AN APPROACH TO ECONOMIC PLANNING
OF
PRIVATE LOGGING OPERATIONS
IN THE PACIFIC NORTHWEST

Gordon D. Hartrick

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The Douglas fir region has been commercially exploited for seventy years. During that time it has furnished every year from a fifth to a half of the total national consumption of softwood lumber. Yet its sawtimber still covers over half of the region's area, and it still makes up half of the nation's remaining supply. It is not only the nation's greatest existing forest resource; it is one of the greatest of any of its resources.

What is done with the rest of this timber is obviously a matter of great public concern. Voluminous government reports have been turned out aimed at the protection of the public interest. Committees have been appointed to investigate the region, and recommendations have been made without number.

All of this is important. But to the man who owns and cuts the timber (half of the timber is in private hands) the important thing is what he is to do now -- today. He recognizes the importance to him and to the nation of public action to perpetuate the resource. But his day-to-day thoughts are those of any businessman -- how can I best plan today's operation so that it will show a profit? How can I meet these expenses? How should I handle this or that problem of production? It is to show an approach to some of these problems of operation and production that this paper is written.

It cannot be hoped to cover the field in its entirety. Neither can it be expected to present an entirely practical job of operations planning for the areas considered when it is done entirely from behind a desk. Road planning, for instance, is not the sort of thing that can be done on paper. A road must be laid out on the ground. The purpose of this paper is not to present a complete or a practical operating plan for the specific areas that will be considered. It is, rather, to illustrate a method of approach -- a flexible method of approach that should be applied on the ground and along with a generous amount of common sense. The formulas and methods developed here are really engineering formulas brought over and adapted to the problem of logging. If a practical operator combines his experience with an exact engineering approach, the result is bound to be better than if he used either one alone.

Since it is impractical to divorce such considerations from reality, the problems will be dealt with by the case method. An actual logging show will be assumed and problems will be dealt with by means of concrete facts, and of dollar and cent values.

CASE PROBLEM

To illustrate some of the problems that an operator might meet, a hypothetical case has been set up on the following pages. As far as possible the figures and costs used are those obtained from a going operation in western Washington. This outfit will be referred to in the following pages as Company X. Wherever the figures from this operation were not applicable or were not obtainable, a fair average figure was used, using Kirkland or Brandstrom as guides.

The problems arising from operation are dealt with in three parts. A small 60 acre tract, which might provide two weeks' cut, is considered first. A detailed operating plan is drawn up for this area. A larger block (960 acres), which might be operated for six months, is studied next. Assuming that any small subdivision of this section and a half might be planned for in the same manner as was the 60 acre show, on this area a more extensive plan is developed. The final consideration is the property as a whole. Only the most general sort of a logging plan is made. However, here are introduced a new series of problems that have to do with the management of the company as a business rather than its operation as a logging chance.

General Setup

The hypothetical timber company is assumed to be operating over an area of 53,440 acres (Fig. VIII). The entire ownership is in one block located along a fairly large river in the Douglas fir-hemlock type of western Washington. Topography is of moderate roughness, being about average for this region. Elevations range from 1,500 feet around the lake to 4,400 feet on the peaks.

The percentage distribution of species (obtained from an actual operation) is represented below.

Species 16" up	
Douglas fir . . .	29.2%
Hemlock	34.1%
Cedar	8.0%
Silver fir . . .	28.7%

These figures have been combined with a stand table given by Kirkland in "Selective Timber Management in the Douglas Fir Region" to produce Figure I and Table I. These show volume distribution by size. While they represent the actual distribution on a single 60 acre plot, and are therefore not representative of a larger area, for the purposes of demonstration they are assumed to represent conditions over the whole 53,440 acres. The methods of planning will remain the same regardless of the volume figures used. Obviously, in planning for any specific show, the figures pertaining to that particular forty or that particular draw would be used. An average figure would be used only for general planning over the whole area.

FIGURE I

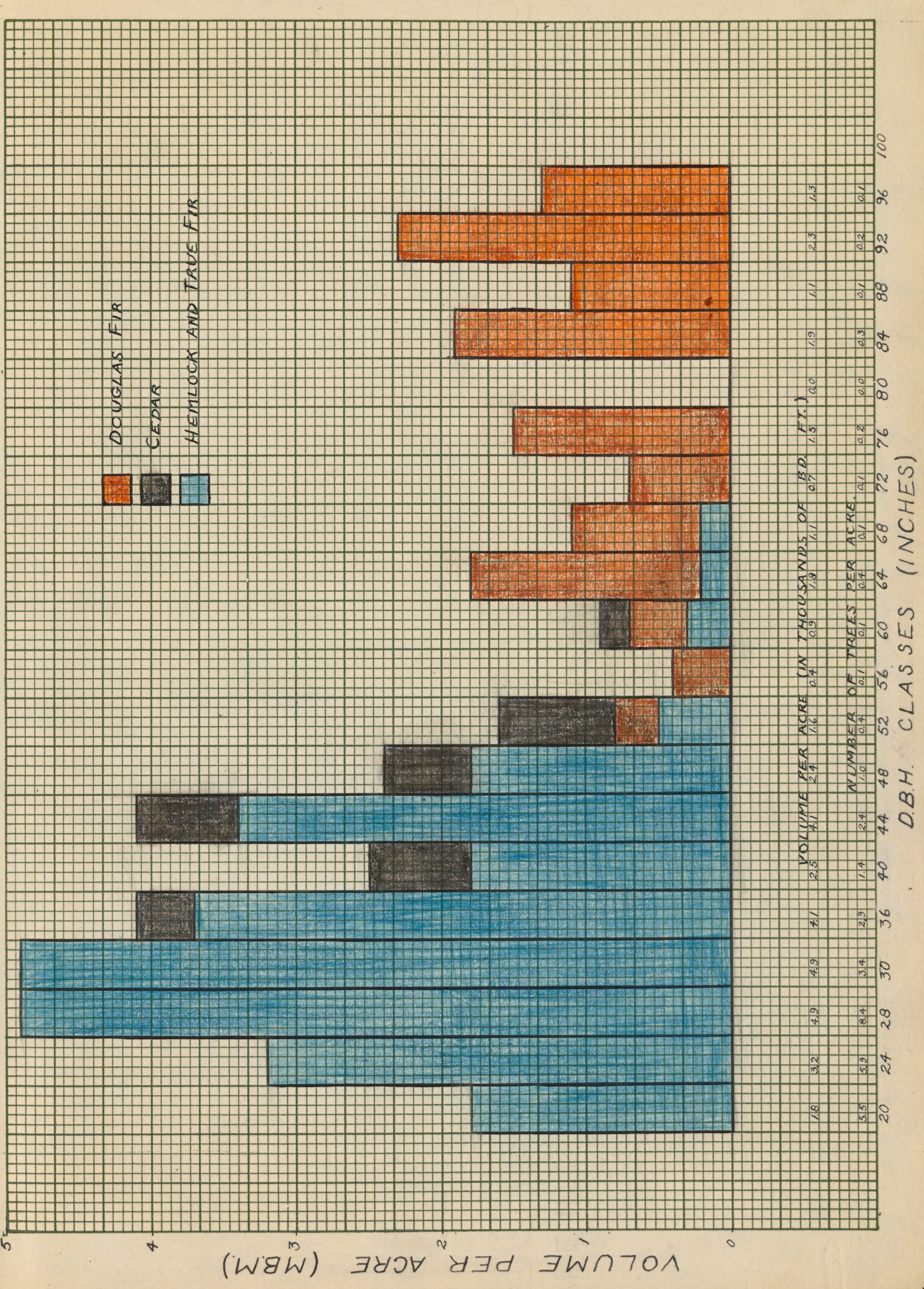

DOUGLAS FIR
CEDAR
HEMLOCK AND TRUE FIR
VOLUME PER ACRE (IN THOUSANDS OF BD. FT.)
1.8 3.2 4.9 4.9 4.1 2.5 4.1 2.4 1.6 0.4 0.9 1.8 1.1 0.7 1.5 0.0 1.9 1.1 2.3 1.3
NUMBER OF TREES PER ACRE
3.5 5.9 8.4 3.4 2.9 1.4 2.4 1.0 0.4 0.1 0.1 0.4 0.1 0.1 0.2 0.0 0.3 0.1 0.2 0.1
20 24 28 30 36 40 44 48 52 56 60 64 68 72 76 80 84 88 92 96 100
D.B.H. CLASSES (INCHES)
0 1 2 3 4 5
VOLUME PER ACRE (MBM)

Table I

Size class	Volume per A. (M b.m.)	Cumu-lative volume per A.	No. of trees per A.	Cumu-lative no. of trees	Douglas fir, volume (M b.m.)	Cedar, volume (M b.m.)	Hemlock and true fir, volume
20	1.8	42.5	5.5	33.0	...	...	1.8
24	3.2	40.7	5.9	27.5	...	...	3.2
28	4.9	37.5	8.4	21.6	...	...	4.9
32	4.9	32.6	3.4	13.2	...	...	4.9
36	4.1	27.7	2.9	9.8	...	0.4	3.7
40	2.5	23.6	1.4	6.9	...	0.7	1.8
44	4.1	21.1	2.4	5.5	...	0.7	3.4
48	2.4	17.0	1.0	3.1	...	0.6	1.8
52	1.6	14.6	0.4	2.1	0.3	0.8	0.5
56	0.4	13.0	0.1	1.7	0.4	0.0	0.0
60	0.9	12.6	0.1	1.6	0.4	0.2	0.3
64	1.8	11.7	0.4	1.5	1.6	...	0.2
68	1.1	9.9	0.1	1.1	0.9	...	0.2
72	0.7	8.8	0.1	1.0	0.7	...	...
76	1.5	8.1	0.2	0.9	1.5	...	...
80	0.0	6.6	0.0	0.7	0.0	...	...
84	1.9	6.6	0.3	0.7	1.9	...	...
88	1.1	4.7	0.1	0.4	1.1	...	...
92	2.3	3.6	0.2	0.3	2.3	...	...
96	1.3	1.3	0.1	0.1	1.3	...	...
Totals	42.5	[illegible]	33.0		12.4	3.4	26.7
				% of total:	29.2	8.0	62.8
				Bd. ft. cut:	12.4	3.4	1.7
				% of cut:	70.8	19.4	9.8

Inspection of these tables shows that the property carries a more or less all-aged stand of hemlock and true fir, with a scattered stand of old Douglas fir in mixture, and a negligible volume of cedar. Although there are but few Douglas fir per acre, they comprise a relatively large proportion of the volume.

The present market is distinctly favorable to these fir. In all but the largest size classes, the market price of the hemlock will not even cover the direct costs of its production. For this reason Company X has decided that it will not pay to cut the hemlock. The present policy is to cut the fir and leave nearly all the hemlock behind. A conscious effort is made to leave the remaining stand in as good a condition as possible, hoping that some day the market will make it profitable to utilize this portion of the stand. The cedar is also cut wherever it occurs.

The result of this policy is to practically eliminate Douglas fir from the stand. Whether this is defensible is a much argued question which I will not attempt to settle here. However, in terms of present day production the policy pays, and for that reason such a system will be assumed for the purposes of illustration to have been adopted by the hypothetical company.

The cut under this plan will amount to:

Douglas fir	12.4 M b.m.	per	acre	or	70.8%
Cedar	3.4 M b.m.	"	"	"	19.4%
Hemlock	1.7 M b.m.	"	"	"	9.8%
Total cut	17.5 M b.m.	"	"	"	100.0%

The company delivers its average annual production of 32,000 M b.m. to a mill ten miles southwest of the lake along June River. A good road leads to the lake from the town which the mill supports.

OPERATING COSTS

Before any planning can be done, it is necessary to determine the cost of owning and operating the various necessary items of equipment. In practice these costs would be found by field timing studies correlated with office records. In this demonstration, field studies were impossible, and costs were obtained from whatever sources seemed most reasonable and reliable. When the actual origin of any figures used in this problem is explained, the field procedure necessary to obtain comparable figures on a going operation will be indicated. Each component item of total cost will be developed separately. The first to be considered is the tractor cost, which is in reality the sum of several costs.

