United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station**

General Technical
Report INT-118

September 1982

Estimating Production Rates and Operating Costs of Timber Harvesting Equipment in the Northern Rockies

Rulon B. Gardner

THE AUTHOR

RULON B. GARDNER was principal research engineer, located at the Intermountain Station's Forestry Sciences Laboratory in Bozeman, Mont., until his retirement in 1979. Mr. Gardner conducted logging systems research studies for 18 years, 15 years of which were spent in the Rocky Mountain area.

RESEARCH SUMMARY

In recent years, logging has become more difficult and expensive because of decreased accessibility, smaller timber, and the need for more expensive specialized equipment. The Intermountain Station has conducted numerous studies to evaluate costs, equipment, and methods for logging under various conditions, treatments, silvicultural and environmental objectives in the Northern Rocky Mountains.

This report summarizes studies completed in the past decade for most types of equipment that have been used or tried in the Northern Rocky Mountain area. The report provides descriptions of equipment and logging methods, and equations, nomographs, tables, and production data for estimating system productivity. Methods for designing systems, computing costs, and estimating fuel requirements are also included.

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INTRODUCTION

Research conducted by the Intermountain Forest and Range Experiment Station during the past 15 years has studied a wide variety of logging systems and equipment. Information from these studies identifies the principal factors affecting productivity of the systems and equipment used in the Northern Rockies and provides a basis for predicting productivity. This paper summarizes the information available and provides published references related to this subject.

The study of logging systems has proved to be difficult primarily because of the many different variables influencing production and the analyst's lack of control over the operation. Logging is carried out under conditions of continued change in the variables affecting production, such as timber size and stand density, terrain, soil, and weather. This makes it difficult to evaluate effects of the variables.

Another complication is the analyst's lack of control of the operation. Operator skill and motivation also affect the logging operation. Despite these obstacles, past studies have produced data useful for analyzing and predicting productivity of systems and equipment under a wide range of conditions.

How are these studies conducted and how can they be used effectively? The objective of any analyst is to be able to represent the functioning of the system studied by means of a model or group of models. Usually logging subsystems are studied independently—that is, felling, or felling and bucking, skidding or yarding, loading, and hauling. Subsystems can then be fitted into a total harvesting system by techniques such as simulation.

Subsystem production is usually expressed by regression equations derived from the study data. The subsystem regression equations can be used by logging system planners to predict equipment productivity under various conditions, to help estimate the cost of logging. Simulation techniques, as suggested, can be used to help select total system designs.

The data usually collected for analysis are equipment operating times, quantities (volume or weight) of timber removed, and measures of variables potentially affecting production. These data are then analyzed to determine the principal variables influencing production.

TIMBER HARVESTING EQUIPMENT, SYSTEMS, AND PRODUCTIVITY

A nearly full range of equipment types found throughout the United States and abroad is being used in the Northern Rockies, with the exception of some of the newer processors. Most of this equipment has been the subject of study and analysis by the Intermountain Station engineering research work unit. (Data collection and analysis methods are discussed in the appendix.)

To enhance usefulness, production equations are given in horsepower or weight classifications for equipment types whenever possible. Symbols for variables in the equations are shown in table 1.

Some of the variables have been transformed as shown in the equations. The dependent variable is turn time in minutes. Turn time can be converted to production using log size, volume, or weight; whatever is needed for conversion. Information from published sources is referenced. Graphs or tables for solving the equations are included with instructions for their use.

Table 1.--Symbols for regression equations

Symbol	Definitions	Units
DI	Skidding distance with load	ft or m
DITOT	Total distance traveled by the skidder	ft or m
LD	Lateral skidding distance	ft or m
SL	Slope	percent
WT	Weight	lb or kg
NL	Number of logs	each
VOL	Volume	M bd. ft., ft^3, M^3
TT	Turn time	min
LN	Natural log	

Following are instructions for use of the nomographs and tables used in this report:

Nomographs:

- Three variables. From the example for the Idaho jammer in figure 8, use a straightedge to connect the variables of slope (SL) and distance (DI) and read the turn time (TT) directly from the scale (11.8 min).
- Four variables. From the example for 25-59 DBHP tracked skidders in figure 3a, use two straightedge materials (two plastic rulers are best) to solve for turn time. Connect the variable on the left scale (SL) with the next variable to the right (NL) to find the index point on the "q" scale. Then connect this point with the variable scale on the right side (DI) of the figure. Where this line intersects the TT scale, the turn time (31.0 min) is read.

Tables:

- For an example use table 2 (running skyline, shelter-wood, uphill). Enter Matrix A with a lateral distance of 40 ft (12.2 m) and a skyline distance of 525 ft (160.0 m) to obtain the value of 5.808. Enter Matrix B with weight of 2,990 lb (1 356 kg) to obtain the value of 1.027. Multiply the value from table 2 Matrix A, by the value from table 2 Matrix B, (5.808 x 1.027) to obtain the turn time of 5.96 min.

Ground Skidding Equipment

Prior to World War II, ground skidding was the most common method for skidding logs in the Rocky Mountain area. This was primarily because good timber was still available on easy-to-log, gentle terrain.

Horse logging, although still practiced in a few areas in eastern Canada and the United States, is seldom used today. Track-laying vehicles, mostly those built for the construction industry and adapted to logging, and articulated rubber-tired skidders perform virtually all of the ground skidding.

Rubber-tired skidders were not used extensively in the Rocky Mountain area until the past 8 or 10 years. However, they are being used more often now, especially for skidding on slopes less than about 35 percent and for the longer skidding distances.

The skidding capacity of all the equipment is dependent on its drawbar horsepower, weight, and traction obtainable under the ground conditions encountered in logging.

Tracked Skidders

Track-laying (crawler) tractors are of two general types--the standard construction type with steel tracks shown in figure 1, and the high-flotation, rubber-mounted type in figure 2. Size classes used for logging range from approximately 8,000 lb (3 885 kg)-25 drawbar horsepower (DBHP) to 45,000 lb (19 600 kg)-130 DBHP. Most crawler skidders are equipped with integral arches and chokers; however, some have used pans for skidding.

Figure 1.--Conventional tractor skidder suited to moderately steep terrain.

Figure 2.--High-flotation tracked skidder.

Turn times for skidders are predicted using equations derived from logging studies.

The equations and nomographs for solving them for tracked skidders follow (fig. 3a, 3b, 3c):

Tracked skidders with drawbar horsepower ratings of 25-59
Turn time in minutes 14.12
+0.1603 X SL
+ .0108 X DI
+1.470 X NL

The degree of variation explained by the variables in this equation is .... 53 percent

---

Tracked skidders with drawbar horsepower ratings of 60-89
Turn time in minutes 4.85
+0.1258 X SL
+ .0054 X DI
+1.3308 X NL

The degree of variation explained by the variables in this equation is .... 20 percent

---

Tracked skidders with drawbar horsepower ratings of 90-130
Turn time in minutes 14.0
-0.1446 X SL
+ .0714 X DI
+ .3360 X NL

The degree of variation explained by the variables in this equation is .... 35 percent

Publication: Brown (1967)

Figure 4.--Articulated rubber-tired skidder with integral arch.

Figure 5.--Articulated grapple rubber-tired skidder.

Rubber-Tired Skidders

All of the rubber-tired skidders in use today are fully articulated and are used with chokers and an integral arch (fig. 4) or a grapple (fig. 5). Size classes range from approximately 10,000 lb (4 235 kg)-55 brake horsepower (BHP) to 18,500 lb (5 633 kg)-150 BHP.

The equation and nomographs follow for rubber-tired skidders with an integral arch and chokers (fig. 6a, 6b, 6c):

Rubber-tired skidders with brake horsepower ratings of 70-90
Turn time in minutes 6.58
-0.368 X NL
+ .00065 X WT
+ .0168 X DITOT

Degree of variation explained by the equation .... 55 percent

---

Rubber-tired skidders with brake horsepower ratings of 110-150
Turn time in minutes .... -0.1971
+1.1287 X NL
+ .0045 X VOL
+ .0063 X DITOT

Degree of variation explained by the equation .... 84 percent

---

Rubber-tired skidders with brake horsepower ratings of 70-150
Turn time in minutes 2.57
+0.8228 X NL
+ .0054 X VOL
+ .0078 X DITOT

Degree of variation explained by the equation .... 76 percent

Publication: Gardner (1979)

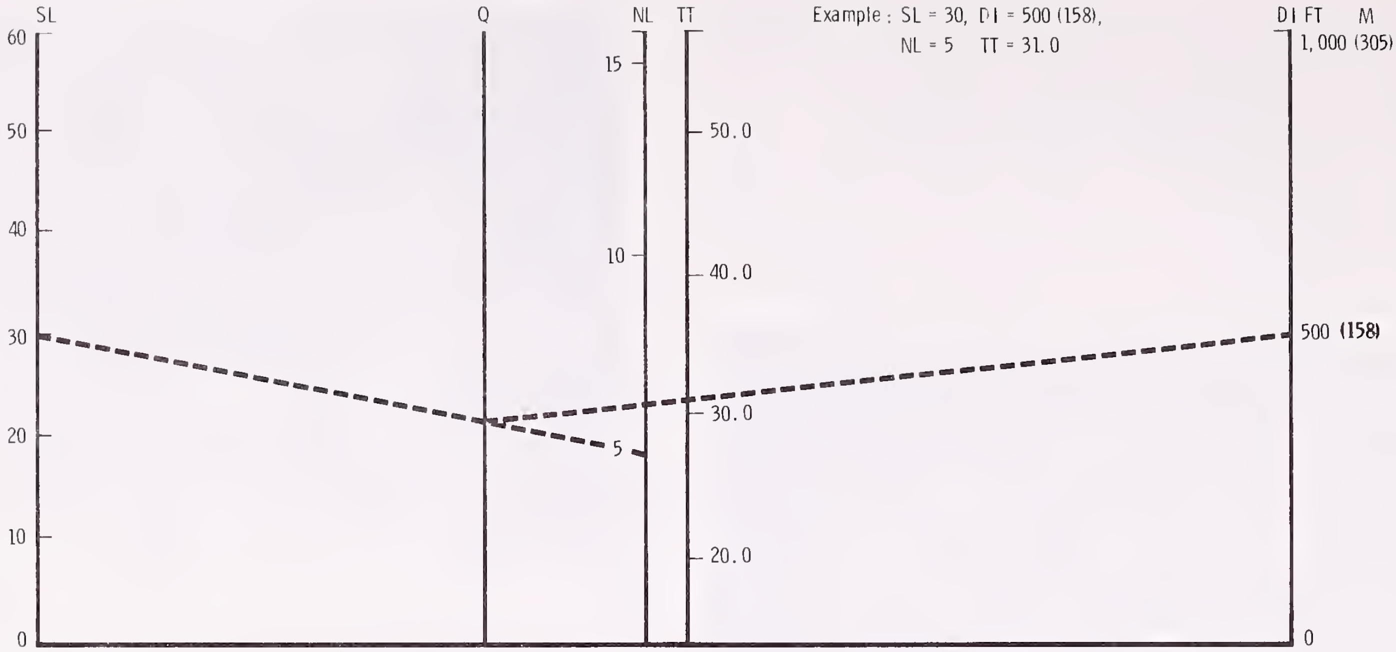

Figure 3a.--Performance nomograph, tracked skidders: 25-59 DBHP.

