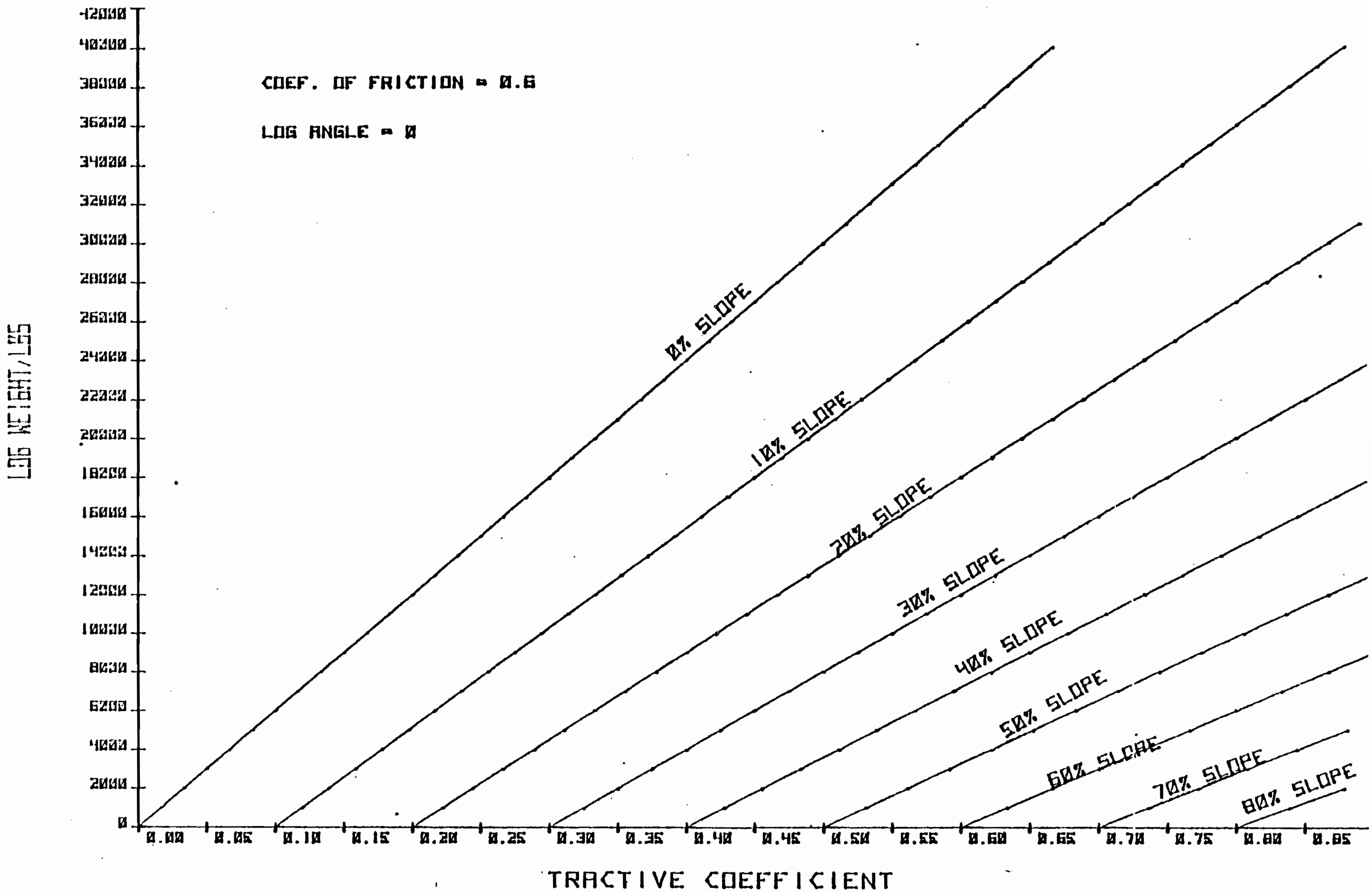


Figure 25. Graph of tractive coefficient and log weight for various slopes(conventional skidder, D-7 Cat