Tractor costs

1. Depreciation. Depreciation is usually figured by the straight line method. That is, an equal portion of the initial cost is charged off each year, so that at the end of a reasonable operating life the machine is left with a zero value on the

company's books. Actual delivered prices of four D8 caterpillar tractors in a coast city of western Washington are given as follows (as obtained from Company X's books for 1937-39).

1 - @	$13,200
1 - @	11,800
1 - @	12,800
1 - @	12,800
4	$50,600
	$12,650 average cost

This price includes all normal attachments (such as front bumper, radiator guard, crankcase guard, front pull hook, upper and lower engine guards, a heavy duty track roller guard, and 22" shoes). In addition, it includes a winch, and an arch including wheels.

Company X has found that five years is a reasonable life on their operation, and this figure checks with figures used by other companies in the region, as well as with estimates of the Caterpillar Company. Two thousand hours a year is generally accepted in the region as a reasonable working year, figuring on 8 hours a day and 6 days a week.

Depreciation is figured as follows:

	Tractor	Winch	Arch	Total
Delivered price. . .	$7,910	$1,610	$3,130	$12,650
Av. depreciation per yr. (5 yr. life) . .	1,582	322	626	2,530
Depreciation per hr. (2000 hrs. per yr.) .	0.791	0.161	0.313	1.265

2. Repairs. It was impossible to use the repair figures from Company X because these were not broken down by items of equipment. In other words, all repairs to mobile equipment including loaders were recorded in one over-all account. It was impossible to break out the proportion chargeable to the tractors alone.

The Caterpillar Company estimates that under severe operating conditions $0.93 an hour is a fair repair charge. Conditions in Company X are considered at least average, certainly better than severe. In Oregon a tractor serviceman of wide experience put the charge at $1.00 a working hour. This latter figure has been used in these calculations. If it errs, it is on the side of conservatism, raising the hourly repair charge so as to allow for unforeseen expenses or unusually high repair costs.

In figuring this charge (as well as the following direct operating costs) for an actual operating company, the figure should be obtained if possible from the company's books. Many companies still do not separate the costs for the individual machines, preferring to keep all the records together, and then to prorate the total charge against separate machines on the basis of operating hours or of capital cost, or both. However, it is becoming recognized as good business to keep separate records of the expenditures for each individual machine. Such a system is explained at some length by Kirkland in "Selective Timber Management in the Douglas Fir Region." He points out that such a system costs little more to maintain than the over-all one, but is of infinitely more value in estimating future costs or in computing the past ones of any particular phase of the operation (as yarding or roading).

If such a cost accounting system has not been adopted, it may be impossible to accurately break out these costs. In that case it will be necessary to use an average figure weighted by a knowledge of operating conditions.

3. <u>Interest</u>. Many companies do not charge interest against their invested capital. In other words, they do not count interest as a cost which must be met just as operating costs are met. Others figure that, since they are deprived of a revenue that they might reasonably expect if their money were invested in some other venture (for instance, if they invested in stocks or bonds), they are justified in demanding the same revenue from its present use. They include interest as an operating cost quite separate from any profit they might be able to return on the investment.

Regardless of the accounting system used, the inclusion or exclusion of interest in the hourly charge will not materially change the operating plan adopted. In this case, interest amounts to only 6.6 per cent of the total hourly cost of the tractor. It is included so as to make the hourly cost developed comparable to those developed from other sources.

Interest costs are based on the average annual investment, which is usually computed by the formula $\frac{(n+1)(\text{first cost})}{2n}$, where n is the life in years of the equipment. In this case, it is computed as follows:

Tractor: $\frac{6 \times 7,910}{10} = 4,746 \div 2,000$ hrs. per yr. = 237.3¢ per hr.

Winch: $\frac{6 \times 1,610}{10} = 966 \div$ " " " " = 48.3¢ " "

Arch: $\frac{6 \times 3,130}{10} = 1,878 \div$ " " " " = 93.9¢ " "

Total: $\frac{6 \times 12,650}{10} = 7,590 \div$ " " " " = 379.5¢ " "

A common charge for interest, taxes and insurance amounts to 10 per cent of the above figures, i.e., interest at 6 per cent, taxes at 2 per cent, and insurance charges at 2 per cent.

4. Driver. Company X pays its tractor drivers $8.00 a day, which may be considered average for a good tractor driver in this region of high labor costs.

5. Ground labor. Company X tries to have its yarding tractors work in pairs, with three men serving each pair of tractors. The bull hook tender is paid $7.50 a day, while the two choker setters working under him get $6.00 a day. These, also, are considered average costs for the region.

6. Fuel, oil and grease. These figures were taken directly from Company X's records. They compare very well with figures based on field tests under average conditions as released by the Caterpillar Tractor Company.

7. Wire rope and chokers. There is little uniformity in the bookkeeping practice in apportioning the cost of wire cable. Many companies prefer to charge wire rope for a whole show into

a separate account, and then to prorate this cost over the yarding machines used, including the loader. This is probably the best thing that can be done on a job using power skidders or skyline swings. On these shows the rigging ahead cost would be difficult to manage in any other manner.

Other companies keep a separate wire rope account which they charge out on a thousand-foot basis. They figure that the cable might be expected to skid a definite board foot volume before it wears out. This again is a practice especially applicable in a power skidding show.

However, in a tractor logging job, wire rope is a part of each tractor. It wears out as the tractor is used. It is reasonable to charge it out on the basis of operating tractor hours. This was the practice in Company X, whose figures are used here. The sum of this charge and the following one for chokers compares reasonably well with the only comparable figure obtainable -- a per thousand foot average charge estimated by a tractor serviceman in western Oregon.

Company X made a separate charge for chokers. These might well be combined with wire rope in a joint account. However, (like the wire rope cost), it is reasonably included as a direct charge against the tractor. It is certainly chargeable against the skidding operation, and the hourly tractor cost is chiefly developed to compute the skidding and yarding cost.

8. Hourly cost. These various tractor costs can be combined into a total hourly tractor cost. This would take the following form.

Table II

Hourly Tractor Cost
(Estimates as of the year 1938)

Costs	Tractor	Winch	Arch	Total
Fixed:				
Depreciation	79.0¢	16.0¢	31.0¢	126.0¢
Repairs	81.0¢	14.0¢	5.0¢	100.0¢
Interest(6%), taxes(2%), insurance(2%) 10% of av. annual investment	23.7¢	4.8¢	9.4¢	37.9¢
Operating:				
Driver	100.0¢	...	...	100.0¢
3/2 Choker setters	116.0¢	...	...	116.0¢
Fuel	22.3¢	...	...	22.3¢
Oil	8.1¢	...	...	8.1¢
Grease	16.6¢	...	...	16.6¢
Arch lines	29.6¢	...	...	29.6¢
Chokers	16.2¢	...	...	16.2¢
Total:	492.5¢	34.8¢	45.4¢	572.7¢
	Or 8.79¢ per min. for skidding with winch (Tractor + Winch)			Or 9.55¢ per minute for roading

These charges have been expressed as a cost of 8.8¢ per minute for ground skidding and 9.55¢ per minute for roading, the difference being merely the ownership cost of the arch. No precedent was found for this procedure, but it seemed to be reasonable. When a tractor and arch are used for roading, all the expenses incident to skidding with the winch go right on, with the cost of the arch representing the principal change in the picture. It is true that the operating and repair costs for a machine operating over a prepared cat road ought to be lower than those for the same machine yarding off roads. However, this saving would be offset by charges incident to the arches -- increased tractor lubrication and fuel charges due to the weight of the arch, as well as lubrication charges on the arch itself. In the absence of specific data about the effect on costs, the procedure followed seems to be the best guess that can be made. Even this is a refinement over most published tractor costs, which often are very vague about the operating conditions the charges apply to. Often such published hourly costs will not even state whether the unit includes an arch, let alone differentiating between the cost with or without it. At any rate, roading costs should not be higher than those estimated here. If they are slightly lower, the difference will act as a factor of safety in the calculations, making allowance for any unforeseen or unusual repair or operating charges.

It might reasonably be asked why any company would use D8's for both yarding and roading, the former operation moving single logs a few hundred feet and the latter moving loads of five M b.m. for a distance of as much as a mile. Why not use a smaller and more mobile unit such as a D6 on the yarding? The answer is to be found in the nature of western logging. Often it is advantageous to concentrate on one phase of operation, or to put all the equipment available on some temporary job. Such an attitude was taken by Company X. They wanted all their tractor units to be interchangeable. They wanted to be able to put any one of them in front of an arch or behind a bulldozer blade, and have it handle the job. They reasoned that the advantages of interchangeability both of parts and of entire units outweighed the unquestioned advantages of specialization that come with the use of several different kinds of equipment.

Loader costs

Company X uses a heel boom loader. No breakdown on the costs of operation is available. However, Brandstrom, in "Logging Costs and Operating Methods in Douglas Fir," made a study of several typical loading operations in the region which used this type of loader, and summarized the loading costs by size of log handled (Table III), quoting a fair daily average cost of $55 a day. In the absence of any better data, these figures will be used, although it is evident that a more accurate figure could be built up by using the same kind of analysis as the one used for the tractors.

The average log on the hypothetical operation is 1250 ft.b.m. The average loading time for this size log (using average figures from the three operations reported on) is three minutes per M, including waiting time, delays, and car spotting time. This figure is obtained from those in the table by dividing the cost per M b.m. including waiting time by the cost per minute, which gives the number of minutes per M b.m.

Table III

Loading with Heel Boom on Three Different Operations

Volume of log	Loading controls yarding	Yarding controls loading	
	Operation I	Operation II	Operation III
100	$1.43	$3.06	$2.13
200	.72	1.51	1.04
300	.48	.99	.69
400	.37	.74	.51
500	.30	.59	.40
600	.25	.49	.33
800	.20	.37	.25
1000	.17	.29	.20
1200	.14	.25	.17
1400	.13	.22	.15
1600	.12	.20	.14
1800	.11	.18	.12
2000	.11	.17	.12
2500	.11	.14	.10
3000	.11	.12	.09
4000	..	.10	.08
5000	..	.09	.08
6000	..	.09	.08
Factor	1.4	1.58	1.90

(factor) x (cost) = cost including waiting time.

Machine rate = $55 a day.

Road costs

Road construction costs vary sharply in the region. The roughness of the topography is an element of primary importance in fixing the cost, followed by the rockiness, the character of the timber, and the standard desired. Costs in general are high; perhaps as high as anywhere else in the country.

Company X has just two road standards. They build cat roads at an average cost of $13 a station, and truck roads at $5,000 a mile. This latter figure seems to be very high, but nevertheless is the actual average cost of the roads built to date. Three thousand dollars of this amount goes to shape and grade the road; $2,000 is used to ballast the bed with 6" of gravel, followed after a season of use by 4" more. The result is a high standard road, much higher in fact than an average logging road any place else in the country. But it is an all-weather road. Any curtailment of road cost would result in a road that would be impassable for four months, at least. Under the present plan of operation the logging season might be shortened by two months.

A possible way to avoid part of this expense is to introduce another road class. If less attention is paid to alignment and grade, and a lighter surface treatment is used, a road will result which costs $3,000 a mile. Company X has never tried this scheme, but believes that this figure is a fair one.

This $3,000 road will be impassable in wet weather. However, in the dry summer months trucks will be able to make almost as fast time on this road as on the better one. The plan, as will be demonstrated later, is to use the all-weather road bed on trunk lines and main roads. The secondary roads will reach out to tap the cat roads. In good weather, operations go on out in the "fingertips," roading the logs in to the $3,000 roads, where they are loaded onto trucks and hauled out of the woods. But in wet weather, landings located along the all-weather roads are used. The operations go on as efficiently as they would if all the roads were of the higher standard.

This scheme was first proposed in the west by Brandstrom in "Logging Costs and Operating Methods in Douglas Fir." With the relatively high mobility of today's operating units, there seems to be no reason why it would not work.