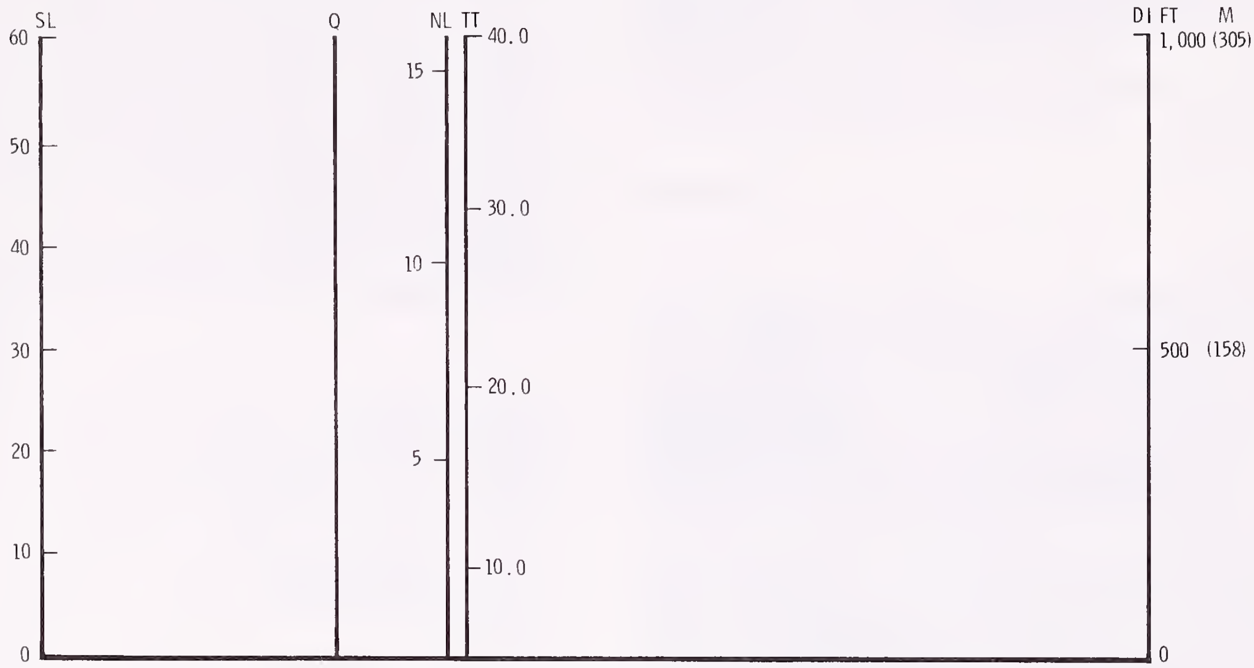

Figure 3b.--Performance nomograph, tracked skidders: 60-89 DBHP.

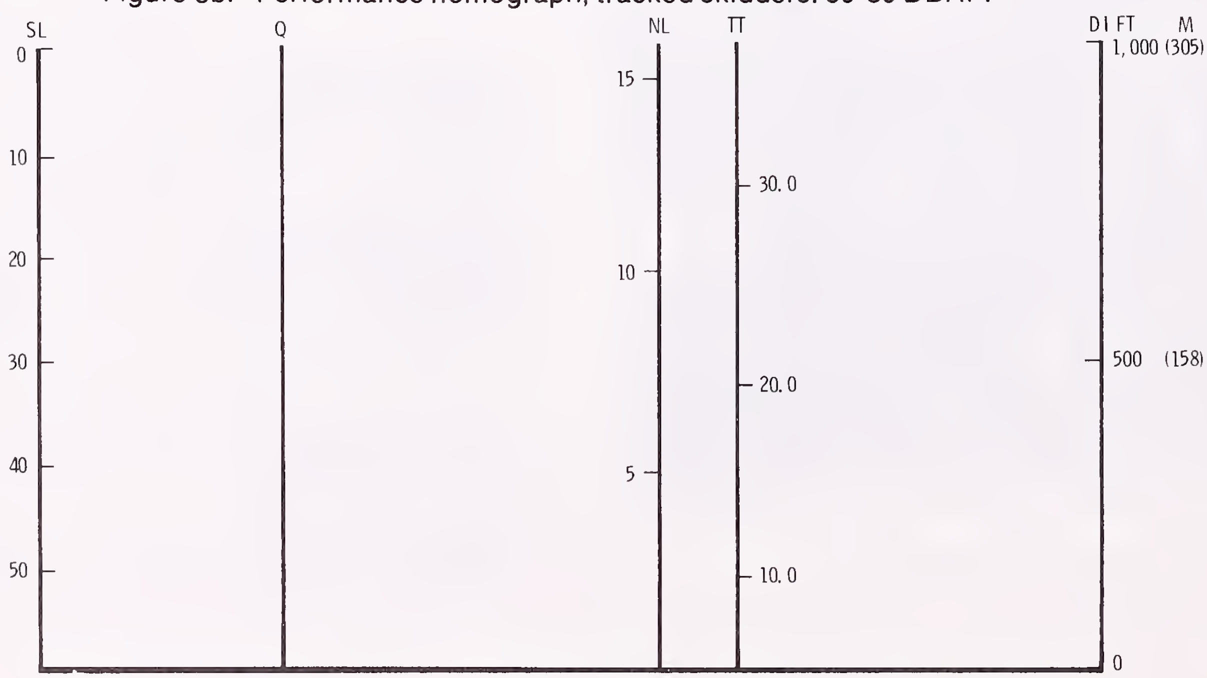

Figure 3c.--Performance nomograph, tracked skidders: 90-130 DBHP.

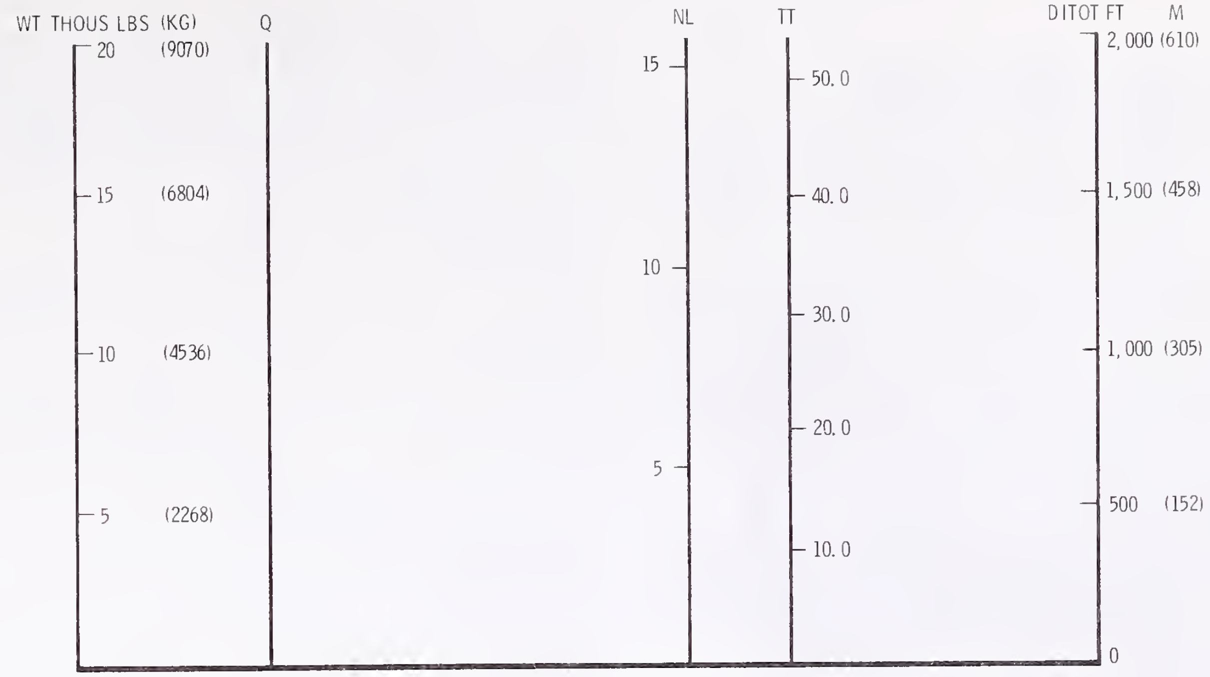

Figure 6a.--Performance nomograph, rubber-tired skidders: 70-90 BHP.