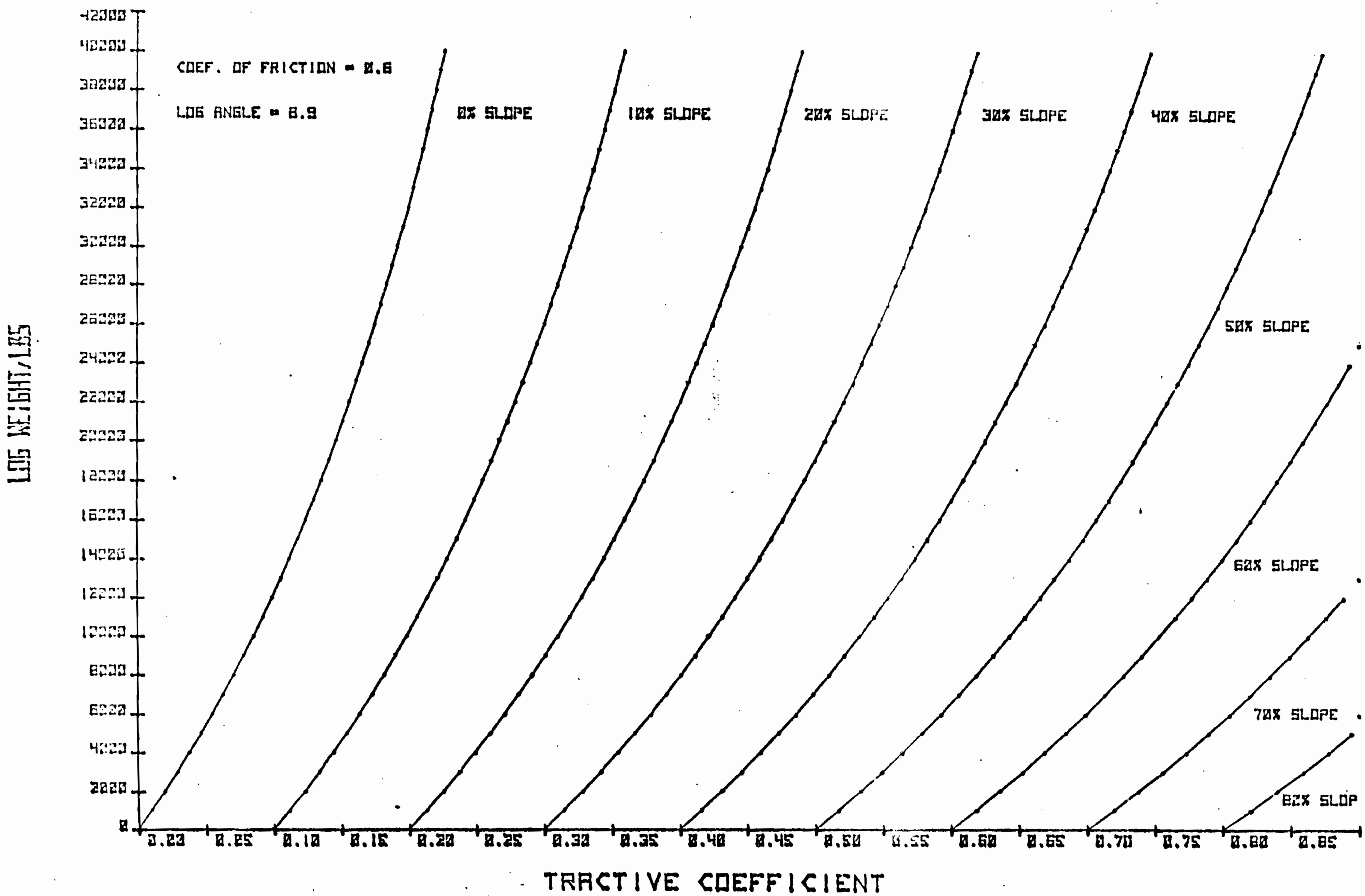


Figure 24. Graph of tractive coefficient and log weight for various slopes(FMC skidder).

A considerable difference in tractive coefficient is shown for the two machines when the same slopes and log loads are compared. For an FMC to pull a 20,000 pound load up a 30 percent slope, the coefficient would only have to be 0.50. For the conventional skidder to pull the same size load up a 30 percent slope, the coefficient of traction would have to be 0.80.