Yarding costs

Yarding costs are determined by combining field timing studies with machine rates. The total turn time is broken down into hook and unhook time, delay time, travel time, and return time. Each item is timed individually, and the average time for each translated into cents per turn by using the tractor hourly costs. These charges are then combined, and expressed as a cost of so much per M b.m. yarded. (If donkeys are used, the procedure is exactly the same, although here, of course, the donkey itself remains stationary, and the times recorded are for the rigging.) By determining log sizes and yarding distances, such data can be presented in the form of Table IV, which is taken from Brandstrom's "Logging Costs and Operating Methods in Douglas Fir." Such a table is useful in determining yarding costs. However, it can only be used in situations comparable to that where the data were compiled. If, for instance, the slope should change so as to slow up the tractor and perhaps to reduce its load, the values in the table become inaccurate. Or if the ground labor is increased so as to shorten hook and unhook time, the whole table has to be revised before it can be used.

The data can be presented in a much more usable form if it is broken down into fixed time per M b.m. and variable time per M b.m. per unit distance. Ordinarily, it would be best to do this when the data were originally collected. The hook and unhook time and the delay time represent fixed times; that is, they occur every turn regardless of the yarding distance traversed. Such fixed per turn time can be expressed as fixed costs per M once the average load has been determined. They will vary, however, with the size of the logs hauled; it does not cost as much, for instance, to hook onto five M b.m. in one log as it does ten logs totalling to five M b.m.

Table IV

Relation of Log Volume and Yarding Distance to Turn Time
60 H.P. Tractor and Arch

Vol. of log, ft. B.M.	Top diam. 32' log, inches	Approx. tree d.b.h. inches	No. logs per turn	Vol. per turn, B.M.	Haulback time, min.	Hauling min.	Hook, unhook, and hangups, min.	Prorated delays, min.	Side-lining, min.	Total yarding time, min.	Time per M, min.
					600 Foot Yarding Distance						
200	13.3	22	3.75	750	2.85	2.83	5.65	1.27	.60	13.20	17.60
400	17.5	31	3.03	1212	2.85	3.10	4.79	1.27	.45	12.46	10.28
800	24.0	42	2.11	1688	2.85	3.23	3.79	1.27	.25	11.39	6.75
1000	26.0	47	1.83	1830	2.85	3.27	3.50	1.27	.20	11.09	6.06
1600	34.0	59	1.41	2256	2.85	3.34	3.10	1.27	.10	10.66	4.73
3000	44.5	79	1.07	3210	2.85	3.47	2.78	1.27	.04	10.41	3.24
					1000 Foot Yarding Distance						
200	13.3	22	4.20	840	4.13	4.73	6.18	1.27	.69	17.00	20.24
400	17.5	31	3.35	1340	4.13	5.07	5.16	1.27	.51	16.14	12.04
800	24.0	42	2.29	1832	4.13	5.28	3.96	1.27	.30	14.94	8.16
1000	26.0	47	1.96	1960	4.13	5.33	3.63	1.27	.22	14.58	7.44
1600	34.0	59	1.47	2352	4.13	5.44	3.15	1.27	.12	14.11	6.00
3000	44.5	79	1.08	3240	4.13	5.65	2.79	1.27	.04	13.88	4.28
					1500 Foot Yarding Distance						
200	13.3	22	4.65	930	5.67	7.12	6.73	1.27	.78	21.57	23.19
400	17.5	31	3.78	1512	5.67	7.58	5.68	1.27	.60	20.80	13.76
800	24.0	42	2.47	1976	5.67	7.89	4.15	1.27	.34	19.32	9.78
1000	26.0	47	2.10	2100	5.67	7.93	3.77	1.27	.25	18.89	9.00
1600	34.0	59	1.54	2464	5.67	8.06	3.21	1.27	.14	18.35	7.45
3000	44.5	79	1.10	3300	5.67	8.34	2.80	1.27	.04	18.12	5.49
					2000 Foot Yarding Distance						
200	13.3	22	4.95	990	7.18	9.58	7.10	1.27	.84	25.97	26.23
400	17.5	31	4.07	1628	7.18	10.13	6.03	1.27	.66	25.27	15.52
800	24.0	42	2.61	2088	7.18	10.49	4.30	1.27	.36	23.60	11.30
1000	26.0	47	2.21	2210	7.18	10.55	3.89	1.27	.28	23.17	10.48
1600	34.0	59	1.59	2544	7.18	10.73	3.26	1.27	.14	22.58	8.88
3000	44.5	79	1.11	3330	7.18	11.08	2.81	1.27	.04	22.38	6.72
					2500 Foot Yarding Distance						
200	13.3	22	5.25	1050	8.72	12.00	7.47	1.27	.90	30.36	28.91
400	17.5	31	4.27	1708	8.72	12.73	6.27	1.27	.70	29.69	17.38
800	24.0	42	2.72	2176	8.72	13.16	4.42	1.27	.39	27.96	12.85
1000	26.0	47	2.30	2300	8.72	13.23	3.98	1.27	.30	27.50	11.96
1600	34.0	59	1.63	2608	8.72	13.42	3.30	1.27	.15	26.86	10.30
3000	44.5	79	1.12	3360	8.72	13.83	2.83	1.27	.05	26.70	7.95
					3000 Foot Yarding Distance						
200	13.3	22	5.45	1090	10.23	14.37	7.71	1.27	.95	34.53	31.68
400	17.5	31	4.40	1760	10.23	15.26	6.43	1.27	.72	33.91	19.27
800	24.0	42	2.80	2240	10.23	15.78	4.52	1.27	.40	32.20	14.38
1000	26.0	47	2.35	2350	10.23	15.86	4.04	1.27	.30	31.70	13.49
1600	34.0	59	1.66	2656	10.23	16.09	3.34	1.27	.16	31.09	11.71
3000	44.5	79	1.12	3360	10.23	16.57	2.83	1.27	.05	30.95	9.21

Travel time, however, is a variable time that increases in direct proportion to the yarding distance. It, also, may be expressed on a per M basis, but, in addition, must be correlated with a unit distance. In this paper the station has been adopted as a convenient unit to use, and variable costs are therefore expressed as the cost per M b.m. per 100 feet of yarding distance.

Such a compilation of data is shown in Table V, which is taken from an unpublished manuscript of D. M. Matthews, "Cost Control in the Logging Industry."

Table V

Cost and Production Figures for Ground Skidding Tree Length Southern Pine with D7 Tractor

(Prepared by Caterpillar Tractor Company)

Av. d.b.h. of stand	No. of trees per trip	Bd.ft. Doyle-Scribner rule	Hook and unhook time, min.	Delay time, min.	Total fixed time, min.	Cost per turn @ $.0511 per min.	Fixed time cost per M.B.M.	Hauling cost per M.B.M. per 100'
16	5.0	600	10.5	2	12.5	$.639	$1.065	$.072
20	3.6	860	8.5	2	10.5	.537	.624	.050
24	2.7	1080	7.2	2	9.2	.470	.435	.040
28	2.0	1240	6.0	2	8.0	.409	.329	.035
32	1.5	1380	4.6	2	6.6	.337	.244	.031
36	1.2	1495	3.5	2	5.5	.281	.188	.029
40	0.9	1575	2.8	2	4.8	.245	.156	.028

It will be seen that the column heads are very similar to those used by Brandstrom. The difference lies in the use made of the figures. Brandstrom uses them to produce a total cost which is accurate for the situation where the data were collected. Matthews uses them to produce a unit fixed and a unit variable cost, which can be applied anywhere the machine is used, once the effect of differing conditions on load or yarding distance has been defined. For instance, assume that rough country forced a reduction of load volumes. Brandstrom's table would still be usable after a correction factor had been applied to each figure in the table. Matthews' unit costs, being expressed on a per M basis, would be as usable as ever without any adjustment. His costs per M would be the same no matter how many M were hauled per turn, other conditions being unchanged.

Brandstrom's table, however, was the only one found which gave complete and accurate time studies for the large tractors used in the west. Most cost analyses give tractor costs as an average of so much per M b.m.; as a total cost, in other words, for the particular chance which is being discussed. Such figures are worthless from the standpoint of further analysis.

For this reason, Brandstrom's figures were used in this report, after being reframed into fixed and variable costs per unit volume such as those used by Matthews. The mechanics of this transformation are as follows.

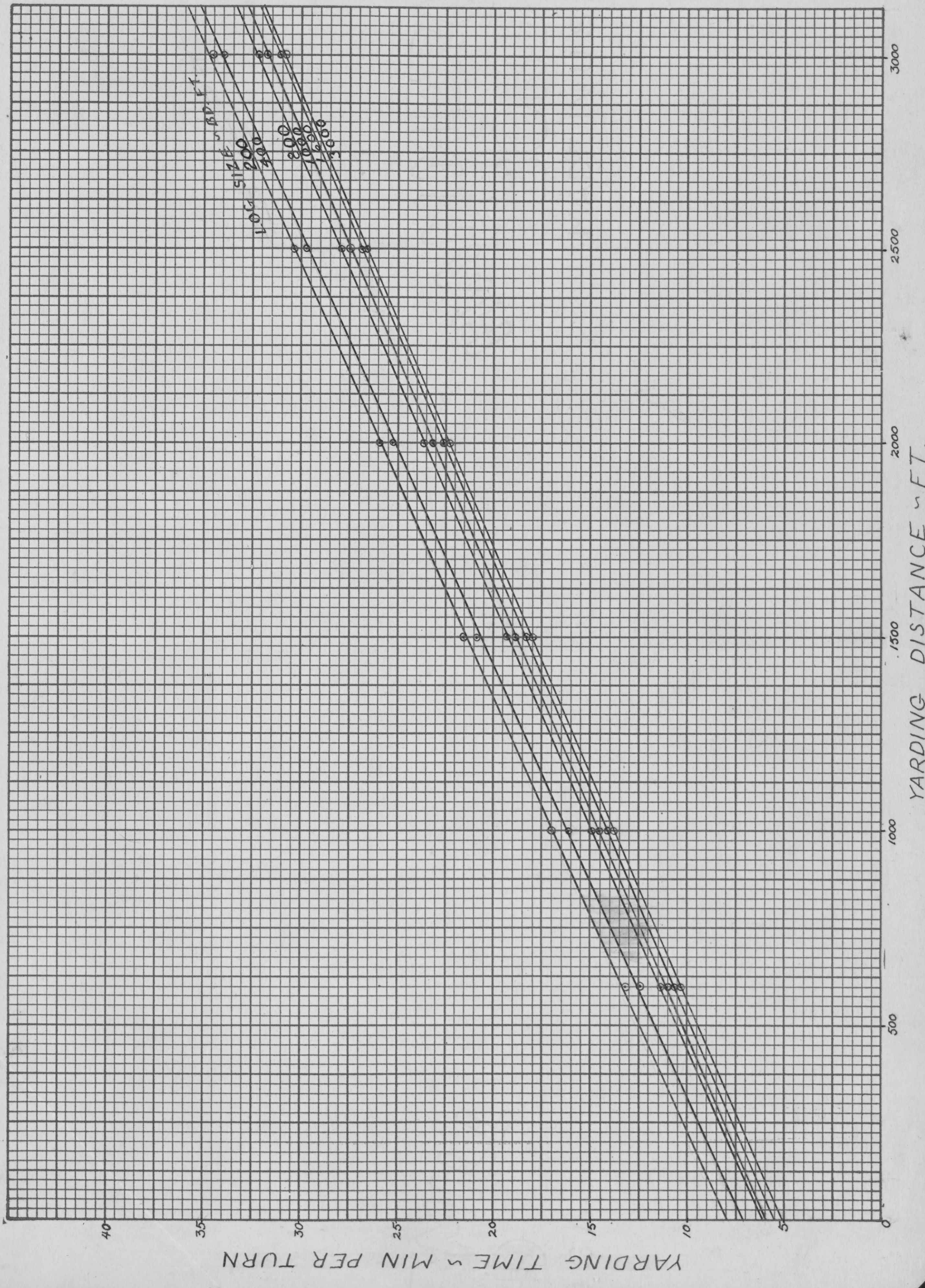
A given log size was traced through the various distances of Brandstrom's table, and the total yarding time plotted against distance (Fig. II). If the theory back of the fixed and variable time concept were sound, these should have plotted in a straight line. They very nearly did, which was a check on the accuracy of the original data, as much as it was a confirmation of the fixed and variable time concept. The line connecting the points for any log size does not come down to zero on the time axis. It starts at a point around six minutes. This is equivalent to saying that regardless of the length of the haul, around six minutes will be used up in the unchanging fixed items of each turn. Even if the yarding distance were only fifty feet, it would still take six minutes for hook, unhook and delays. The variable element of total yarding cost was then determined by measuring the average time over and above this fixed time for each 100 feet of travel time. In other words, it was determined by the slope of the total time line.