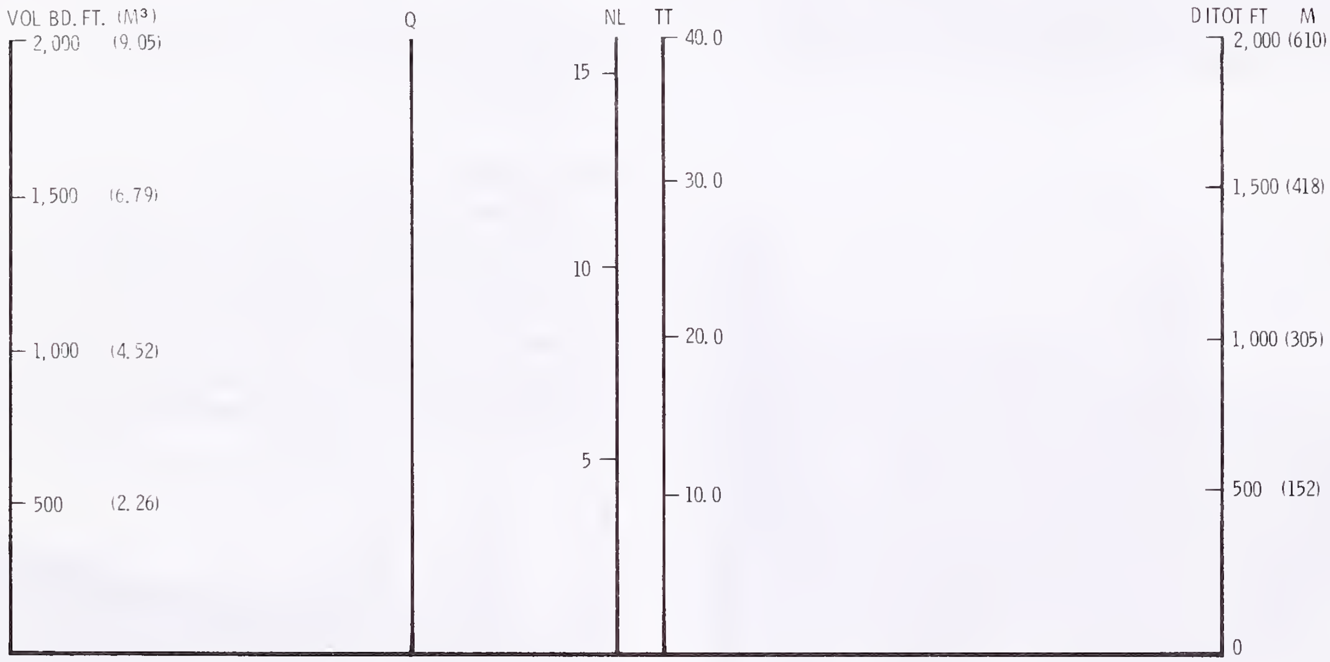

Figure 6b.--Performance nomograph, rubber-tired skidders: 110-150 BHP.

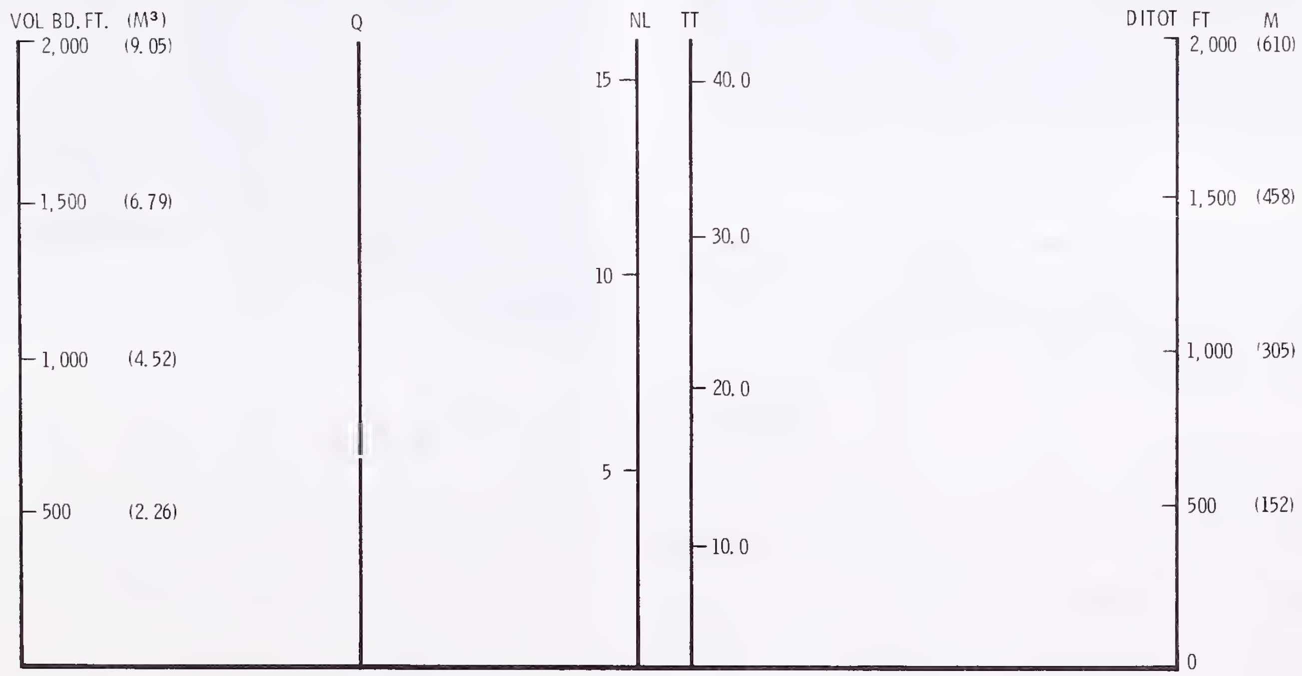

Figure 6c.--Performance nomograph, rubber-tired skidders: 70-150 BHP.

Cable Skidding or Yarding Equipment

Since the mid-1940's, Idaho jammers and high-lead systems have been used in the Rocky Mountain area to log slopes too steep for crawler tractors. Skyline systems, on the other hand, have come into use within the past 10 years or so.

Cable skidding can be classified as jammer, high-lead, and skyline. Jammer and high-lead systems do not require deflection or a carriage (both are required for skyline systems). Logs are ground skidded to the yarder by chokers attached to the butt rigging. Skyline systems partly or fully suspend the logs during yarding.

Idaho Jammer

An Idaho jammer (fig. 7) can be assembled from almost any prime mover on which a boom or spar and two drums can be mounted. Everything from a surplus Army truck to a 50,000-lb (21 800-kg) crawler tractor has been converted to an Idaho jammer. The size of the equipment and the rigging determine maximum load sizes and skidding distances. However, skidding distances of more than 300-400 ft (91-122 m) are seldom used because of the tendency of logs to "hang up" during skidding.

Figure 7.--Idaho jammer built on heavy truck chassis.

Jammer data are from two operations. Both yarded one log per cycle, with an average log size of 237 bd.ft. ($1.1 m^3$) at an average distance of 57 ft (17.3 m).

An equation and nomograph follow (fig. 8):

Turn time in minutes .... 12.774 -0.0468 X SL + .0132 X DI

Degree of variation explained by the equation .... 11 percent

Publication: Brown (1967)

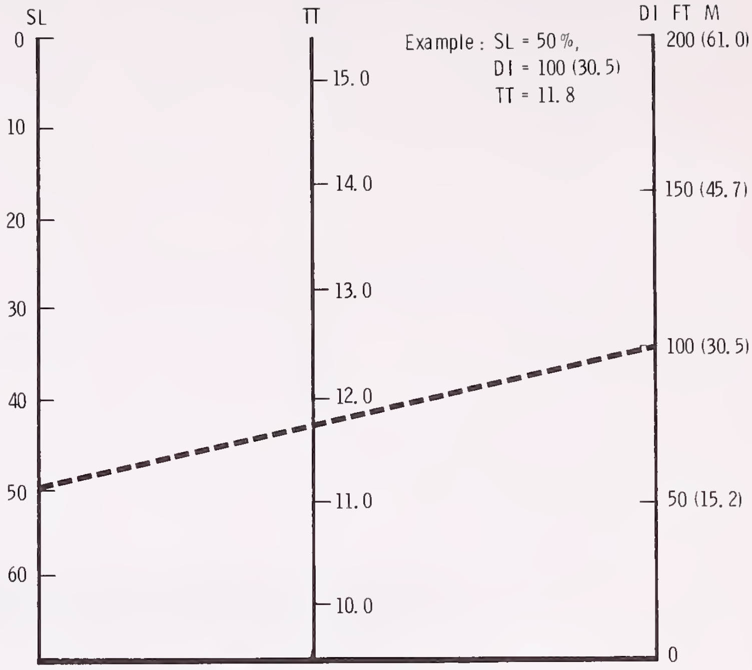

Figure 8.--Performance nomograph, Idaho jammer.

High Lead

High-lead yarding (fig. 9) is generally done with a portable tower or boom and a double-drum yarder. Main and haulback lines vary in size from five-eights inch (1.6 cm) to 1-1/4 inches (3.2 cm) for the larger systems. Distances up to about 800 ft (243 m) are loggable with these systems, depending on the terrain, timber stand, and cutting system. Yarding distances of 400-500 ft (122-152 m) are most common.

Figure 9.--High lead yarder.