Horsepower was not a consideration in this analysis. For a complete description of the derivation of these tractive coefficients, see appendix B

CONCLUSION

This paper provides information and procedures on production rates and skidding costs on the FMC model 210 CA skidder. The analysis suggests that skidding time is generally a function of distance and number of logs per turn, with slope and volume playing a minor role.

As compared to conventional tracked skidders, slope has very little effect on the efficiency of the FMC skidder. The machine is not horsepower limited and will skid large turns if the volume is available. The study area was in Eastern Oregon where trees are more scattered and smaller than in Western Oregon. A procedure has been mentioned by which tree distribution under open stand conditions can be determined. It is felt that tree distribution can give a more accurate estimate of skidding cost and possibly a better job of logging.

The basic design of the machine has been pointed out and its ability to skid adverse slopes has been discussed. The FMC model 210 CA, which was introduced in July, 1976, has so far been relatively maintenance-free (Sheets, 1976, Burgess, 1976). The major change between the model 200 CA and the model 210 CA has been a heavier construction of the suspension system, conversion of the road-wheels to an all steel design, and elimination of the pivotable steering feature.

The better weight distribution, along with a corresponding lower ground pressure, may enable timber operators to extend their logging season. The machine can be worked on wetter sites with less soil compaction than other sypes of skidders. Even on drier sites, current studies being conducted (Froehlich, 1976) indicate that soil compaction is less than with other ground based equipment.

My feeling is that this is a machine that has many possibilities. It has several good features and should, if used correctly, enable the timber industry to do a better job of logging. It is not, of course, the answer to all the problems faced by loggers. But it is certainly a step in the right direction.

This study was an initial effort to analyze the FMC skidder. Further research needs to be undertaken in the area of skidding cost estimation. Follow-up on the determination of tree distribution is essential and more study is certainly warranted. Hopefully, the use of regression equations to predict production and skidding costs can be improved.

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APPENDICES

APPENDIX A

SPECIFICATION SHEET OF THE FMC MODEL 210 CA

Model 210CA

Choker Arch High Speed Logging Vehicle

Specifications

General

Model Designation	210 CA
Shipping Weight	26 500 lb (12 000 kg

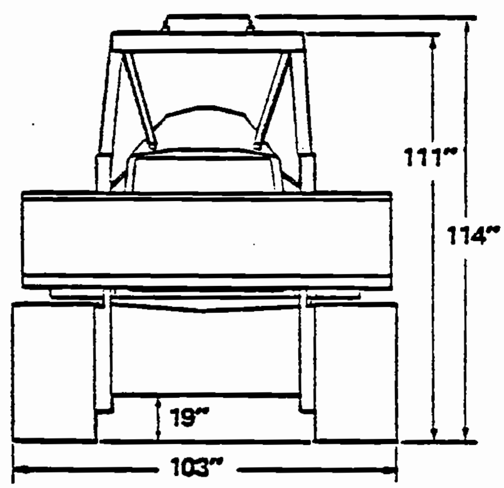
Dimensional (Vehicle in unloaded condition)