Records of Company X show that the average log roaded scaled 1,250 ft.b.m. and the average total load under the arch was 5,000 ft.b.m. The graph shows a fixed time of six minutes per turn when the load is made up of 1,250-foot logs. From the tractor machine rates, we have already determined that a roading tractor costs 9.55¢ a minute. The fixed roading cost per thousand therefore equals

$$\frac{6 \text{ min. @ } 9.55¢}{5 \text{ M}} = 11.45¢\text{, fixed time cost per M.}$$

p. 26

FIGURE II



The variable time per M was found to be 0.86 minutes per station of hauling distance.

$$\frac{0.86 \text{ min. @ } 9.55¢}{5 \text{ M}} = 1.64¢\text{, variable cost per M per 100'.}$$

These figures are for roading with the arch, since Brandstrom's figures were evidently for that operation, although he was not very clear on the matter. Since it would be impractical to take the arches very far off the cat road, it is evident that the logs would have to be prebunched at the road, or at least hauled alongside of it. For this reason, it was also desired to have a fair cost for ground skidding with the winch. No data could be found for this operation. Obviously, if a field study were producing these figures (as would be the case if this plan were being drawn up for an actual operation), these costs would be gathered along with the others and worked up in the same way. For the purpose of illustration, it is here assumed that fixed time per turn would be about the same as on the roading job; this is at least close to the truth. Combining this fixed time with the yarding tractor hourly cost and the average load of 1,250 ft.b.m., fixed cost would be

$$\frac{6 \text{ min. @ } 8.79¢}{1.25 \text{ M}} = 42.2¢ \text{ per M}$$

Variable time per station could reasonably be assumed to rise somewhat because of the rougher going. If a time of one minute per hundred feet is assumed, costs will be

$$\frac{1 \text{ min. @ } 8.79¢}{1.25 \text{ M}} = 7.03¢ \text{ per M per 100 ft.}$$

In the above calculations, the following costs have been developed:

	Fixed cost per M	Variable cost per M per 100 ft.
Roading tractor (arch)	11.45¢	1.64¢
Yarding tractor (winch)	42.2¢	7.03¢

<u>Hauling costs</u>

With the large logs and long hauls that are common to the west, the tendency has been toward using larger and larger trucks. Even though their initial cost and their operating costs are both higher than those of smaller trucks, the larger volume they carry results in a lower cost per M b.m. of pay load. As long ago as 1937, Truman Collins decided, on the basis of carefully kept hauling costs which were published in the <u>Timberman</u>, that on his operation, at least, the best machine was a specially built Fageol Diesel carrying an average load of 10 M b.m. -- in other words, the largest machine obtainable. His costs were rearranged by Matthews and are presented in Table VI. These truck costs will be assumed to be applicable in the hypothetical case.

If such an hourly truck cost were being developed for an actual operation, the procedure would be very similar to that already demonstrated in building up the tractor costs. Field timing studies would be combined with office records to produce first an hourly charge and then a cost per M b.m. per station.

Table VI

Comparative Truck Machine Rates

	Chevrolet		Mack and Federal		Fageol Cummins Diesel	
Fixed cost per hour:						
Operating labor	$.89		$1.16		$1.48	
Depreciation						
Truck	.34		.71		1.40	
Trailer	.18		.38		.47	
Interest @ 6%	.05		.11		.25	
Total per hour		$1.46		$2.36		$3.60
Operating cost per hour:						
Tires	.53		.85		1.65	
Repairs						
Labor	.26		.30		.47	
Parts	.36		.39		.76	
Gas and oil	.47		.96		.61	
Total per hour		$1.62		$2.50		$3.49
Total running cost per hour:		$3.08		$4.86		$7.09
Average load	3.2 M b.m.		4.6 M b.m.		10 M b.m.	
Fixed cost per minute (i.e., standby charge)	$\frac{1.46}{60} = 2.4¢$		$\frac{2.36}{60} = 3.9¢$		$\frac{3.60}{60} = 6¢$	

The largest machine is not universally the best one to use, however. It is only with large volumes and long hauls that their higher fixed costs can be carried by the loads they haul. On short hauls the loading or standby charge is too considerable an item; smaller trucks will pay better. This brings up the point that at some distance of haul either truck will cost the same. Which truck will be used will depend on whether the haul is longer or shorter than this distance, as will be illustrated later.

For the present it will be assumed that the company operating the hypothetical show has decided on the basis of the above figures to use the Fageol Diesel, in view of their ten-mile external haul. The hauling cost for any given speed of travel can then be easily figured. Hourly cost divided by miles per hour gives cost per mile. This figure divided by the load per trip gives the cost per M b.m. per mile of distance. Since the truck has to travel a round trip mile, this figure has to be doubled. Total cost per mile can then be expressed as

$$\frac{\text{Hourly cost x 2}}{\text{m.p.h. x load}}$$

If the cost is desired on the basis of a 100-foot station, this figure should then be divided by 52.8, the number of stations per mile. In other words,

$$\frac{\text{Hourly cost x 2}}{\text{m.p.h. x load x 52.8}} = \text{Hauling cost per M per 100'.}$$

On the road standards assumed, trucks could reasonably be assumed to travel 20 miles per hour (average round trip speed on high standard road), and 15 miles per hour (low standard road during good weather).

Inserting these values in the formula, we find the following hauling costs per 100 ft. per M for the Fageol Diesel:

15 m.p.h. $\frac{7.09 \times 2}{15 \times 10 \times 52.8} = \frac{14.18}{7,920} =$ 0.178¢ per M per 100 ft.

20 m.p.h. $\frac{7.09 \times 2}{20 \times 10 \times 52.8} = \frac{14.18}{10,560} =$ 0.136¢ per M per 100 ft.

Landing costs

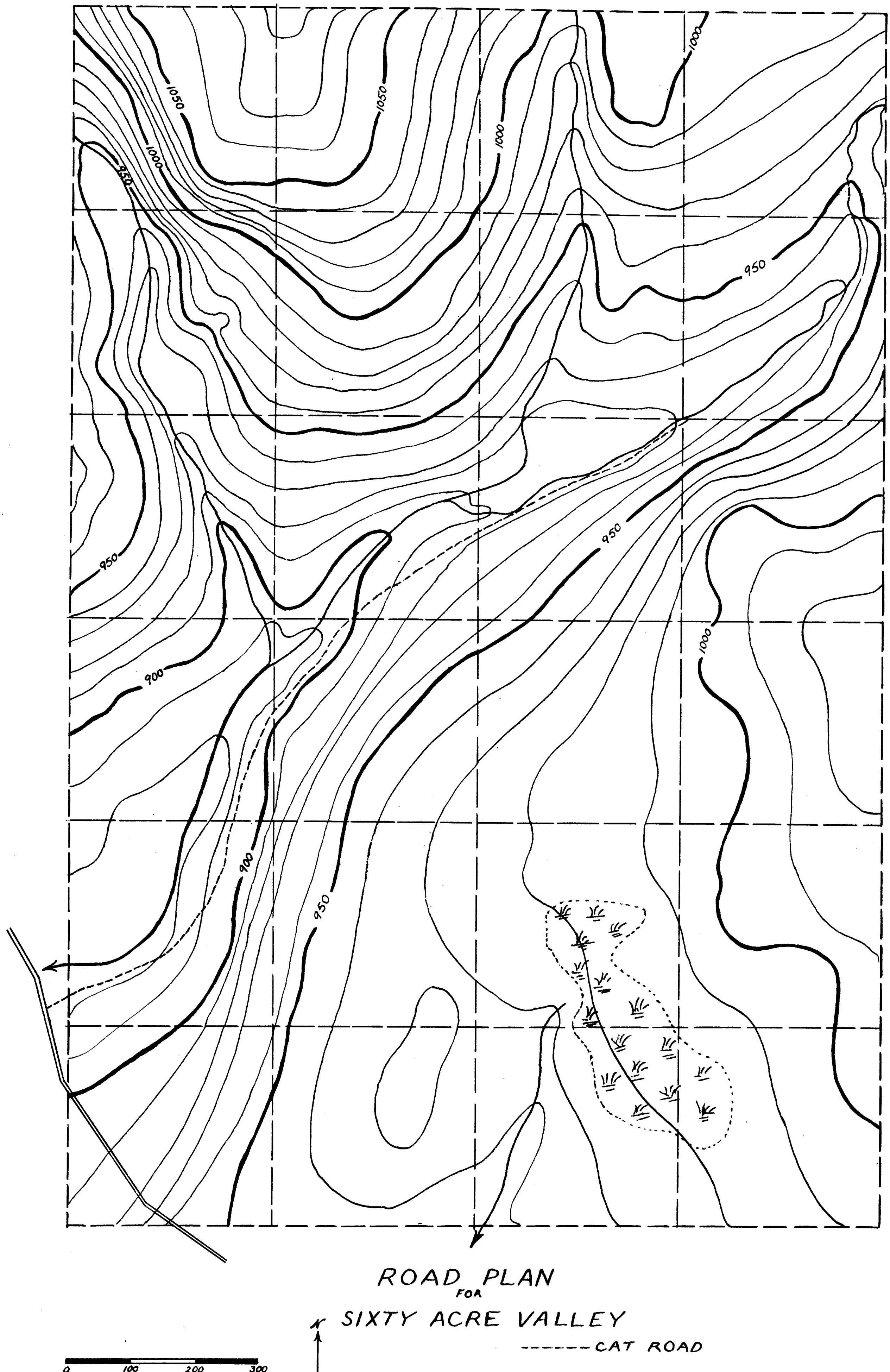
Landings carry a cost varying between wide limits. Ordinarily, the costs of landings on a railroad job, where spurs must be laid, are very high, running up to $500 each. Large storage landings on a tractor job, their site chosen with an eye to the cost of their development and leveled off with a bulldozer, will cost around $500 also (one acre) according to Brandstrom in his "Logging Cost Analysis." Smaller landings such as are desirable on a trucking job may cost $100 each. This latter figure will be used in the case being considered.

OPERATING PLANS

Plan for sixty acre tract (Fig. III)

The problem of planning for this sixty-acre tract is essentially one of choosing the road standard. Brown, in "Logging Principles and Practices," states that, "The correct solution of the transportation problem is the key to successful logging." He simply means that an operator can have more effect on his costs by manipulation of his transportation system than by any other single thing he can do. The logging superintendent

FIGURE III



ROAD PLAN FOR SIXTY ACRE VALLEY

is the first to realize this. He knows that the adoption of too high a road standard or too wide a road spacing (boosting skidding costs) will have more effect on cost per M than any other error of judgment he can make. Following this line of reasoning, the plans that will be drawn up for each of the areas considered will be road plans. It will be assumed that if the transportation from stump to mill is efficiently handled little more could be asked for.

The first road to be considered on the sixty-acre tract is the one going into the small draw in the northwest quarter of the area. This draw averages 500 feet in width (Fig. III). The location of the road in this case is quite evident. In tractor logging the logs should always, to whatever extent is possible, move down a favorable grade. The obvious thing to do is to locate the road down the center of the valley or draw, unless the valley is so wide as to make more than one road necessary, in which case contour roads might possibly pay.

Since the location of the road is fixed, its standard is the only consideration. Of course, it will not pay to run a truck road into a small valley like this one. It may not even pay to run in a cat road. If the watershed is long and carries a large volume, however, it ought to pay to build at least some road, thus reducing the length of haul for the yarding and bunching tractors. Yarding tractors running through the woods without roads, we have seen, carry a charge per M b.m. four times as much per station as does a tractor and arch over prepared roads. As the yarding distance increases, at some distance a point will be reached where the cost of yarding per M has risen so high that the cost of building a cat road to that point will be more than balanced by the saving in reduced yarding costs. Similarly, at a still greater distance from the end of the watershed, a point will be reached where the cost of building a low grade truck road will be more than offset by the reduction in hauling costs, since roading costs six times as much per M per station as does truck hauling.