The high-lead operations averaged 4.0 logs per load, with an average log size of 150 bd.ft. (0.68 m³) and an average yarding distance of 518 ft (157 m). Following is an equation and accompanying nomograph (fig. 10):

Turn time in minutes 26.06
+0.05718 X SL
+ .04638 X NL

Degree of variation explained by the equation .... 12 percent

Publication: Brown (1967)

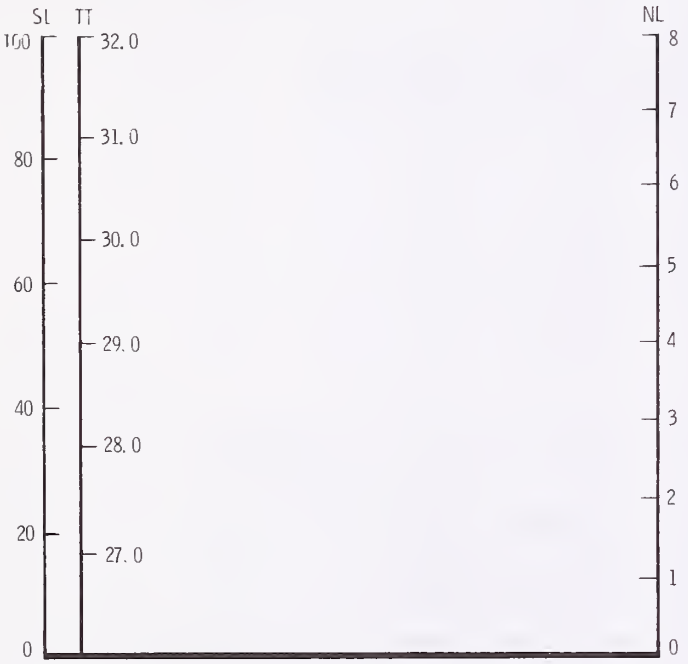

Figure 10.--Performance nomograph, high lead yarder.

Figure 11.--Live skyline yarder.

Figure 12.--Running skyline yarder.

Skyline Yarders

The skyline equations are for running and live skylines for three silvicultural prescriptions and for uphill and downhill yarding.

Live skyline.--The live skyline (fig. 11) uses a gravity carriage and is often rigged with a slack-pulling line to pull out main line for lateral skidding. Yarder and drum sizes determine cable sizes that in turn determine yarding distances and load sizes.

Distances of up to 2,000 ft (610 m) have been logged when enough deflection is available; however, most yarding distances are 1,000 ft (305 m) or less.

Running skyline.--In a running skyline (fig. 12), the carriage runs on the haulback line and is usually a slack-pulling carriage controlled by the slack-pulling line. Yarding distances like the live skyline are dependent on deflection, the equipment size, and yarding drums. Yarding distances of 1,000-1,200 ft (305-366 m) are near maximum for most running skyline systems.

The equations for live and running skylines are a function of the natural logarithms. The natural logarithms can be obtained from tables. However, the equations can be more easily solved using tables 2 through 8.

Table 2.--Turn time prediction factors, running skyline, shelterwood, uphill (numbers in italics are used in instructions, page 2)

	Matrix A Lateral distance, ft (m)										
Skyline distance	0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
Feet (Meters)											
25 (7.6)	4.350	4.400	4.451	4.502	4.554	4.606	4.660	4.713	4.767	4.822	4.878
125 (38.1)	4.567	4.620	4.673	4.727	4.781	4.836	4.892	4.948	5.005	5.063	5.121
225 (68.6)	4.795	4.850	4.906	4.962	5.019	5.077	5.136	5.195	5.255	5.315	5.376
325 (99.1)	5.034	5.092	5.150	5.210	5.270	5.330	5.392	5.454	5.517	5.580	5.644
425 (130.0)	5.285	5.346	5.407	5.469	5.532	5.596	5.661	5.726	5.792	5.858	5.926
525 (160.0)	5.548	5.612	5.677	5.742	*5.808*	5.875	5.943	6.011	6.080	6.150	6.221
625 (190.0)	5.825	5.892	5.960	6.028	6.098	6.168	6.239	6.311	6.384	6.457	6.531
725 (221.0)	6.115	6.186	6.257	6.329	6.402	6.476	6.550	6.626	6.702	6.779	6.857
825 (252.0)	6.420	6.494	6.569	6.645	6.721	6.798	6.877	6.956	7.036	7.117	7.199
925 (282.0)	6.740	6.818	6.896	6.976	7.056	7.137	7.220	7.303	7.387	7.472	7.558
1,025 (312.0)	7.076	7.158	7.240	7.324	7.408	7.493	7.580	7.667	7.755	7.844	7.935
1,125 (343.0)	7.429	7.515	7.601	7.689	7.777	7.867	7.957	8.049	8.142	8.236	8.330
	Matrix B Weight, lb (kg)										
	30 (13.6)	**1,510 (685)**	***2,990* (1 356)**	**4,470 (2 028)**	**5,950 (2 699)**	**7,430 (3 370)**	**8,910 (4 042)**	**10,390 (4 713)**	**11,870 (5 384)**	**13,350 (6 056)**	**14,830 (6 729)**
	1.000	1.014	*1.027*	1.041	1.055	1.069	1.083	1.098	1.112	1.127	1.142

Table 3.--Turn time predication factors, running skyline, shelterwood, downhill

Matrix A

Number of logs	Lateral distance, ft (m): 0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
1	1.968	1.972	1.977	1.982	1.987	1.991	1.996	2.001	2.006	2.011	2.015
2	1.968	1.977	1.987	1.996	2.006	2.015	2.025	2.035	2.045	2.054	2.064
3	1.968	1.982	1.996	2.011	2.025	2.040	2.054	2.069	2.084	2.099	2.115
4	1.968	1.987	2.006	2.025	2.045	2.064	2.084	2.104	2.125	2.145	2.166
5	1.968	1.991	2.015	2.040	2.064	2.089	2.115	2.140	2.166	2.192	2.218
6	1.968	1.996	2.025	2.054	2.084	2.115	2.145	2.176	2.208	2.240	2.272
7	1.968	2.001	2.035	2.069	2.104	2.140	2.176	2.213	2.251	2.289	2.328
8	1.968	2.006	2.045	2.084	2.125	2.166	2.208	2.251	2.294	2.339	2.384
9	1.968	2.011	2.054	2.099	2.145	2.192	2.240	2.289	2.339	2.390	2.442
10	1.968	2.015	2.064	2.115	2.166	2.218	2.272	2.328	2.384	2.442	2.501

Matrix B

Slope (percent)	Volume, bd.ft. (m^3): 5 (0.02)	30 (0.14)	55 (0.25)	80 (0.36)	105 (0.48)	130 (0.59)	155 (0.70)	180 (0.82)	205 (0.93)	230 (1.04)	255 (1.16)
-30	1.005	1.029	1.054	1.080	1.106	1.133	1.160	1.189	1.218	1.247	1.277
-25	1.004	1.024	1.045	1.066	1.088	1.110	1.132	1.155	1.178	1.202	1.226
-20	1.003	1.019	1.036	1.053	1.070	1.087	1.104	1.122	1.140	1.159	1.177
-15	1.002	1.015	1.027	1.039	1.052	1.064	1.077	1.090	1.103	1.117	1.130
-10	1.002	1.010	1.018	1.026	1.034	1.042	1.051	1.059	1.068	1.076	1.085
- 5	1.001	1.005	1.009	1.013	1.017	1.021	1.025	1.029	1.033	1.037	1.042
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5	.999	.995	.991	.987	.983	.979	.976	.972	.968	.964	.960
10	.998	.990	.983	.975	.967	.959	.952	.944	.937	.929	.922
15	.998	.986	.974	.962	.951	.940	.928	.917	.906	.895	.885
20	.997	.981	.965	.950	.935	.920	.906	.891	.877	.863	.849

Matrix C

	Distance, ft (m): 25 (7.6)	105 (32.0)	185 (56.4)	265 (80.8)	345 (105)	425 (130)	505 (154)	585 (178)	665 (204)	745 (227)	825 (251)
	1.531	1.851	1.995	2.093	2.167	2.228	2.279	2.324	2.364	2.399	2.432

Table 4.--Turn time predication factors, running skyline, group selection, uphill

	Matrix A Weight, lb (kg)										
Number of logs	200 (90.7)	1,200 (544)	2,200 (998)	3,200 (1 452)	4,200 (1 905)	5,200 (2 359)	6,200 (2 823)	7,200 (3 266)	8,200 (3 720)	9,200 (4 173)	10,200 (4 627)
1	1.788	1.795	1.802	1.809	1.817	1.824	1.831	1.838	1.846	1.853	1.861
2	1.789	1.804	1.818	1.833	1.847	1.862	1.877	1.892	1.907	1.923	1.938
3	1.791	1.812	1.834	1.856	1.879	1.901	1.924	1.948	1.971	1.995	2.019
4	1.792	1.821	1.850	1.880	1.910	1.941	1.973	2.004	2.037	2.070	2.103
5	1.793	1.830	1.867	1.904	1.943	1.982	2.022	2.063	2.105	2.147	2.191
6	1.795	1.838	1.883	1.928	1.976	2.024	2.073	2.123	2.175	2.228	2.282
7	1.796	1.847	1.900	1.954	2.009	2.066	2.125	2.185	2.248	2.311	2.377
8	1.798	1.856	1.917	1.979	2.043	2.110	2.178	2.249	2.323	2.398	2.476
9	1.799	1.865	1.934	2.004	2.078	2.154	2.233	2.315	2.400	2.488	2.579
10	1.801	1.874	1.951	2.030	2.113	2.199	2.289	2.383	2.480	2.581	2.687
	Matrix B Lateral distance, ft (m)										
Slope (percent)	**0**	**10 (3.0)**	**20 (6.1)**	**30 (9.1)**	**40 (12.2)**	**50 (15.2)**	**60 (18.3)**	**70 (21.3)**	**80 (24.4)**	**90 (27.4)**	**100 (30.5)**
22	0.935	0.953	0.971	0.990	1.009	1.029	1.049	1.070	1.090	1.112	1.133
27	.920	.938	.956	.975	.994	1.013	1.033	1.053	1.074	1.095	1.116
32	.906	.924	.942	.960	.979	.998	1.017	1.037	1.057	1.078	1.099
37	.892	.910	.982	.946	.964	.983	1.002	1.021	1.041	1.062	1.082
42	.879	.896	.913	.931	.949	.968	.987	1.006	1.025	1.045	1.066
47	.865	.882	.899	.917	.935	.953	.972	.990	1.010	1.029	1.049
52	.852	.869	.886	.903	.921	.938	.957	.975	.994	1.014	1.033
57	.839	.856	.872	.889	.906	.924	.942	.960	.979	.998	1.018
62	.826	.842	.859	.876	.893	.910	.928	.946	.964	.983	1.002
67	.814	.830	.846	.862	.879	.896	.914	.931	.949	.968	.987
72	.801	.817	.833	.849	.866	.882	.900	.917	.935	.953	.972
	Matrix C Distance, ft (m)										
	50 (15.2)	**170 (51.8)**	**290 (88.4)**	**410 (125)**	**530 (162)**	**650 (198)**	**770 (235)**	**890 (271)**	**1,010 (308)**	**1,130 (344)**	**1,250 (381)**
	2.118	2.678	2.967	3.171	3.331	3.464	3.579	3.679	3.770	3.852	3.927