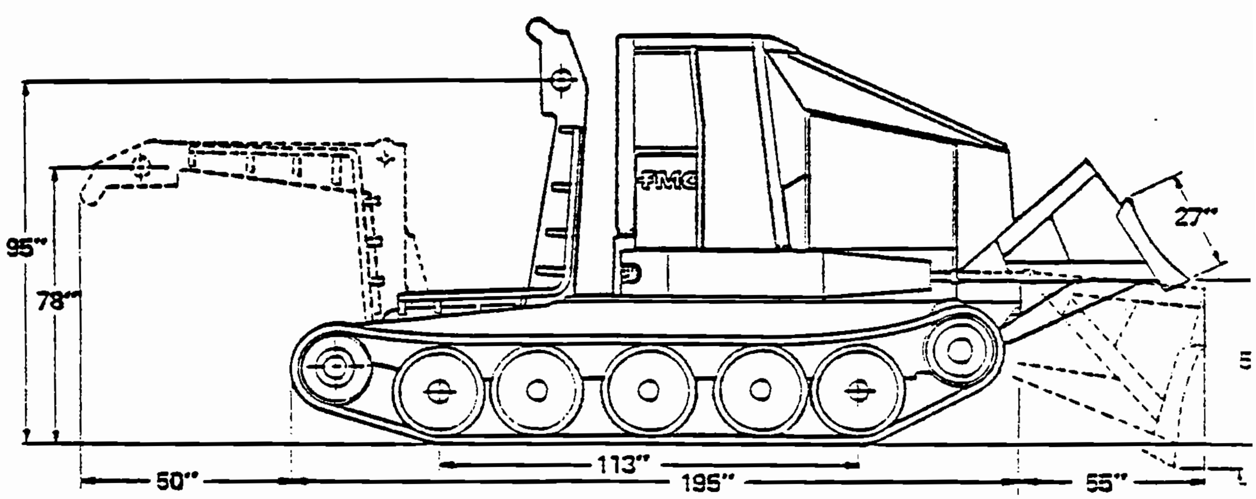
Maximum overall length with blade (arch retracted)	250"	(6350 mm)
Maximum overall length with blade (arch extended)	300"	(7620 mm)
Overall length without blade (arch retracted)	195"	(4953 mm)
Overall length without blade (arch extended)	245"	(6223 mm)
Overall height	114"	(2896 mm)
Overall width	103"	(2616 mm)
Ground clearance	19"	(483 mm)
Blade height	27"	(686 mm)
Blade width	102"	(2591 mm)
Blade lift height above ground	59"	(1499 mm)
Blade drop below ground	15"	(381 mm)
Fairlead roller height above ground (arch retracted)	95"	(2413 mm)
Fairlead roller height above ground (arch extended)	78"	(1981 mm)
Main fairlead roller diameter	7.25"	(184 mm)
Diameter of side, top and arch rollers	5"	(127 mm)

Suspension/Track

Type of suspension	Roadwheels, torsion b sprung
Type of track	Forged steel grousers, rubber bushed hinge
Track shoe width	22" (559 mm)
Gauge	81" (2057 mm)
Type of roadwheels	All steel
Number of roadwheels	5 dual on each side
Diameter of roadwheels	24.5" (622 mm)
Length of track on ground	113" (2870 mm)
Area of track on ground	4972 in^2 (32 079 cm^2
Ground pressure at shipping weight	5.33 PSI (36.75 kPa)

Maximum total log load	35 000 lb (15 876 kg)
Maximum weight on vehicle	21 000 lb (9500 kg)





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Engine

Make	General Motors — Detroit Diesel
Model	6V53N
Type of fuel	Diesel
Number of cylinders	6
Bore	3-7/8" (99 mm)
Stroke	4-1/2" (114 mm)
Displacement	318 in^3 (5.2 lit)
Horsepower, brake	197
Governed rpm	2600
Torque (maximum at 1500 rpm)	445 lb-ft (603 N.m)
Electrical:	
Starting	12 volt
Battery (capacity & quantity)	150 amp. hrs, one
Alternator	55 amp

Operational

Horsepower, drawbar (calculated)	121
Drawbar pull (calculated)	48 500 lb (215 700 N)

	First		Second		Third		Fourth	
	mph	km/hr	mph	km/hr	mph	km/hr	mph	km/hr
Forward	3	4.8	5	8.0	9	14.5	15	24.1
Reverse	3	4.8	5	8.0	9	14.5	15	24.1

Turning circle clearance	48' (14.6 m)

Capacity

	U.S. gal	(liters)
Cooling system	13	(49.2)
Fuel tank	50	(189.2)
Engine lubricating oil	4	(15.1)
Transmission/winch	9.25	(35.0)
Differential	5.5	(20.8)
Final drive	1.12	(4.3)

Powertrain

Transmission	Clark HR28420-3 power-shift, four speeds forward, four speeds reverse
Torque converter	Integral with transmission
Differential	Controlled
Final drive	Planetary
Brakes, service	Hydraulic, transmission mounted
Brakes, parking	Manual, transmission mounted
Brakes, steering	Controlled differential