It was to help in determining these breakeven points that the last two columns of Table VII were drawn up. These columns show the increase in road costs and the decrease of hauling costs per station if we decide to go one road standard higher than the present one.

Table VII

Road class	Cost of construction per 100'	Hauling cost per 100'	Cost of improving to the indicated standard from the next lower one	Saving in hauling cost over lower standard (per 100 ft. per M)
Off roads	...	7.03¢	...	...
Cat roads	1300¢	1.64¢	1300¢	5.39¢
Fair weather truck (15 m.p.h.)	5680¢	0.178¢	4380¢	1.462¢
All weather truck (20 m.p.h.)	9475¢	0.136¢	3795¢	0.042¢

The savings made in hauling costs as the road standard is improved are expressed as savings per M b.m. per station of road length. However, each station of valley length carries many M b.m. In this case, the valley in our 60-acre area is 500 feet wide and each station carries

$$\frac{500 \text{ ft. x } 100 \text{ ft.}}{43,560} \text{ x } 17.5 \text{ M per A.} = 20.1 \text{ M per station.}$$

The figures applicable to this particular valley would therefore be as follows:

Road class	Cost of improvement per 100 ft. of road raised one standard	Total hauling savings per 100 ft.of road improved one standard (20.1 M)
Off roads	...	...
Cat roads	1300¢	108.0¢
15 m.p.h. truck road	4380¢	29.4¢
20 m.p.h. truck road	3795¢	0.84¢

As an example of what these figures mean, suppose we built two stations of cat road. The cost would be 2 x 1300¢ = 2600¢. Hauling costs would be smaller than they would on the same two stations without the cat road. The savings realized would be:

2 x 108¢ = 216¢ on timber tributary to the second station
1 x 108¢ = 108¢ " " " " first "
324¢ total savings

The saving on the second station is 2 x 108¢ because the timber tributary to that station is hauled over both stations with a hauling cost saving on each of them. In tabular form, this could be expressed as follows:

Stations built	Savings on last station built	Total savings
1	S	S
2	2S	S + 2S
3	3S	S + 2S + 3S
.	.	.
.	.	.
.	.	.
n	nS	$\frac{n}{2}$ (S + nS)

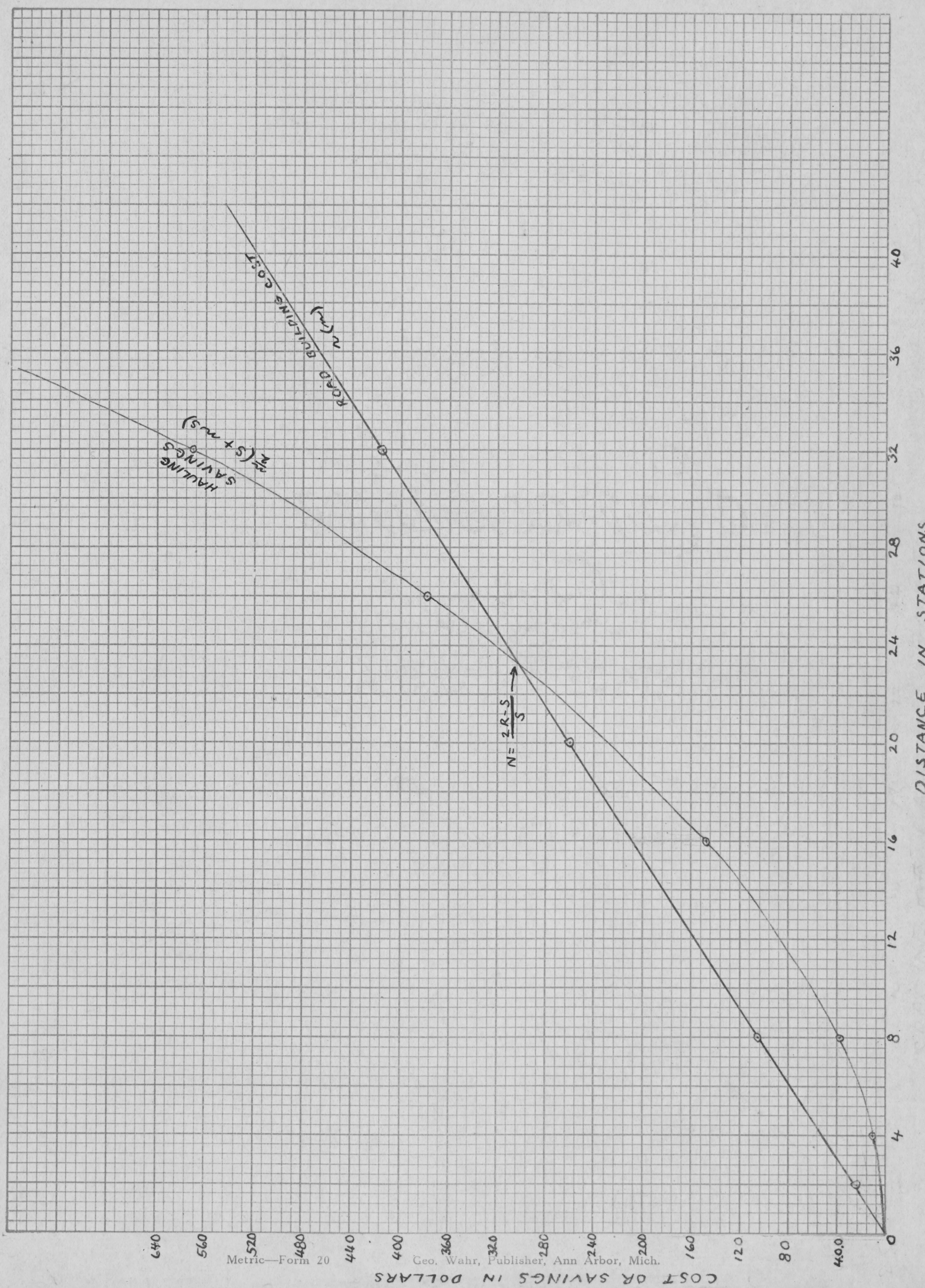
The last formula given (the sum of an arithmetical progression) is perfectly general. If we improve the road standard any number of stations (n) to the end of a draw, the total savings in hauling will be $\frac{n}{2}(S + nS)$.

The savings in hauling cost and their balancing road construction costs are shown graphically in Figure IV. In this case, the costs being compared are for building a cat road as compared to skidding on the ground.

It can be seen that at about 23 stations the costs and savings are equal. This is equivalent to saying that if we are twenty-three stations from the end of a draw, it will not affect our total cost if we build a cat road clear to its end or if we skid the entire distance without a road.

If we are at the end of a draw that is 25 stations long, however, we lose money if we try to skid the entire distance without a road. We also lose money if we build a road clear to the end of the draw. The problem is, how far in can we go?

FIGURE IV



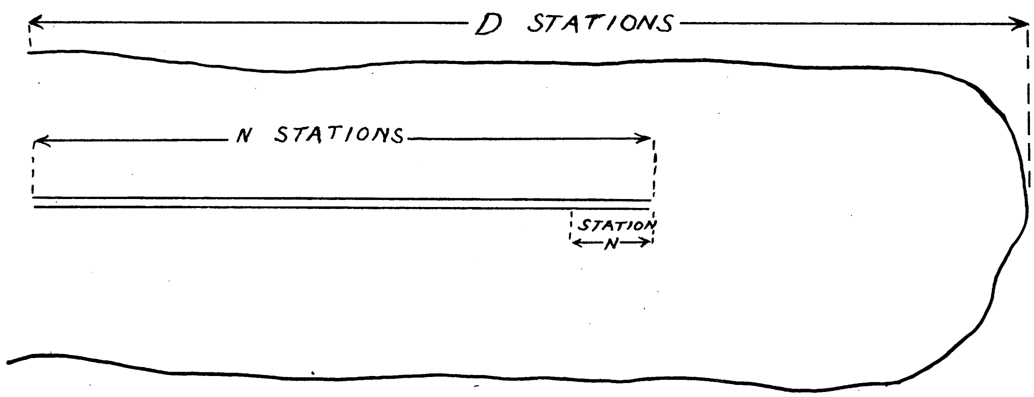
ROAD BUILDING COST
HAULING SAVINGS
N = (2R-S)/S
DISTANCE IN STATIONS
0
4
8
12
16
20
24
28
32
36
40
COST OR SAVINGS IN DOLLARS
40.0
80
120
160
200
240
280
320
360
400
440
480
520
560
640

To find a general formula that will be applicable in all cases, let us set up a generalized problem.

If the road standard is raised one step,

S = savings in hauling for the entire volume tributary to one station hauled one station on the improved road.
R = increased road construction costs per station.
n = number of stations we will tap the valley.
D = total length of valley in stations.

Schematic Sketch of Valley



What we want to do is to determine the length of road (n stations) at which road building costs will be carried by the savings effected. Road building costs are n x R. Savings along the road are cumulative. At the last station built (station n), the savings are those that come from carrying the volume tributary to (D - n) stations over one station of improved road, plus the savings accruing to the timber tributary to that station itself. In other words, it is $[(D - n) + 1]\ S$. Savings on the station at the mouth of the valley are DS, since all the timber in the valley goes over that station. Using the formula for an arithmetic progression, $x = \frac{n}{2}(a + L)$, to find total savings over all the stations built, we have:

$$\text{Total savings} = \frac{n}{2}\left\{\left[(D - n) + 1\right] S + DS\right\}.$$

Since we want to find the point where road costs are balanced by hauling savings, we equate the two and have:

$$n \times R = \left\{\left[(D - n) + 1\right] S + DS\right\} \frac{n}{2}$$

$$R = \frac{\left[(D - n) + 1\right] S + DS}{2}$$

$$2R = DS - nS + S + DS$$

$$nS = DS + DS + S - 2R$$

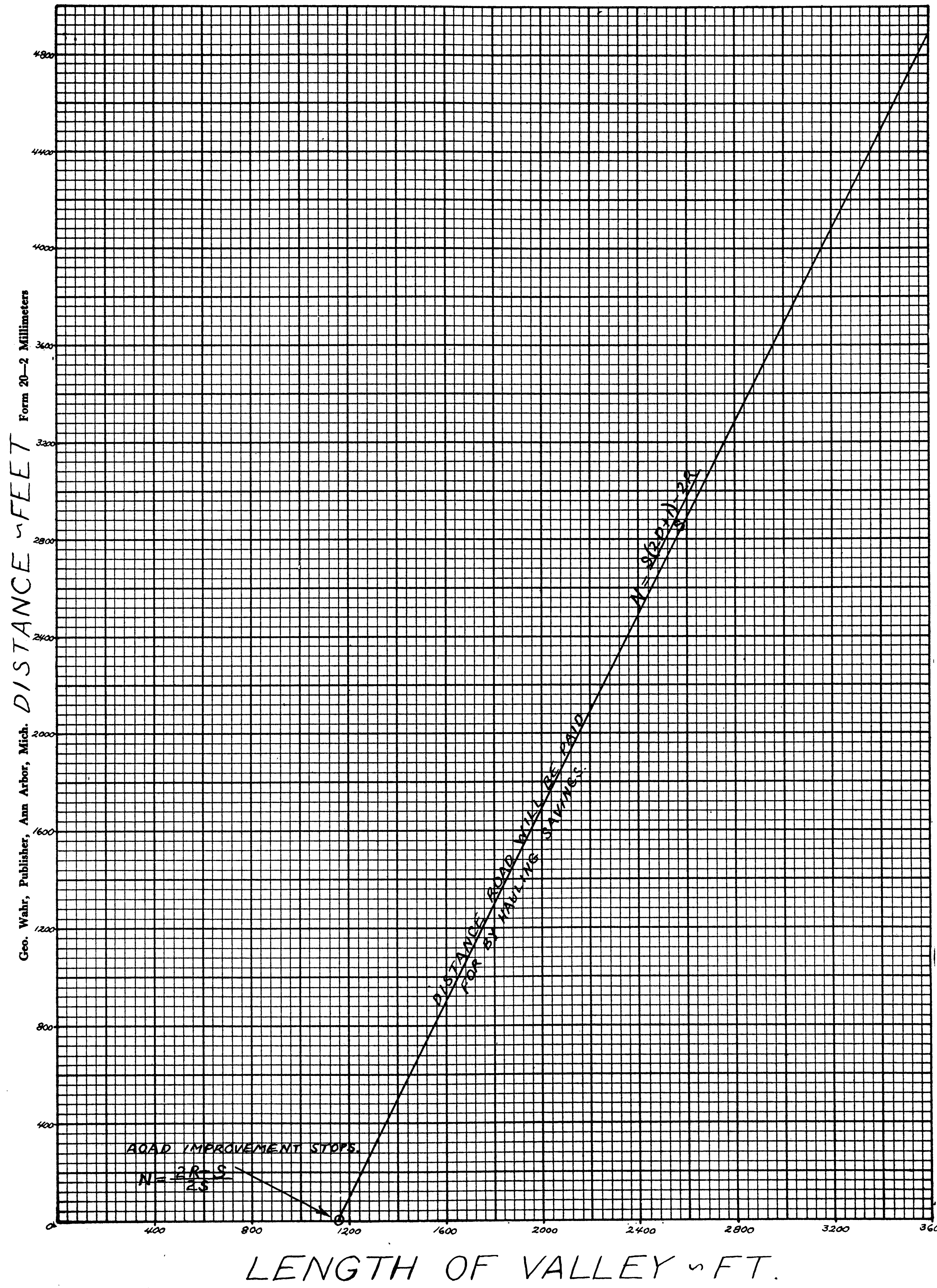
$$n = \frac{2DS + S - 2R}{S}$$

$$n = \frac{S\ (2D + 1) - 2R}{S}$$

This formula has been used to build up the following tabulation (using figures applicable to the 500-foot side valley in Figure III). These in turn were used to construct Figure V, which graphically illustrates what happens when the formula is applied to different possible valley lengths.

Length of valley in stations (D)	Length of road justified, in stations (n)
11	0.0
12	0.9
15	6.8
18	13
22	21
23	23
24	25
26	29

FIGURE V


DISTANCE ~ FEET
LENGTH OF VALLEY ~ FT.
4800
4400
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
400
800
1200
1600
2000
2400
2800
3200
3600
DISTANCE ROAD WILL BE PAID FOR BY HAULING SAVINGS.
N = S(2D+1) − 2R / S
ROAD IMPROVEMENT STOPS.
N = 2R − S / 2S
Geo. Wahr, Publisher, Ann Arbor, Mich. Form 20—2 Millimeters

At 11.5 stations the equation equals zero because the two members of the numerator become equal. That is, $S\ (2D + 1) = 2R$. If we want to find in terms of R and S what this length of valley (D) is (where the length of road we can construct becomes zero), we can isolate the D from this equation.

$$S\ (2D + 1) = 2R$$

$$2DS + S = 2R$$

$$2DS = 2R - S$$

$$D = \frac{2R - S}{2S}$$

This formula will give us the length of valley at which we can no longer justify the construction of one more station of road by the savings its construction will create. As an example of its application, say we have a valley 30 stations long, in which our values for R and S will apply, and into which we propose to build a cat road.

If we use the formula $n = \frac{S\ (2D + 1) - 2R}{S}$, we find that we are justified in building a road clear to its end, with some savings to spare over the road construction costs. If we make the calculation at twenty-six stations from the end, we still have these excess hauling savings as shown in the tabulation on page 39. At twenty-three stations (as we have seen) we just break even. We can build a cat road clear to the end of the draw, or we can build none at all, and the total cost in the end will be the same. At fifteen stations, we find that we are justified in going ahead with the construction, but can not plan on taking the road clear to the end. And finally, a calculation at eleven stations will show that we must stop. The construction of even one more station of road will not result in savings large enough to justify its cost.

This is the distance we are interested in. We can forget all about the formula $n = \frac{S(2D+1) - 2R}{S}$ as applied to this problem (although it has some other uses, as will be illustrated later), and use only the formula $n = \frac{2R - S}{2S}$, which will tell us how many stations we may leave at the end of the valley in the lowest class considered (in this case, how many we should leave without any road whatever).

The next problem is how many stations we should put in the next higher standard, in this case in cat roads. We can approach this problem in exactly the same manner. Using the same symbols as before, the cost of constructing n stations of this new road standard will be $n \times R$. The savings realized on the last station toward the back of the valley, if x equals the number of stations already allotted to the lower standard by the preceding calculations, is $(x+1)S$. The savings on the station closest to the valley mouth will be $(x+n)S$. Our equations will therefore read:

$$nR = \frac{n}{2}\left[(x+1)S + (x+n)S\right]$$

$$R = \frac{(x+1)S + (x+n)S}{2}$$

$$2R = (x+1)S + (x+n)S$$

$$2R = xS + S + xS + nS$$

$$nS = 2R - 2xS - S$$

$$n = \frac{2R - (2x+1)S}{S}$$

This formula will give us the justifiable distance to construct the second class of roads, in this case the cat roads.

And so we may proceed through as many standards as we have costs for. In this illustrative case we have the four standards listed with their costs and savings in Table VII. The pertinent data are repeated here for convenience.

Road class	Cost of improvement to this standard from the next lower one, per 100'	Saving in hauling cost over lower standard per 100' per M	Saving in hauling cost per 100' of road in 500-ft. side valley
Off roads	...	...	...
Cat roads	1300¢	5.39¢	108¢
Poor truck	4380¢	1.462¢	29.4¢
Good truck	3795¢	0.042¢	0.85¢

Application of these methods to the small, 500-foot side valley would show that no road can be built into it.

R = 1300

S = 108

$$n = \frac{2R - S}{2S} = \frac{2600 - 108}{216} = \frac{2492}{216} = 11.5 \text{ stations without cat road.}$$

Since the valley is less than 1000 ft. long, we would not be justified in building even a short cat road into it. This will be proven by total cost calculations a few pages farther along.

The two forks of the main stream should be considered next. The north fork serves a valley about 500 feet wide, and so the figures that applied to the side valley will be applicable here. Since it, too, is less than 1000 feet long, we will not be able to build a road into it.

The south fork serves even less area, and no road can be built into its watershed unless it is to carry timber from outside the watershed in sufficient volume to make a road profitable.

So now all three of the smaller streams are taken care of. The main river bottom road, if any, will serve the whole 60 acres. We can follow the same procedure in planning this road, assuming that the main valley bottom goes from forty line to forty line along the south fork, roughly bisecting the tract.

Average width served by river road = 1320 ft.

$$\text{Volume per station} = \frac{1320 \times 100}{43,560} \times 17.5 = 53 \text{ M per station}$$

Road class	Cost of improving to this standard, per 100 ft.	Saving in hauling cost over lower standard per 100' per M	Saving in hauling cost per 100' in 1320-ft. main valley
No road	...	...	...
Cat road	1300¢	5.39¢	286¢
Low cost truck	4380¢	1.462¢	77.5¢

I. Length of main valley without roads:

$S = 5.39¢$ per sta. per M x 53 M = 286¢ per station

$R = 1300¢$

$$n = \frac{2R - S}{2S} = \frac{2600 - 286}{572} = \frac{2314}{572} = 4.05 \text{ sta. without roads.}$$

II. Length of cat road:

$S = 1.462¢ \times 53$ M = 77.5¢ per station

$R = 4380¢$

$x = 4.05$ stations

$$n = \frac{2R - (2x+1)S}{S} = \frac{2 \times 4380 - (9.1)(77.5)}{77.5} = \frac{8055}{77.5} = 104 \text{ sta. of cat roads.}$$

This figure means that if the valley continued indefinitely, only 104 stations would be allotted to cat roads. By that time the volumes concerned would have risen so high that it would pay to bring in a truck road. In our case, since the watershed is only 1800 feet long, it simply means that except for 400 feet at the end of the valley, a cat road will go its whole length.

While these answers come out to an exact figure, in the woods it is impractical to break a road standard at any particular station just because the formula says that there is the point of maximum economy. It is true that greatest savings come if we leave 400 feet without roads. But if we leave any distance from 300 to 600 feet, we still are near the bottom of a rather flat cost curve, and our total costs will not be greatly affected by exactly where we stop construction. But that does not mean that it is not worthwhile figuring these distances. The answers will act as guides, with the exact point where we change road standards governed by the woods conditions. In this case, we would build in a cat road as shown on the map by a red line, and yard to this cat road with the tractor-winch units. The tractor-arch units would then road the logs down the cat road to the truck road, where a landing would be necessary.

Suppose, for the sake of illustration, that the truck road had not come right by this sixty acre tract. Suppose, instead, that this were an isolated holding left untouched from a previous power logging operation that had gone down the main valley and left this little pocket behind. To tap it now would require the construction of a quarter mile of deadline cat road across a logged-out area that would carry no volume to help bear the road cost. Could we still afford to come in and out this timber?

We have already developed the formula that can be used to answer this problem. The formula

$$n = \frac{S\ (2D + 1)\ -\ 2R}{S}$$

will give us the distance in stations that we can afford to construct a road tapping an area D stations long. In this case the pertinent values are:

S = 286¢ = savings in hauling per station for 1320-foot main valley.

D = 18 stations = depth of the tract.

R = 1300¢ = cost of improving from no road to a cat road per station.

$$n = \frac{286\ (2 \times 18 + 1) - (2 \times 1300)}{286}$$

$$n = \frac{286\ (37) - 2600}{286} = \frac{7990}{286}$$

n = 27.9 stations of cat road can be built.

Since four stations are to be left without any road at all, this means that we could afford to construct (27.9)-(18 - 4) 14 stations of deadline road. If a quarter mile of deadline road is necessary, it would pay to build it rather than to try to skid direct.

Total cost under plan

Now that we have fixed the road layout, it is possible to compute the logging costs F.O.B. the mill.

Total cost resolves itself into the following items:

a. Felling and bucking
b. Skidding to cat roads
c. Roading to truck roads
d. Loading and unloading
e. Landing cost
f. Truck haul
g. Cat road cost
h. Truck road cost

The logging plan we adopt on these sixty acres will only affect three of these costs, however. As we change the plan, the per M cost of skidding on the ground, the roading cost per M, and the cost of cat road construction per M will be changed. As far as logs from this particular area are concerned, the other costs are constant. We can, therefore, compute the costs for this 60 acres under any plan we may consider by determining the cost of these variable items under the plan, and then adding to them the constant quantity representing the other costs. Or we can compare any two plans by computing the sum of these three items under each of the plans, ignoring the unchanging costs altogether. The resulting costs will show the relative merits of any plan as well as would the total cost.

As an illustration, let us determine the costs of timber delivered to the central valley from the small side valley, 500 feet wide, which we have decided should not have any road built into it (Fig. III).

The valley is about 900 feet long and 500 feet wide. With no road to tap it, all timber must be skidded out direct. We have already decided that costs for skidding are:

Fixed per M = 42.2¢

Variable per M per 100 ft. = 7.03¢

Average skidding distance would be $\frac{900 \text{ ft.}}{2}$ = 450 feet. Total average skidding cost per M would therefore be

4.5 stations (7.03¢) = 31.6¢ variable cost
42.2¢ fixed cost
73.8¢ total skidding cost per M

The valley has an area of 10.3 acres.

$$\frac{900 \times 500}{43,560} = 10.3 \text{ acres}$$

It therefore carries a volume of 180 M b.m.

$$10.3 \times 17.5 \text{ M} = 180 \text{ M b.m.}$$

Total cost delivered to the central valley, exclusive of felling and bucking, would be

180 M b.m. @ 73.8¢ = $133.

As a check on our decision to skid direct without using a cat road, we could calculate costs using such a road, as follows. Logs would now be skidded down to the cat road, and average skidding distance would be

$$\frac{500 \text{ ft.}}{4} = 125 \text{ ft.}$$

Cost of skidding would be computed by the same method as before.