Table 5.--Turn time predication factors, running skyline, group selection, downhill

Matrix A Weight, lb (kg) Number of logs	250 (113)	1,150 (526)	2,050 (930)	2,950 (1 338)	3,850 (1 746)	4,750 (2 155)	5,650 (2 563)	6,550 (2 971)	7,450 (3 379)	8,350 (3 788)	9,250 (4 196)
2	0.503	0.506	0.509	0.513	0.516	0.519	0.522	0.526	0.529	0.533	0.536
3	.503	.508	.513	.518	.523	.528	.533	.538	.543	.549	.554
4	.504	.510	.517	.523	.530	.537	.544	.551	.558	.565	.572
5	.504	.512	.521	.529	.537	.546	.555	.564	.573	.582	.591
6	.505	.514	.524	.534	.545	.555	.566	.577	.588	.599	.611
7	.505	.517	.528	.540	.552	.565	.577	.590	.604	.617	.631
8	.506	.519	.532	.546	.560	.574	.589	.604	.620	.636	.652
9	.506	.521	.536	.551	.567	.584	.601	.618	.636	.655	.674
10	.506	.523	.540	.557	.575	.594	.613	.633	.653	.674	.696
11	.507	.525	.544	.563	.583	.604	.625	.648	.671	.695	.719

Matrix B Distance, ft (m) Lateral distance	180 (54.9)	240 (73.2)	300 (91.4)	360 (110)	420 (128)	480 (146)	540 (165)	600 (183)	660 (201)	720 (219)	780 (238)
Feet (Meters)											
10 (3.0)	5.934	6.540	7.052	7.499	7.900	8.265	8.600	8.912	9.204	9.478	9.738
20 (6.1)	6.093	6.715	7.241	7.701	8.112	8.487	8.831	9.151	9.450	9.732	9.999
30 (9.1)	6.257	6.895	7.435	7.907	8.330	8.714	9.068	9.396	9.704	9.993	10.267
40 (12.2)	6.424	7.080	7.634	8.119	8.553	8.948	9.311	9.649	9.964	10.261	10.543
50 (15.2)	6.597	7.270	7.839	8.337	8.783	9.188	9.561	9.907	10.232	10.537	10.826
60 (18.3)	6.774	7.465	8.049	8.561	9.018	9.434	9.817	10.173	10.506	10.819	11.116
70 (21.3)	6.955	7.665	8.265	8.790	9.260	9.688	10.081	10.446	10.788	11.110	11.414
80 (24.4)	7.142	7.871	8.487	9.026	9.509	9.947	10.351	10.726	11.077	11.408	11.720
90 (27.4)	7.333	8.082	8.715	9.268	9.764	10.214	10.629	11.014	11.374	11.714	12.035
100 (30.5)	7.530	8.299	8.948	9.517	10.026	10.488	10.914	11.309	11.679	12.028	12.357

Table 6.--Turn time predication factors, running skyline, clearcut, uphill

	Matrix A Volume, bd.ft. (m³)										
Distance	5 (0.02)	25 (0.11)	45 (0.20)	65 (0.29)	85 (0.38)	105 (0.48)	125 (0.57)	145 (0.66)	165 (0.75)	185 (0.84)	205 (0.93)
Feet (Meters)											
60 (18.3)	3.172	3.212	3.252	3.293	3.334	3.375	3.417	3.460	3.503	3.579	3.591
145 (44.2)	3.440	3.483	3.527	3.571	3.615	3.660	3.706	3.752	3.799	3.846	3.894
230 (70.1)	3.701	3.747	3.794	3.842	3.889	3.938	3.987	4.037	4.087	4.138	4.190
315 (96.0)	3.951	4.000	4.050	4.101	4.152	4.204	4.256	4.309	4.363	4.417	4.473
400 (122)	4.184	4.237	4.289	4.343	4.397	4.452	4.508	4.564	4.621	4.678	4.737
485 (148)	4.397	4.452	4.507	4.563	4.620	4.678	4.736	4.796	4.855	4.916	4.977
570 (174)	4.584	4.641	4.699	4.758	4.817	4.877	4.938	4.999	5.062	5.125	5.189
655 (200)	4.741	4.800	4.860	4.921	4.982	5.045	5.108	5.171	5.236	5.301	5.367
740 (226)	4.866	4.926	4.988	5.050	5.113	5.177	5.242	5.307	5.373	5.440	5.508
825 (251)	4.954	5.016	5.079	5.142	5.206	5.271	5.337	5.403	5.471	5.539	5.608
910 (277)	5.005	5.067	5.130	5.194	5.259	5.325	5.391	5.459	5.527	5.596	5.665

	Matrix B Lateral distance, ft (m)										
Slope (percent)	0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
20	1.000	1.009	1.017	1.026	1.035	1.044	1.053	1.062	1.071	1.080	1.090
25	1.000	1.011	1.022	1.033	1.044	1.055	1.067	1.078	1.090	1.102	1.113
30	1.000	1.013	1.026	1.039	1.053	1.067	1.080	1.095	1.109	1.123	1.138
35	1.000	1.015	1.031	1.046	1.062	1.078	1.095	1.111	1.128	1.145	1.162
40	1.000	1.017	1.035	1.053	1.071	1.090	1.109	1.128	1.148	1.167	1.188
45	1.000	1.020	1.039	1.060	1.080	1.102	1.123	1.145	1.167	1.190	1.213
50	1.000	1.022	1.044	1.067	1.090	1.113	1.138	1.162	1.188	1.213	1.240
55	1.000	1.024	1.048	1.074	1.099	1.126	1.152	1.180	1.208	1.237	1.267
60	1.000	1.026	1.053	1.080	1.109	1.138	1.167	1.198	1.229	1.261	1.294

	Matrix C Number of logs									
	1	2	3	4	5	6	7	8	9	10
	1.020	1.040	1.061	1.081	1.103	1.125	1.147	1.169	1.193	1.261

Table 7.--Turn time predication factors, live skyline, group selection, uphill

Matrix A

Slope (percent)	Lateral distance, ft (m) 0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
40	4.189	4.262	4.336	4.411	4.488	4.566	4.645	4.726	4.808	4.891	4.976
45	3.995	4.064	4.135	4.207	4.280	4.354	4.430	4.506	4.585	4.664	4.745
50	3.810	3.876	3.943	4.012	4.081	4.152	4.224	4.297	4.372	4.448	4.525
55	3.633	3.696	3.760	3.825	3.892	3.959	4.028	4.098	4.169	4.242	4.315
60	3.464	3.525	3.586	3.648	3.711	3.776	3.841	3.908	3.976	4.045	4.115
65	3.304	3.361	3.419	3.479	3.539	3.601	3.663	3.727	3.791	3.857	3.924
70	3.150	3.205	3.261	3.317	3.375	3.434	3.493	3.554	3.615	3.678	3.742

Matrix B

Number of logs	Weight, lb (kg) 75 (34.0)	875 (397)	1,675 (760)	2,475 (1 123)	3,275 (1 486)	4,075 (1 848)	4,875 (2 211)	5,675 (2 574)	6,475 (2 937)	7,275 (3 300)	8,075 (3 663)
1	1.000	1.002	1.005	1.007	1.009	1.011	1.014	1.016	1.018	1.020	1.023
2	1.000	1.005	1.009	1.014	1.018	1.023	1.027	1.032	1.037	1.041	1.046
3	1.001	1.007	1.014	1.021	1.028	1.034	1.041	1.048	1.055	1.062	1.069
4	1.001	1.010	1.019	1.028	1.037	1.046	1.056	1.065	1.074	1.084	1.094
5	1.001	1.012	1.023	1.035	1.046	1.058	1.070	1.082	1.094	1.106	1.118
6	1.001	1.015	1.028	1.042	1.056	1.070	1.084	1.099	1.114	1.129	1.144
7	1.001	1.017	1.033	1.049	1.066	1.082	1.099	1.116	1.134	1.152	1.170
8	1.002	1.020	1.038	1.056	1.075	1.095	1.114	1.134	1.154	1.175	1.196
9	1.002	1.022	1.043	1.064	1.085	1.107	1.129	1.152	1.175	1.199	1.223
10	1.002	1.025	1.048	1.071	1.095	1.120	1.145	1.170	1.197	1.224	1.251
11	1.002	1.027	1.052	1.078	1.105	1.132	1.160	1.189	1.218	1.248	1.279
12	1.002	1.030	1.057	1.086	1.115	1.145	1.176	1.208	1.240	1.274	1.308

Matrix C

	Distance, ft (kg) 50 (15.2)	125 (38.1)	200 (61.0)	275 (83.8)	350 (107)	425 (130)	500 (152)	575 (175)	650 (198)	725 (221)	800 (244)
	1.048	1.125	1.207	1.295	1.390	1.491	1.600	1.717	1.842	1.977	2.121