Steering

Vehicle	Controlled differential

Hydraulic system

Pump capacity	50 gpm (189.2 lit/min)
Hydraulic tank capacity	20 U.S. gal. (75.7 lit)
System relief valve setting	1800 psi (12 000.4 kPa)
Filtration	Tank strainers & full flow by-pass, replaceable cartridge return filter—10 micron
Hydraulic cylinders:	
Blade	2 each, double acting, 4" (102 mm) bore, 2.25" (57 mm) rod, 34" (864 mm) stroke
Arch	2 each, double acting, 5" (127 mm) bore, 2" (51 mm) rod, 20.62" (524 mm) stroke

Winch

Model	Clark WD-413-1
Cable drum diameter	12" (305 mm)
Cable drum capacity:	313' (95.4 m) of 5/8" (16.0 mm) wire rope 216' (65.8 m) of 3/4" (19.1 mm) wire rope 159' (48.5 m) of 7/8" (22.4 mm) wire rope 120' (36.6 m) of 1" (25.4 mm) wire rope
Drum control	Remote mounted, hydraulic, 3 position, single lever

	Bare drum	Full drum
Line pull, maximum	40 000 lb (178 000 N)	28 000 lb (56 500 N)
Speed, maximum	373 fpm (98.5 m/min)	488 fpm (148.7 m/min)

Standard Equipment

Air cleaner	Dry type with precleaner
Antifreeze	Protection to −34°F (−37°C)
Arch	Arcs hydraulically, 4 roller fairlead
Blade	Decking, with log deflectors
Bottom guarding	Full plate with cleaning/service access
Brakes	Service, parking and steering
Canopy	SAE Code ROPS, with front, side & rear screens, and front brush deflectors
Differential oil cooler	
Engine side enclosures	
Fan	Reversible
Gauges:	
Air filter restriction indicator	
Ammeter	
Differential oil temperature	
Engine oil pressure	
Engine water temperature	
Hour-meter	
Tachometer	
Transmission oil pressure	
Transmission oil temperature	
Grille	Reinforced, hinged
Mufflers, with spark arresters (2)	
Paint	Ivory and Woodlands red
Seat	Adjustable, torsion bar suspended with arm rests
Seat belt	
Transmission oil cooler	

FMC has a continuing program of product improvement; specifications, equipment, and prices are subject to change without notice.

For more information contact your nearest FMC Woodlands Equipment dealer or:

FMC Corporation
Woodlands Equipment Division
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San Jose, California 95103 Phone: (408) [illegible]-3135

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APPENDIX B

DERIVATION OF SKIDDING CAPABILITY OF FMC SKIDDER AND CONVENTIONAL TRACKED SKIDDER

The derivation of skidding capability is shown first for the FMC. Horsepower is not considered in this analysis and the force needed to overcome rolling resistance has also been neglected. The main purpose is to show the weight advantage that the FMC has over tracked skidders not equipped with a retractable arch.

The symbols used in the following figures and equations are defined as follows:

W1 = weight of the skidder, in lbs.

W2 = weight of the log, in lbs.

N1 = normal force of the skidder, in lbs.

N2 = normal force of the log, in lbs.

S = ground slope angle, in degrees.

T = angle between log and ground, in degrees.

U = coefficient of friction between log and ground.

f = coefficient of traction between skidder and ground.

L = length of the log, in ft.

V,H = vertical and horizontal components of the tension in the skidding line.

In figure B2, we can determine the normal force N2 by summing moments at the upper end of the log (point o). The diameter of the log is considered small as compared to its length and has been omitted. The center of gravity of the log is assumed to be located at the middle of the log and conditions