1.25 stations @ 7.03¢ =	8.8¢	variable cost per M
	42.2¢	fixed cost per M
	51.0¢	total cost per M for skidding

The average roading distance is $\frac{900 \text{ ft.}}{2} = 450$ feet. Fixed cost for this operation has been determined as 11.5¢ per M, and the variable cost as 1.64¢ per 100 ft. per M b.m. Roading cost is therefore

4.5 stations @ 1.64¢ =	7.4¢	variable cost per M
	11.5¢	fixed cost per M
	18.9¢	total cost per M

The cost of road construction must also be computed. A distance of nine stations would be built at a cost of $13 a station. Total road cost would therefore be 9 x $13 = $117.

Total volume has already been computed as 180 M b.m., so cost per M would be $\frac{\$117}{180} = \$0.65$ per M.

Summarizing these individual costs:

Skidding to cat road	= 51.0¢
Constructing cat road	= 65.0¢
Roading to central valley	= 18.9¢
	134.9¢ total cost per M delivered to central valley

We almost double the cost of production per M by putting a cat road into this draw, which does not carry a large enough volume to justify it.

The computation of costs need not be as long a procedure as the one just followed. By examination of the factors involved we can set up short formulas which are easily and quickly solved.

Skidding cost was estimated by multiplication of the skidding cost per M per 100 feet by the average skidding distance. We could have used the following symbols:

C = variable skidding cost per M per 100 ft.
F = fixed skidding cost per M
S = width of timber area served by road, in stations
S/4 = average skidding distance when timber extends on both sides of road

Skidding cost could then have been stated as follows:

$$\text{Skidding cost} = F + C\,\frac{S}{4}.$$

Inserting the values used in the last illustration, we would have the same cost as before:

$$42.2 + 7.03\,\frac{5}{4} = 51¢ \text{ skidding cost per M.}$$

Roading cost could be approached from the same point of view. Here we would introduce one new symbol:

D = depth of valley in stations

$\frac{D}{2}$ = average roading distance in stations.

Total cost would be the same as was computed before:

$$F + C\left(\frac{D}{2}\right) = 11.5 + 1.64\left(\frac{9}{2}\right) = 18.9¢.$$

Road cost could also be more simply stated. If the road served a 100-foot strip of timber, one mile of road would serve

$$\frac{5280 \times 100}{43,560} = 12.1 \text{ acres.}$$

Since the road actually serves a strip of timber "S" stations wide, one mile of road serves S(12.1) acres. If V equals volume in M b.m. per acre, this is equivalent to V(12.1)(S) Mb.m. Expressing this as a formula, we have

$$\text{Road cost per M b.m.} = \frac{R}{V(12.1)S}, \text{ where}$$

R = road cost per mile (if expressed as cost per station multiply by 52.8),

S = width served by road, in stations,

V = volume per acre, in M b.m.

Inserting values from the illustration, we have

$$\text{Road cost per M b.m.} = \frac{(\$13)\ 52.8}{17.5(12.1)5} = \$0.65.$$

Turning to another example of the use of these formulas, costs per M b.m. for the whole 60 acres, under the plan finally adopted, would be computed as follows.

Costs at trucks, exclusive of felling and bucking:

$C_S\left(\frac{S}{4}\right) = 7.03\left(\frac{14}{4}\right)$ = 24.6¢ variable skidding cost

F_S = 42.2¢ fixed skidding cost

$C_R\left(\frac{D}{2}\right) = 1.64\left(\frac{14}{2}\right)$ = 11.5¢ variable roading cost

F_R = 11.5¢ fixed roading cost

$\frac{R}{V(12.1)S} = \frac{68,600}{17.5(12.1)14}$ = 23.1¢ cost of road construction

112.9¢ total cost per M, exclusive of felling and bucking, delivered at truck road

where S = width of timber belt served by road = 14 sta. (from map)

D = length of road built, in stations = 14 sta.

C_S = variable skidding cost per M per 100' = 7.03¢

F_S = fixed skidding cost per M = 42.2¢

C_R = variable roading cost per M per 100' = 1.64¢

F_R = fixed roading cost per M = 11.5¢

R = cost of cat road per mile = 68,600¢

V = volume per acre = 17.5 M b.m.

Operating plan for 960-acre tract (Fig. V)

This section and a half is mapped in Figure V. The area is tapped by the main haul road which shows in the margins.

It will be seen on inspection that the area must, because of topography, be logged in two parts. Almost the whole of section three goes out on the north watershed, while the other 350 acres comes out along the stream in the southern portions of the area.

Plan for southern 350 acres. For clarity of explanation, the approximate watershed boundaries have been sketched in green on the map. The area inside each of these outlined blocks comes out over one watershed.

The southern side divided itself into two watersheds, each of which can be treated just as we did the ones on the 60-acre area. To further illustrate the method of attack, the calculations will be briefly outlined.

I. South Creek - serves an area 1500 feet wide

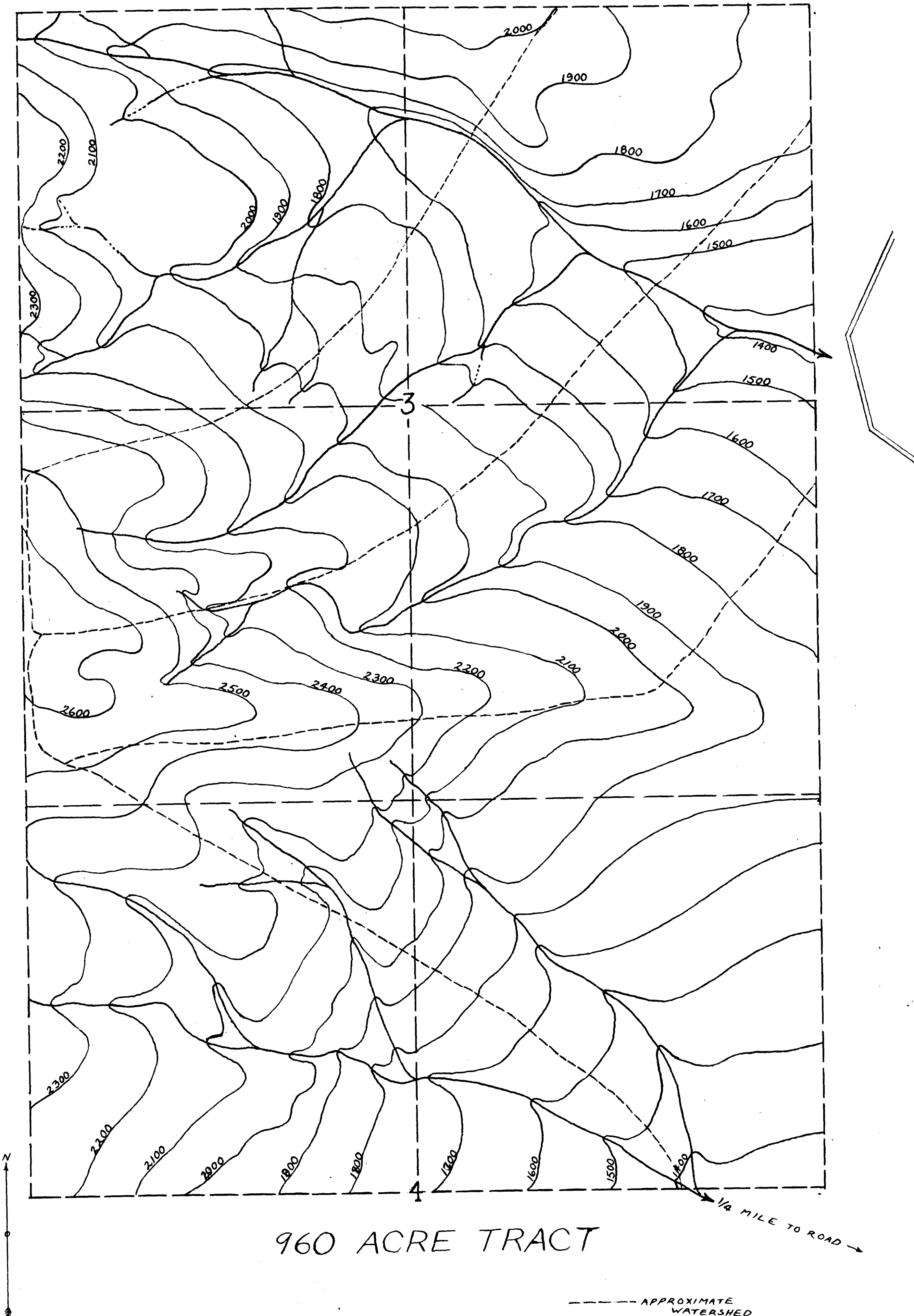
$$\text{Volume} = \frac{1500 \times 100}{43,560} \times 17.5 = 60.2 \text{ M per station}$$

$$R = 1300$$

$$S = (60.2)(5.39¢) = 324¢$$

$$n = \frac{2R - S}{2S} = \frac{2600 - 324}{648} = \frac{2276}{648} = 3.5 \text{ stations or 350 feet.}$$

FIGURE V



960 ACRE TRACT

APPROXIMATE WATERSHED BOUNDARY

TRUCK ROAD.

II. North Creek - serves an area 2,000 feet wide

$$\text{Volume} = \frac{2000 \times 100}{43,560} \times 17.5 = 80.3 \text{ M per station}$$

$$R = 1300$$

$$S = (80.3)(5.39¢) = 432¢$$

$$n = \frac{2600 - 324}{864} = \frac{2276}{864} = 2.6 \text{ stations or 250 feet}$$

Plan: build cat roads up both streams to within 350 feet of the watershed's end in the south fork, and within 250 feet of the end in the north fork.

A further problem is presented by the external haul from the juncture of these two cat roads to the main haul road one-fourth mile away. What standard should it be?

This problem must be attacked differently because no timber is being hauled directly to the tapline road. It is therefore called "dead line" road.

The tapline road will carry timber from approximately 360 acres, i.e. -

$$\frac{3000 \text{ ft.} \times 5280 \text{ ft.}}{43,560} = 360 \text{ acres}$$

360 acres @ 17.5 M = 6300 M b.m. will go over the road. We may compare total costs for different possible road standards in the following form.

Road class	Cost of road per station	Cost of road per sta. per M (Column 1÷ 6300 M b.m.)	Hauling cost per station per M b.m.	Total cost per station per M b.m.
Cat	1300¢	.206¢	1.64¢	1.846¢
Low cost truck	5680	.902	0.178	1.080
High cost truck	9470	1.502	0.136	1.638

Comparing total costs, it is evident that the tapline road should be a low cost, 15 m.p.h. truck road. This means that there would have to be a landing where the road standard changes, where the roading tractors would drop their logs and the trucks could be loaded.

Costs delivered at the landing, exclusive of felling and bucking, would be calculated just as they were in the 60-acre tract.

I. Costs of logs per M from north fork. Unit costs have all been developed previously, but are listed below for convenience.

S =	width served by road = 20 stations	
D =	length of cat road = 35 stations	
C_S =	variable skidding cost per M per 100'	7.03¢
F_S =	fixed skidding cost per M	42.2¢
C_R =	variable roading cost per M per 100'	1.64¢
F_R =	fixed roading cost per M	11.5¢
R =	cost of cat road per mile	68,600¢
V =	volume per acre	17.5 M b.m.

$$F_S + C_S \frac{S}{4} = 42.2 + 7.03\left(\frac{20}{4}\right) = 42.2 + 35.1 = 77.3¢ \text{ skidding cost}$$

$$F_R + C_R \frac{D}{2} = 11.5 + 1.64 \frac{35}{2} = 11.5 + 28.7 = 40.2¢ \text{ roading cost}$$

$$\frac{R}{V(12.1)S} = \frac{68{,}600}{17.5(12.1)20} = \frac{68{,}600}{4{,}240} = 16.2¢ \text{ road construction cost}$$

133.7¢ per M b.m. delivered to landing

II. Cost of logs per M from south fork.

Values inserted in the formulas are the same except for S and D.

$$S = 17 \text{ stations}$$

$$D = 45 \text{ stations}$$

$$F_S + C_S \frac{S}{4} = 42.2 + 7.03\left(\frac{17}{4}\right) = 42.2 + 29.9 = 72.1¢$$

$$F_R + C_R \frac{D}{2} = 11.5 + 1.64\left(\frac{45}{2}\right) = 11.5 + 36.9 = 48.4¢$$

$$\frac{R}{V(12.1)S} = \frac{68{,}600}{17.5(12.1)17} = \frac{68{,}600}{3{,}600} = 19.1¢$$

139.6¢ per M b.m. delivered to landing

<u>Plan for northern side (600 acres)</u> (Fig. V). The main stream only will be considered. Each of the three tributary valleys could be individually planned in the same manner as those we have gone over in detail.