Table 8.--Turn time prediction factors, live skyline, clearcut, uphill

Distance ft (m)	Matrix A Lateral distance, ft (m) 0	10 (3.0)	20 (6.1)	30 (9.1)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)
Feet (Meters)											
10 (3.0)	6.790	6.935	7.084	7.236	7.390	7.549	7.710	7.875	8.044	8.216	8.392
90 (27.4)	7.093	7.245	7.400	7.558	7.720	7.885	8.054	8.226	8.402	8.582	8.766
170 (51.8)	7.409	7.567	7.729	7.895	8.064	8.236	8.413	8.593	8.777	8.965	9.157
250 (76.2)	7.739	7.905	8.074	8.247	8.423	8.604	8.788	8.976	9.168	9.364	9.565
330 (101)	8.084	8.257	8.434	8.614	8.799	8.987	9.179	9.376	9.577	9.781	9.991
410 (125)	8.444	8.625	8.810	8.998	9.191	9.387	9.588	9.794	10.003	10.217	10.436
490 (149)	8.820	9.009	9.202	9.399	9.600	9.806	10.016	10.230	10.449	10.673	10.901
570 (174)	9.214	9.411	9.612	9.818	10.028	10.243	10.462	10.686	10.915	11.148	11.387
650 (198)	9.624	9.830	10.041	10.255	10.475	10.699	10.928	11.162	11.401	11.645	11.894
730 (223)	10.053	10.268	10.488	10.713	10.942	11.176	11.415	11.660	11.908	12.164	12.425
810 (247)	10.501	10.726	10.955	11.190	11.429	11.674	11.924	12.179	12.440	12.706	12.978
890 (271)	10.969	11.204	11.444	11.689	11.939	12.194	12.455	12.722	12.994	13.272	13.557
970 (296)	11.458	11.703	11.954	12.209	12.471	12.738	13.010	13.289	13.573	13.864	14.161

Slope (percent)	Matrix B Number of logs 1	2	3	4	5	6	7	8	9	10
45	0.486	0.598	0.641	0.644	0.678	0.687	0.694	0.699	0.703	0.707
50	.470	.578	.620	.642	.655	.664	.671	.676	.680	.683
55	.454	.559	.599	.620	.633	.642	.648	.653	.657	.660
60	.439	.540	.579	.599	.612	.621	.627	.631	.635	.638
65	.424	.522	.560	.579	.592	.600	.606	.610	.614	.617
70	.410	.505	.541	.560	.572	.580	.586	.590	.593	.596

Running skyline, shelterwood cut, logging .... Uphill
Natural log of turn time in minutes ....

$$1.45805 + .0004865 \times DI + .001145 \times LD + .00000896 \times W$$

Degree of variation explained by equation .... 34 percent

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Running skyline, shelterwood cut, logging .... Downhill
Natural log of turn time in minutes ....

$$0.676830 + .000240 \times NL \times LD + .132343 \times LN(DI) - .000032 \times S \times V$$

Degree of variation explained by equation .... 44 percent

---

Running skyline, group selection cut, logging .... Uphill
Natural log of turn time in minutes ....

$$0.580136 - .003076 \times S + .001928 \times LD + .191832 \times LN(DI) + .000004 \times NL \times W$$

Degree of variation explained by equation .... 68 percent

---

Running skyline, group selection cut, logging .... Downhill
Natural log of turn time in minutes ....

$$-0.689134 + .002647 \times LD + .337807 \times LN(DI) + .00000354 \times NL \times W$$

Degree of variation explained by equation .... 32 percent

---

Running skyline, clearcut logging .... Uphill
Natural log of turn time in minutes ....

$$1.089454 + .019567 \times NL + .001065 \times DI + .000617 \times V - .00000054 \times (DI)^2 + .000043 \times LD \times S$$

Degree of variation explained by equation .... 48 percent

Live skyline selection cut, logging .... Uphill
Natural log of turn time in minutes ....

$$1.812551 + .000940 \times DI - .00950 \times S + .001721 \times LD + .000002773 \times NL \times W$$

Degree of variation explained by equation .... 42 percent

---

Live skyline, clearcut logging .... Uphill
Natural log of turn time in minutes ....

$$1.910023 + .000545 \times DI - .006795 \times S + .002118 \times LD - .4162 \times \left(\frac{1}{NL}\right)$$

Degree of variation explained by equation .... 41 percent
Publication: Gardner (1980)

Aerial Yarders

Helicopter logging experimentation began in the early 1960's, but helicopters were not used to any extent until the 1970's. Balloon logging experiments began a little later in the 1960's, and balloon logging is still largely experimental. Both systems are used primarily in steep country where roads are very costly to construct, are prohibited, or will severely damage the environment. More recently, both of these systems have also been used to log areas with unstable ground conditions, such as swampland in the South. The potential environmental advantages of these systems must be weighed against the increased cost of yarding and lack of access for timber stand improvement, fire, and other management tasks.

Balloon Yarding

In a balloon yarding system, the balloon (fig. 13) suspends the cables needed to control it and the logs. The balloon is rigged similar to a running skyline and uses an interlocking double-drum yarder, with main and haulback lines. In the balloon system, the choker lines are suspended from the butt rigging, which is attached to the drop line from the balloon. The balloon is positioned over the load by movement of the main and haulback lines; the choker line (can be varied in length) is brought to the ground by locking the main line drum and reeling in the haulback line. This process is reversed to suspend the load, and actuating the interlocking drum system brings the load to the landing.

The only operational system at the present time utilizes a Raven Industries 530,000 ft^3 (15 010 m^3), helium-filled, natural-shaped balloon (fig. 13) and a Washington Iron Works Aero Yarder, Model 608A. The main line drum has a capacity of 5,550 ft (1 672 m) of 1-inch (2.54-cm) cable, and the haulback drum, 7,000 ft (2 128 m) of 1-inch (2.54-cm) cable. Yarding distance depends on drum size, but is in the 3,000-4,000-ft (912-1 216-m) range.

Figure 13.--Natural-shaped logging balloon

The balloon data are for the only commercial balloon logging equipment available, discussed under Aerial Yarders. The equation for turn time in minutes is taken from Hartsog (1978):

Balloon logging,
selection cut .... Downhill
Turn time in minutes 3.43
+0.00391 X DI
+ .0036 X LD

Publication: Hartsog (1978)
See figure 14 for nomograph.

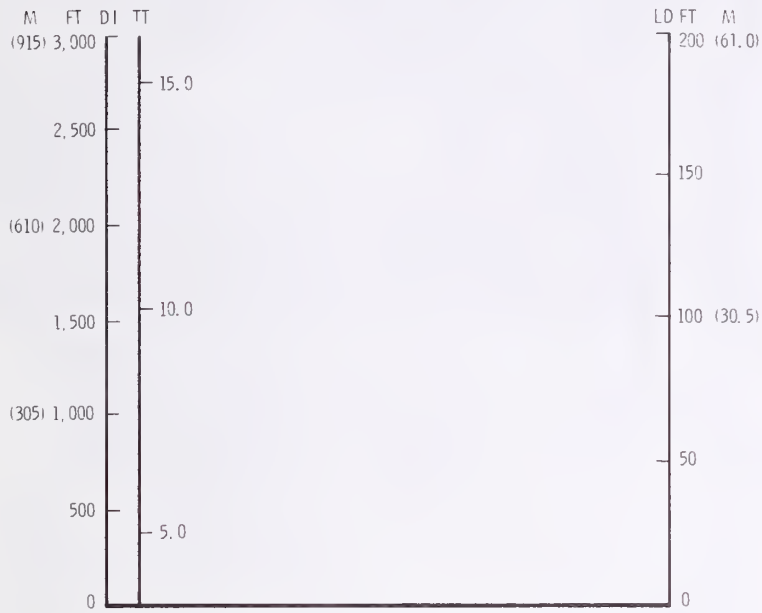

Figure 14.--Performance nomograph, balloon yarding system.

Figure 15.--Helicopter logging with Boeing Vertol 107-11.

Helicopter Yarding

There are more than 35 helicopters (fig. 15) with a 1,000-lb (453-kg) or more payload, and about 12 of these have payloads exceeding 5,000 lb (2 268 kg) that could be used for logging. However, two helicopters with approximately 8,000-lb (3 629-kg) payloads and one with a 20,000-lb (9 072-kg) payload have been used for practically all of the commercial logging to date.

Although expensive to operate, a helicopter has great versatility for logging. and under favorable conditions it is competitive with other systems. In some cases, the helicopter is the only system capable of performing the logging operation; for instance, where roads are prohibited and yarding distances are too great for balloon or cable logging.

The following data are averages for three helicopters:

Helicopter	No. turns	TT *Minutes*	NL	VOL *Bd.ft.* *(m^3)*	DI *Feet* *(m)*
Boeing Vertol 107-11	777	2.4	1.9	499.5 (2.26)	1,184 (360)
Sikorsky S-61	309	2.9	2.2	450.6 (2.04)	2,546 (774)
Sikorsky S-64	86	3.0	3.2	3,101.4 (14.03)	1,232 (375)

Tree Processors

Machines that combine harvesting operations, or perform operations in the field that are normally done elsewhere, are becoming increasingly common. Not many of these machines are in common use in the Northern Rocky Mountain area; however, single-stem feller-bunchers have become more popular the past 10 years.

Feller-Buncher

Many machines now available perform the felling-bunching (fig. 16) operation. As the name implies, they fell the tree (usually by shearing) and place it in a pile designed to facilitate skidding. Most models are capable of handling trees up to 24-26 inches (0.61-0.66 m) in diameter, and can operate effectively on slopes up to about 15 percent. They are mounted on either a rubber-tired or tracked tractor. Track mounting is most popular because it is more stable and because great speed is often unimportant. In recent years, feller heads have been combined with accumulators to improve production for thinning dense stands of small timber. Table 9 gives production figures from Coughran[1] for single-stem and accumulating feller-buncher heads mounted on loaders or excavators, and for a tree combine. Accumulators are much more efficient for the smaller stems that would typically be encountered in thinning operations.

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[1]Coughran, Sam. [n.d.] Feller-buncher application. Unpubl. rep. Rome Industries, Cedartown, Ga.

Figure 16.--Feller-buncher harvesting lodgepole pine.