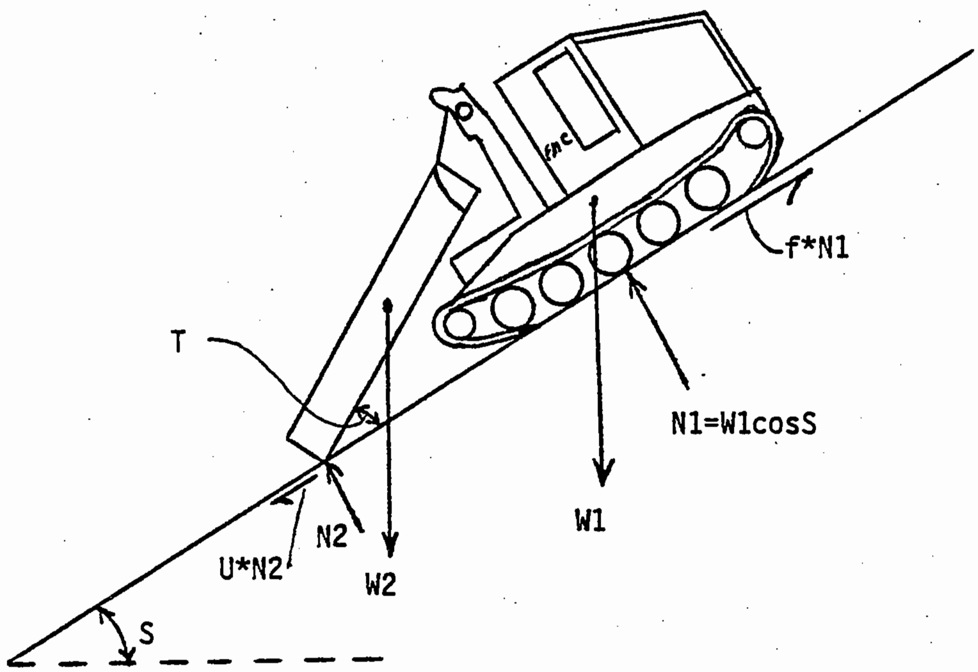

Figure B1. Diagram of the forces acting on the FMC skidder.

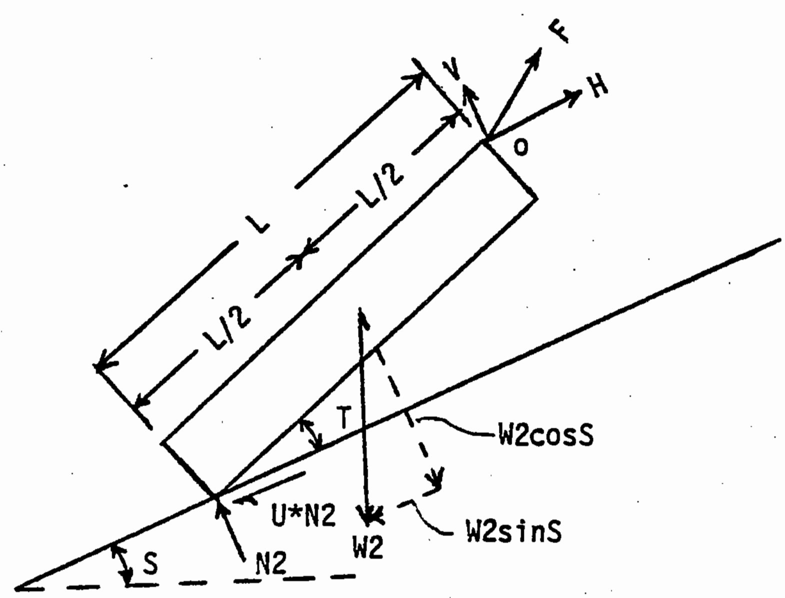

Figure B2. Free-body diagram of the forces acting on the log.

of equilibrium are also assumed (constant velocity).

$\sum M_O = 0$

N2*(LcosT)+U*(LsinT)+(W2*sinS)*(L/2*sinT)-(W2*cosS)*(L/2*cosT)=0

Rearranging and solving for N2,

$$N2 = \frac{(W2*cosS)*(cosT)-(W2*sinS)*(sinT)}{2*(cosT+U*sinT)} \qquad (1)$$

Summing forces in directions parallel and perpendicular to the slope, we can solve for the vertical and horizontal forces in the skidding line as follows:

$\sum$ forces perpendicular = 0

V+N2-(W2*cosS) = 0

V = W2*cosS - N2 (2)

$\sum$ forces parallel = 0

H - U*N2 - W2*sinS = 0

H = W2*sinS + U*N2 (3)

The vertical force V calculated above increases the normal force on the skidder.

By using figure B1, the skidding capability can be calculated by summing forces on the skidder parallel to the ground slope.