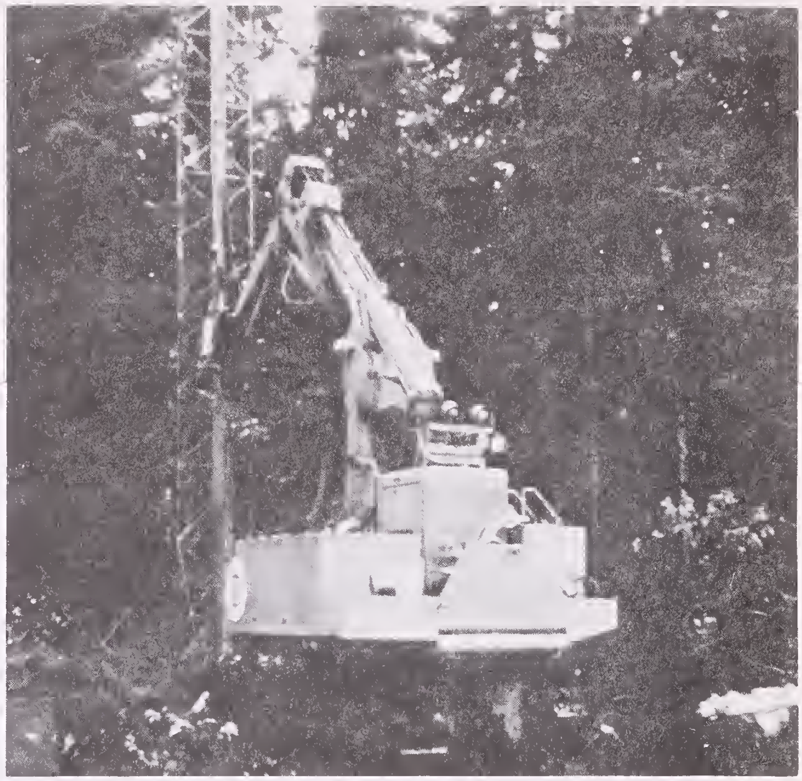

Figure 17.--Feller-buncher-limber designed to clearcut small, dense timber stands.

Feller-Buncher-Limber

This type of processor has been available for several years and has been used primarily for pulpwood operations (fig. 17). It is most effective in the smaller, dense stands on relatively flat terrain for clearcutting operations.

Mobile Chipper

Chipping in the woods (fig. 18), usually at the landing, although a relatively old concept, has not been used much anywhere until the past several years. It is not now in use in the Northern Rocky Mountain area because the few pulp mills in the area are adequately supplied by sawmill residue.

In a whole-tree experimental lodgepole pine logging study in Wyoming (Gardner and Hartsog 1973) piece size averaged 13.6 logs/M bd. ft. (61.5 logs/m^3) and production averaged 57.0 tons/h (52.0 t/h) (productive hours) for the Morbark Chipharvestor SL-22 shown in figure 18.

Log Loaders

Various kinds of loaders, from A-frames to hydraulic knuckle-boom loaders, are being used. The loader selected for a harvesting operation depends on the timber size and method of logging. More types and makes of equipment are available for loading than for any other

Table 9.--Production in trees per hour for feller-bunchers (FB) and tree combines (TC)

D.B.H.	85 hp grapple feller	100 hp loader, single stem FB	130 hp excavator, single stem FB	100 hp loader, accumulator FB	130 hp excavator, accumulator FB	70 hp loader TC
Inches						
3						350
4				270	240	320
5				250	220	280
6		125	150	200	200	260
7		120	145	160	165	210
8		120	140	140	150	160
9		115	135	120	140	140
10	90	110	130	110	135	130
12	88	105	130	105	130	90
14	88	105	120	100	120	
16	85	100	120	100	120	
18	85	95	110	95	110	

logging operation. The most versatile loader is the hydraulic knuckle-boom because it gives such positive control of the log.

Figure 18.--Mobile chipper processing lodgepole pine residue.

Heel-Boom Loader

Heel-boom loaders (fig. 19) are equipped with either a grapple or tongs. The grapple is the more versatile because it can be operated by the operator in the cab of the loader. The logs are heeled against a jam for control.

Figure 19.--Heel-boom loader.

Knuckle-Boom Loader

The knuckle-boom loader (fig. 20) gives positive control of the log as it rests against a jam, and the log can be placed very accurately wherever desired on a truck.

Figure 20.--Hydraulic knuckle-boom loader.

Long-Boom Loader

Long booms (fig. 21) are usually used when logs must be loaded from decks that are difficult to reach, such as those at or near the bottom of a road fill. This type of loading usually requires a tong and tong setter.

Figure 21.--Long-boom loader.

Front-End Loader

Front-end loaders are either tracked (fig. 22) or rubber-tired (fig. 23) and load from the front as shown.

Figure 22.--Track-mounted front-end loader.

Figure 23.--Rubber-tired front-end loader.

The following production data are averages for the loading equipment listed:

Equipment type	No. turns	TT *Minutes*	NL	VOL *Bd.ft. (m^3)*	W *Lb (kg)*
Heel-boom/ grapple	635	0.6	1.2	194.8 (0.88)	1,415 (642)
Long-boom/ tongs	277	.5	1.2	183.7 (0.83)	1,390 (630)
Long-boom/ air tongs	99	.7	1.1	54.7 (0.25)	516 (234)
Jammer	192	1.6	1.0	220.7 (1.00)	1,876 (851)

This summarizes the general equipment types used for various logging systems in the Northern Rocky Mountain area. Most of this same equipment or same type of equipment is used to varying degrees in other areas of the United States and abroad.

LOGGING COSTS, FUEL REQUIREMENTS, AND SYSTEM DESIGN

Logging costs and energy consumption vary with efficiency and, therefore, depend on the equipment and manpower applied to a harvesting situation. The fundamentals of planning are the same as for any other process; however, the planning of logging has generally lagged behind most other industries because of lack of vital information, difficult environmental conditions, lack of trained logging engineers, or just lack of interest. Because of the high cost of modern logging equipment, especially for equipment such as helicopters, planning has increased in the past few years.

In nearly all of the Experiment Station's studies time and motion were measured using a stopwatch, so productivity could be measured, predicted, and converted to cost. The following sections describe and illustrate a method for estimating production costs and designing logging systems.

Estimating Costs and Fuel Consumption

Costs can be estimated from the production data in the previous sections by using equipment and manpower costs appropriate for the place and time. The Internal Revenue Service accepts several methods of depreciating equipment; the operation should use the one that best fits the situation. We have used straightline depreciation and a standard method of computing fixed and operating costs for equipment. The form used is shown in the appendix. Wage rates common to the area are used.

Energy consumption estimates, based on average fuel consumption of equipment types applied to productive hours, can be used to compare the relative energy efficiency of various systems on a unit basis: cubic foot, board foot, cubic meter.

To estimate costs and energy consumption, the planner needs the usual information about variables such as average piece size, number of chokers, number of logs per cycle, average yarding distance, and so on. In the following examples turn times will be computed using the appropriate equation. (Use of nomographs, or tables for skidders and yarders, was discussed in a previous section of this report.)

Example No. 1

given: - running skyline system logging uphill in a shelterwood cut
- average skidding distance - 500 ft (152 m)
- average piece size - 13 ft^3 (0.37 m^3)
- average lateral skidding distance = 50 ft (15.2 m)
- average weight of load/turn - 3,000 lb (1 361 kg)
- average logs per turn = 4.5
- average productivity* = 0.67

from page 15, use equation 1, or use table 2 on page 8.

Volume per hour

**LN (Turn Time) = 1.458 + (0.001) (0.48654) DI + 0.0011 LD + (0.001) (0.00896) W
= 1.458 + 0.24 + 0.06 + 0.02
= 1.78

TT = *5.93 min*

Volume/turn = 13.0 ft^3 (0.368 m^3) (average piece size) x 4.5 (average number of logs)
= *58.5 ft^3*

Productivity = *58.5 ft^3 (1.65 m^3)/turn* ÷ 5.93 min/turn
= 9.87 ft^3 (0.279 m^3)/min or *592 ft^3 (16.8 m^3)/h*

Running skyline equipment and crew cost

- equipment Skagit GT-3 (fixed and operating cost)	=	$42.00/h
- crew: operator	=	7.20
chaser	=	6.60
2 choker setters @ 6.60	=	13.20
1/2 foreman charge @ 7.20 (assume two sides operating)	=	3.80
1 rigger (half of crew) @ 6.60	=	6.60
Total	=	$79.40/h

Unit cost = *$79.40/h* ÷ 592 ft^3 (16.8 m^3)/h ÷ 0.67 (ave. prod.)
= *$0.200/ft³*
or = *$0.032/bd.ft.*
or = *$32.00/M bd.ft. ($7.06/m³)*

*Percentage of time actually spent yarding.

**LN = natural log.

Example No. 2

given: - 120 BHP rubber-tired skidder
- average total skidding distance = 1,000 ft (304 m)
- average piece size = 12.0 ft^3 (0.34 m^3)
- average logs per cycle = 7.0
- average volume = 520 bd.ft. (2.35 m^3)
- average productivity = 0.70

from page 3, use equation for 120 BHP, or use figure 6b on page 5.

Volume per hour

TT = -0.1971 + 1.1287 NL + 0.0045 VOL + 0.0063 DITOT
= -0.1971 + 7.90 + 2.34 + 6.30

TT = 16.34 min

Volume/turn = 12.0 ft^3 (0.34 m^3) (average piece size) x 7.0 (average number of logs)
= *84.0 ft^3* (2.38 m^3)

Productivity = *84.0 ft^3* (2.38 m^3)/turn ÷ 16.34 min/turn
= 5.14 ft^3 (0.146 m^3)/min
or *308 ft^3* (8.73 m^3)/h

Skidder and operator cost

- skidder	=	$9.40
- operator	=	$6.60
Total		$16.00/h

Unit cost = $16.00/h ÷ 308 ft^3 (8.73 m^3)/h ÷ 0.70 (ave. prod.)
= *$0.0742/ft³*
or = *$0.01187/bd.ft.*
or = *$11.87/M bd.ft.* ($2.62/m³)

Example No. 3

given: - heel-boom/grapple loader
- average piece size = 11.0 ft^3 (0.31 m^3)
- average productivity = 0.60

from page 20, use averages for heel-boom.

Volume per hour

Average TT = *0.6 min*

Average NL = 1.2

Volume/turn = 11.0 ft^3 (0.31 m^3) (average piece size) × 1.2 (average number of logs)
= 13.2 ft^3 (0.373 m^3)

Productivity = 13.2 ft^3 (0.373 m^3)/turn ÷ 0.6 min/turn
= 22.0 ft^3 (0.63 m^3)/min
or 1,320 ft^3 (37.4 m^3)/h

Loader and operator cost

- loader	=	$15.50
- operator	=	7.20
Total		$22.70/h

Unit cost = *$22.70/h* ÷ 1,320 ft^3 (37.4 m^3)/h ÷ 0.60 (ave. prod.)
= $0.0287/ft³
or = *$0.00459/bd.ft.*
or = *$4.59/M bd.ft.* ($1.01/m³)

Simulating Logging System Design

Computer programs are available, some of which are listed in the references, for simulating logging systems. Such programs can be used when a planner has access to a computer and the necessary input for analysis. When a computer is not available, other means can be used to help design a system. Gardner's method (1966) is expanded to include energy requirements and is used to illustrate how the foregoing information might be used.

The example shows a trial and error approach to balancing the equipment for a system to harvest a hypothetical timber stand averaging 11-13 ft^3 (0.31-0.37 m^3) piece size by clearcutting in an area with slopes of 15 percent or less. (If a computer is available, this step should probably be used anyway to estimate equipment requirements for input for the first trial run.) The example assumes a hot logging operation--all equipment operating simultaneously. The felling-bunching and skidding operations could have been separated from loading and hauling; for example, if adequate decking space was available and it was desired to load and haul part or all of the harvested material later.

For this example we have used the production estimated for the conditions of previous examples No. 2 and 3 for skidding and loading. The estimated production for the feller-buncher and the hauling were taken from other studies listed in the references. (A 40-mile haul is assumed for the hauling production.)

Any system, of course, can only produce at the rate of the least productive unit or combination of units. For trials 1 and 2, the loader controls the rate, and for trial 3, the skidders control. The objective is to balance production in column (6) as well as possible by adjusting the number of units in column (5).

For fuel consumption computed in columns (9), (10), and (11), average consumption figures for diesel-powered units provide for comparisons of systems. For tracked vehicles fuel consumption is 0.04 gal/hph; for wheeled units, 0.025 gal/hph. Fuel consumption can vary considerably, depending on the condition of the equipment, the operator, altitude, season of the year, and so on. If a logging system planner has better information about fuel consumption, it should be used. (Note on trial 1 that fuel costs are approximately 12 percent of the estimated harvest cost. This figure is very likely to increase in the years ahead.)

Trial 2 produced a better balance of equipment use and therefore lower cost and energy consumption. This relatively simple procedure, largely dependent on good production estimates, represents the minimum analysis that should be done before assigning equipment to any logging operation.

Trial 1.--Logging system design--cost and fuel consumption estimates

Operation (1)	Equipment: Description (2)	Equipment: Cost per hour (3)	Estimated production per hour (4)	Estimated number of units (5)	Production (6)	Cost: Per hour (7)	Cost: Per M ft³ (8)	Horse-power (9)	Fuel consumption (10)	Fuel consumption (11)
			Ft³		*Ft³/h(m³/h)*				*Gal/h*	*Gal/M ft³ (Gal/m³)*
Felling/ bunching	Feller/ buncher	$25.00	1,500	1	1,500 (42.4)	$ 25.00	$18.94	130	5.20	3.94 (0.14)
Skidding	RTS	16.00	310	5	1,550 (43.9)	80.00	60.61	130	16.25	12.31 (0.43)
Loading	Heel B/ grapple	23.00	1,320	1	1,320 (37.4)	23.00	17.42	130	5.20	3.94 (0.14)
Hauling	Tk/Trlr (6.0 M bd.ft.)	20.00	300	5	1,500 (42.4)	100.00	75.76	220	27.50	20.83 (0.74)
					Totals	$228.00	$172.73		54.15	41.02 (1.45)

Cost per M bd.ft. and m³: $\frac{\$172.73 \text{ M ft}^3}{6.25}$ = $27.64 M bd.ft. ($6.10/m³)

Estimated fuel cost: 41.02 gal x $0.50/gal = $20.51/$172.73 - 12 percent of total

Trial 2.--Logging system design--cost and fuel consumption estimates

	Equipment		Estimated	Estimated		Cost				
Operation (1)	Description (2)	Cost per hour (3)	production per hour (4)	number of units (5)	Production (6)	Per hour (7)	Per M ft³ (8)	Horse-power (9)	Fuel consumption (10)	(11)
			Ft³		*Ft³/h(m³/h)*				*Gal/h*	*Gal/M ft³ (Gal/m³)*
Felling/ bunching	Feller/ buncher	$25.00	1,500	2	3,000 (84.9)	$ 50.00	$18.94	130	10.40	3.94 (0.14)
Skidding	RTS	$16.00	310	9	2,790 (79.0)	144.00	54.54	130	29.25	11.10 (0.39)
Loading	Heel B/ grapple	23.00	1,320	2	2,640 (74.7)	46.00	17.42	130	10.40	3.94 (0.14)
Hauling	Tk/Trlr	20.00	300	9	2,700 (76.4)	180.00	68.18	220	49.50	18.75 (0.66)
					Totals	$420.00	$159.09		99.55	37.71 (1.33)

Cost per M bd.ft. and m³: $\frac{\$159.09}{6.25}$ = $25.45/M bd.ft. ($5.62/m³)

Trial 3.--Logging system design--cost and fuel consumption estimates

	Equipment		Estimated	Estimated		Cost				
Operation (1)	Description (2)	Cost per hour (3)	production per hour (4)	number of units (5)	Production (6)	Per hour (7)	Per M ft³ (8)	Horse-power (9)	Fuel consumption (10)	(11)
			Ft³		*Ft³/h(m³/h)*				*Gal/h*	*Gal/M ft³ (Gal/m³)*
Felling/ bunching	Feller/ buncher	$25.00	1,500	3	4,500 (127)	$ 75.00	$17.28	130	15.60	3.59 (0.13)
Skidding	RTS	16.00	310	14	4,340 (123)	224.00	51.61	130	45.50	10.48 (0.37)
Loading	Heel B/ grapple	23.00	1,320	4	5,280 (149)	92.00	21.20	130	20.80	4.79 (0.17)
Hauling	Tk/Trlr	20.00	300	15	4,500 (123)	300.00	69.12	220	82.50	19.00 (0.67)
					Totals	$691.00	$159.16		164.40	37.88 (1.34)

Cost per M bd.ft. and m³: $\frac{\$159.22}{6.25}$ = $25.48/M bd.ft. ($5.62/m³)

SUMMARY

Most of the equipment and methods used for logging in the Northern Rocky Mountain areas have been discussed. Production rates and methods for estimating production, fuel requirements, and costs are presented. Using the information presented in this report, one can plan a logging system for most situations found in the Northern Rocky Mountain area and estimate probable logging costs and fuel requirements. Logging systems should always be carefully evaluated in the office before using them on the ground. If the information presented here is used as suggested, a logging job can be reasonably well planned.

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APPENDIX

Data Collection and Analysis

Data collection was performed by time study crews at logging operations throughout the Northern Rocky Mountain area and for some operations, such as helicopters, at locations in the Pacific Northwest. Each element such as travel empty, setting chokers, etc., is usually timed by continuous stop-watch readings. Variables affecting production such as terrain, log size, skidding distance, and others are also recorded. The techniques used for data collection are described in detail in a publication by Gibson and Rodenberg (1975).

The analysis of logging systems presents many problems, discussed in the introduction. However, information from these studies is the most effective means of improving logging efficiency and cost when it is used as a tool for planning. Production equations are the final result of most logging studies.

From past studies, variables influencing logging production have been well defined and usually include a combination of some of the following:

- -distance, skidding, or yarding (lateral distance when it applies)
- -log volume or weight
- -number of logs
- -timber stand density
- -slope
- -human factors
- -deck location and size
- -landings
- -foreign element delays
- -terrain
- -weather.

All of the above variables are self-explanatory, except foreign elements and human factors. Foreign elements are delays associated with machines, manpower, material, or environmental factors. Human factors, for example, have usually been evaluated by rating the operators. The principal factors influencing production for each equipment type are shown in the regression equations in this publication. Most of the equations include distance, and either volume or weight, and number of logs. These variables were usually the most significant. Many of the other variables were found to be either insignificant or constitute only minor contributions to the correlation coefficient and were therefore not included in the final equations.

The format and procedure used to develop equipment cost estimates is indicated by the following data form.

EQUIPMENT DATA SHEET

Specifications

Mfg. ____________________

Model ____________________

Engine ____________________

General Specs. ____________________

Standard Costs

Est. Life (N) ____________________

Est. Use/Yr. ____________________

Purchase Cost & Fgt. (I) ____________________

Sal. Value (S) ____________________

Fixed	**Ann.**
Dep. $\frac{I-S}{N}$	________
Ave. Value of Invest. $\frac{I-S(N+1)}{2N}$ = ________	
10% AVI for Int., Tx. and Storage	________
Repairs and Maintenance (100% of Dep.)	________
Total Ann. Cost	________
Oper.	**Hour**
Fixed Costs ÷ Hours of Use	________
Fuel, Lub., etc.	________
Total Cost/h	________

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1982. Estimating production rates and operating costs of timber harvesting equipment in the Northern Rockies. USDA For. Serv. Gen. Tech. Rep. INT-118, *29* p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Summarizes studies of ground, cable, and aerial logging systems in the Northern Rockies over a 15-year period. Provides nomographs and tables for calculating productivity and a system for comparing energy requirements.

KEYWORDS: logging, productivity, cost, fuel requirements

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The Intermountain Station, headquarted in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)