$\sum$ forces on skidder parallel to slope = 0

f*N1 = H + W1*sinS

Using this expression with equations 1, 2, and 3, we obtain the following expression for the log weight, W2:

$$W2= \frac{W1*sinS - f*W1*cosS}{f*cosS-sinS-\left(\frac{f*cosS*cosT-f*sinS*sinT+U*cosS*cosT-U*sinS*sinT}{2*(cosT+U*sinT)}\right)} \qquad (4)$$

The Hewlett-Packard 9830 programmable calculator was used to plot the log weight as a function of slope and coefficient of traction. The result is the graph that was shown in figure 24.

For the conventional tracked skidder, the log is skidded by a cable attached to a winch mounted on the rear of the vehicle. With this arrangement, the assumption is that the entire log will be in contact with the ground during skidding and no additional weight is transferred to the vehicle to increase its normal force.

Referring to figure B3, we can sum forces parallel to the slope and calculate the skidding capability as follows:

$\sum$forces parallel to slope = 0

f*N1 = W1*sinS+W2*sinS+U*N2

Solving for W2, we obtain;

$$W2 = \frac{f*W1*\cos S - W1*\sin S}{\sin S - U*\cos S} \qquad (5)$$

Again using the Hewlett-Packard 9830 calculator, the graph shown in figure 25 was generated.

The conclusion to be drawn from this analysis is the importance of transferring a portion of the log weight to the vehicle to obtain better traction when working in strong soils. In weak soils, such as clay, this transfer of weight could be a disadvantage because of the tracks sinking into the soil. Therefore, caution must be used in the application of these graphs.

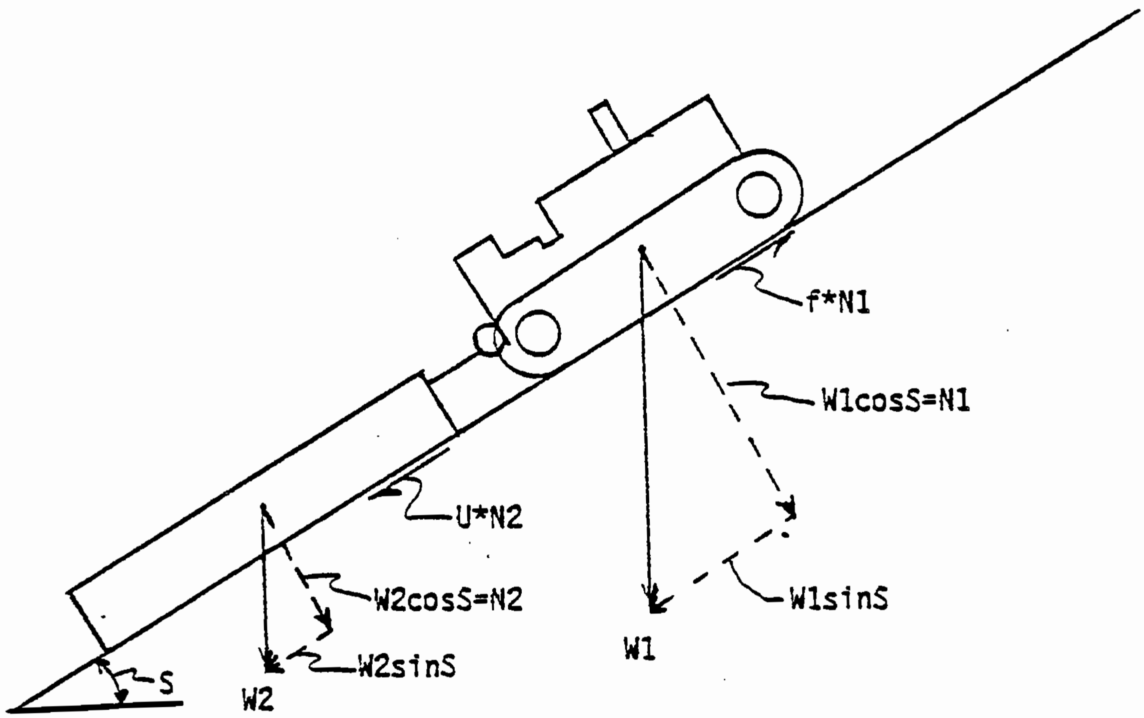

Figure B3. Diagram of the forces acting on the conventional tracked skidder.