The main valley presents a new problem, however. Here all the timber in any one of the three tributary watersheds reaches the main valley at one point. In effect, timber is being supplied at 1000-foot intervals, with only minor amounts being yarded directly to the road between these points. How should we handle our road standard in this case?

In the first place, it can be seen that each of the three tributary watersheds (as outlined in green) accounts for about the same area of about 200 acres. This simplifies the solution, although the same methods of analysis would be used if this were not so. Each one, therefore, carries about

$$\frac{600 \text{ acres} \times 17.5 \text{ M}}{3} = 3{,}500 \text{ M b.m.}$$

We can use the same line of reasoning as before. However, the unit of distance will not be the station, but the distance between watersheds, or 1000 feet. Our cost summary would take this form:

Road class	Road cost per 1000'	Hauling cost per 1000 ft.	Cost of improvement per 1000 ft.	Savings in hauling cost per 1000' per M	Savings in hauling per 1000' (3500 MBM)
Cat	13,000¢	16.4¢	...	...	...
Low cost truck	56,800¢	1.78¢	43,800¢	14.62¢	51,200¢
High cost truck	94,700¢	1.36¢	37,900¢	0.42¢	1,470¢

I. Length of cat road:

$R = 43{,}800$

$S = 51{,}200$

$$n = \frac{2R - S}{2S} = \frac{87{,}600 - 51{,}200}{102{,}400} = \frac{36{,}400}{102{,}400} = .355 \text{ units of cat road.}$$

II. Length of low cost truck road:

$R = 37{,}900$

$S = 1{,}470$

$x = .355$

$$n = \frac{2R - (2x + 1)S}{S} = \frac{75{,}800 - (1.71)(1{,}470)}{1{,}470} = \frac{73{,}290}{1{,}470}$$

$= 49.8$ units of low grade truck road.

Since it is logical to break the standard of the road at one of the side valley landings, we would disregard the 350 feet of cat road in the main valley, and our plan would be:

(a) Cat roads up the tributary valleys

(b) Landings at the mouths of these valleys

(c) A low cost truck road down the main valley (from the main haul road as far in as the fork in the main stream (3000 ft.)).

Cost of logs delivered to the mouth of any one of these tributary valleys could easily be figured by the same methods used before. However, it is not necessary to go to all the labor of computing the cost for each valley separately if we want only an average cost for the whole 600 acres. Substantially the same end result will be obtained if average figures are used in one over-all calculation. For instance, the actual average skidding distances range from 300 feet to 500 feet, and we could get the skidding cost by multiplying each of these figures by the tractor cost and averaging the results. However, one calculation of skidding cost, using an average skidding distance of 400 feet, will give the same per M cost for the whole production as would the longer method. Similarly, we can use average roading distances to find the roading cost.

If we are to figure the cost delivered to the main haul road outside the tract, several new cost elements enter into the picture. We now have landing costs, loading costs, truck hauling costs, and truck road construction costs entering into total cost and varying as we change the logging plan.

The simplest way to handle the landing cost, in this case, is to divide the total landing cost by the total volume.

$$\frac{3 \text{ landings x } \$100}{600 \text{ acres x } 17.5 \text{ M b.m.}} = \frac{30{,}000¢}{10{,}500 \text{ M b.m.}} = 2.86¢ \text{ per M}$$

Loading costs are really the sum of two cost elements. Both the standby charge of the truck, and the cost of the loading machine itself, are legitimately chargeable against the logs that are loaded out. We have already figured that the heel boom loader will take three minutes to load a M ft.b.m. The machine rate for the loader is 11.45¢ per minute. The loading cost itself is, therefore,

3 minutes x 11.45¢ = 34.3¢ per M b.m.

The truck standby charge arises from the fact that fixed charges (such as depreciation and the driver's wages) go right on regardless of whether the truck is running or not. This charge has been computed (Table VI) as being 6¢ per minute.

3 minutes x 6¢ = 18¢ per M b.m.

34.3¢ + 18¢ = 52.3¢ total loading cost per M.

The actual cost of hauling, per station, and the cost of road construction per station, have already been computed, and were presented in Table VII. We therefore know all the cost elements, and can list them as follows:

S_c = average width served by cat roads = 16 stations

S_T = average width served by truck roads = 50 stations

D_R = average length of roading tractor haul = 33 stations

D_T = length of truck haul = 35 stations

H = cost of truck haul per 100' per M = 0.18¢

F_H = fixed cost of truck haul (loading) per M = 52.3¢

T = cost of truck road per mile = $3000

L_D = cost of landings per M = 2.86¢

C_s = variable cost of skidding per M per 100' = 7.03¢

F_s = fixed cost of skidding per M = 42.2¢

C_R = variable cost of roading per M per 100' = 1.64¢

F_R = fixed cost of roading per M = 11.5¢

R = cost of cat road per mile = 68,600¢

V = volume per acre = 17.5 M

Total cost delivered to the main haul road would be computed as follows:

	Cost per M b.m.	
$F_s + C_s\left(\frac{S_c}{4}\right) = 42.2 + 7.03\left(\frac{16}{4}\right)$	= 70.4¢	= skidding cost
$F_R + C_R\left(\frac{D_R}{2}\right) = 11.5 + 1.64\left(\frac{33}{2}\right)$	= 38.6¢	= roading cost
$F_H + H\left(\frac{D_T}{2}\right) = 52.3 + .18\left(\frac{35}{2}\right)$	= 55.4¢	= loading and trucking cost
$\frac{R}{V(12.1)S_c} = \frac{68,600}{17.5(12.1)16}$	= 20.2¢	= cat road construction cost
$\frac{T}{V(12.1)S_T} = \frac{300,000}{17.5(12.1)50}$	= 28.3¢	= truck road construction cost
L_D	= 2.9¢	= landing cost
	215.8¢	= total cost exclusive of felling and bucking delivered to the main road

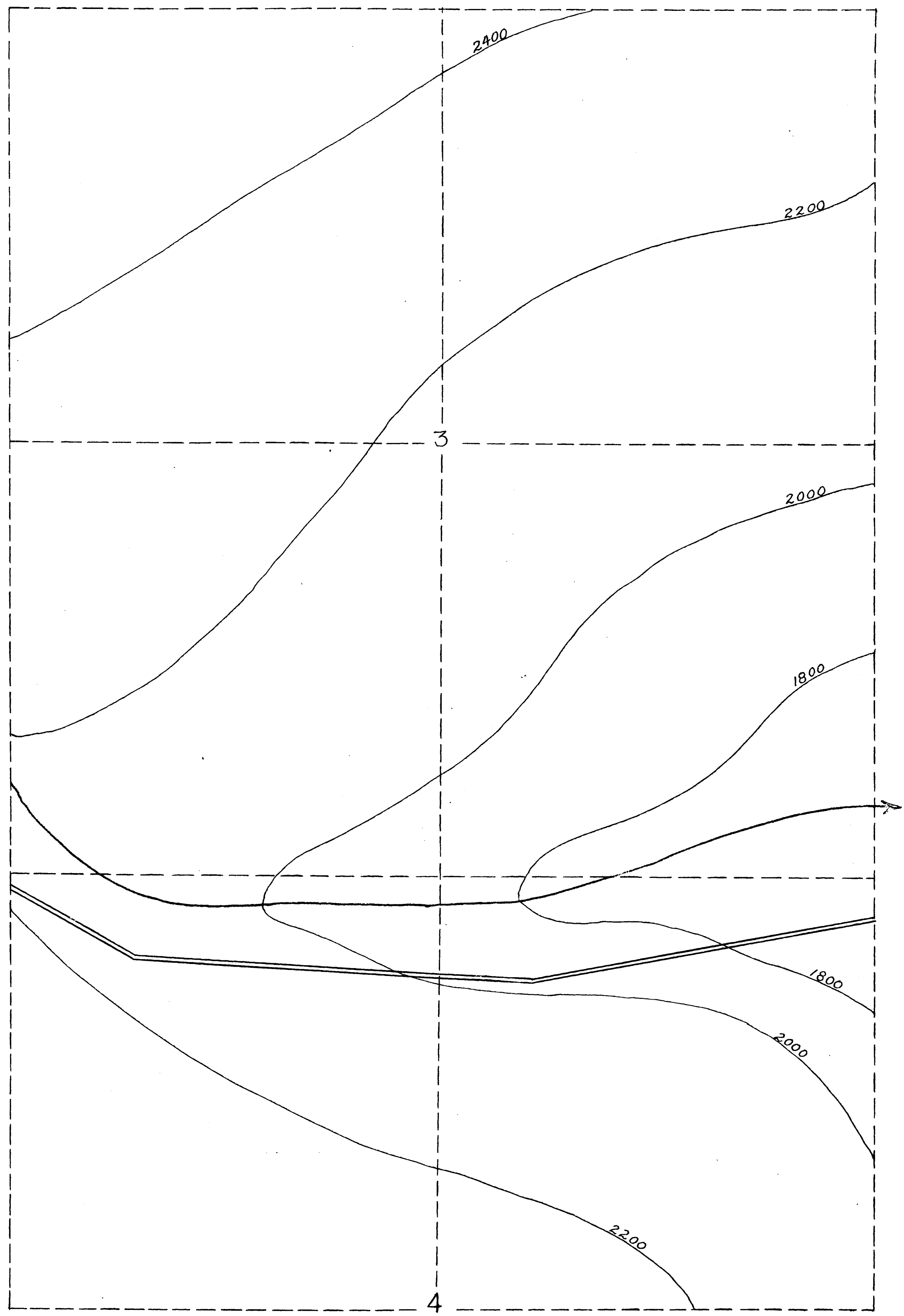
<u>Operating plan for 960 acres with a gentle slope</u> (Fig. VI)

On level or gently sloping ground, topography no longer controls the location of roads. This makes further economies possible, because we can put our roads at whatever spacing will make the total cost a minimum. If roads are spaced farther and farther apart, their costs of construction per M become less and less, but skidding costs rise so as to overbalance the saving. If they are spaced too closely, skidding costs are low, but the road cost becomes too great.

It can be shown by calculus that the minimum total cost comes at the spacing where variable skidding cost $\left(C\frac{S}{4}\right)$ equals the road cost $\left(\frac{R}{V(12.1)S}\right)$. An easier way to prove the same thing is to make a graph showing how the costs are affected by changing the road spacing in a specific instance. Such a graph has been made in Figure VII. The costs of skidding and of road construction (using the formulas for these costs as already developed) were plotted first. Then the total cost (the sum of the other two costs) was plotted. The lowest point on the total cost curve is at the spacing (1360 feet) where the road construction cost is equal to the skidding cost.

If this is true, we can find a formula for this optimum road spacing by setting the one cost against the other in an algebraic equation, using the formulas already developed.

FIGURE VI



960 ACRES ~ GENTLE SLOPE

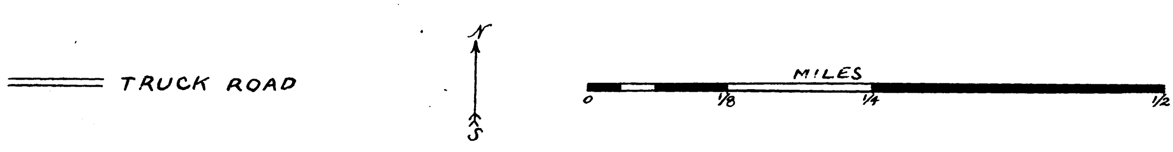
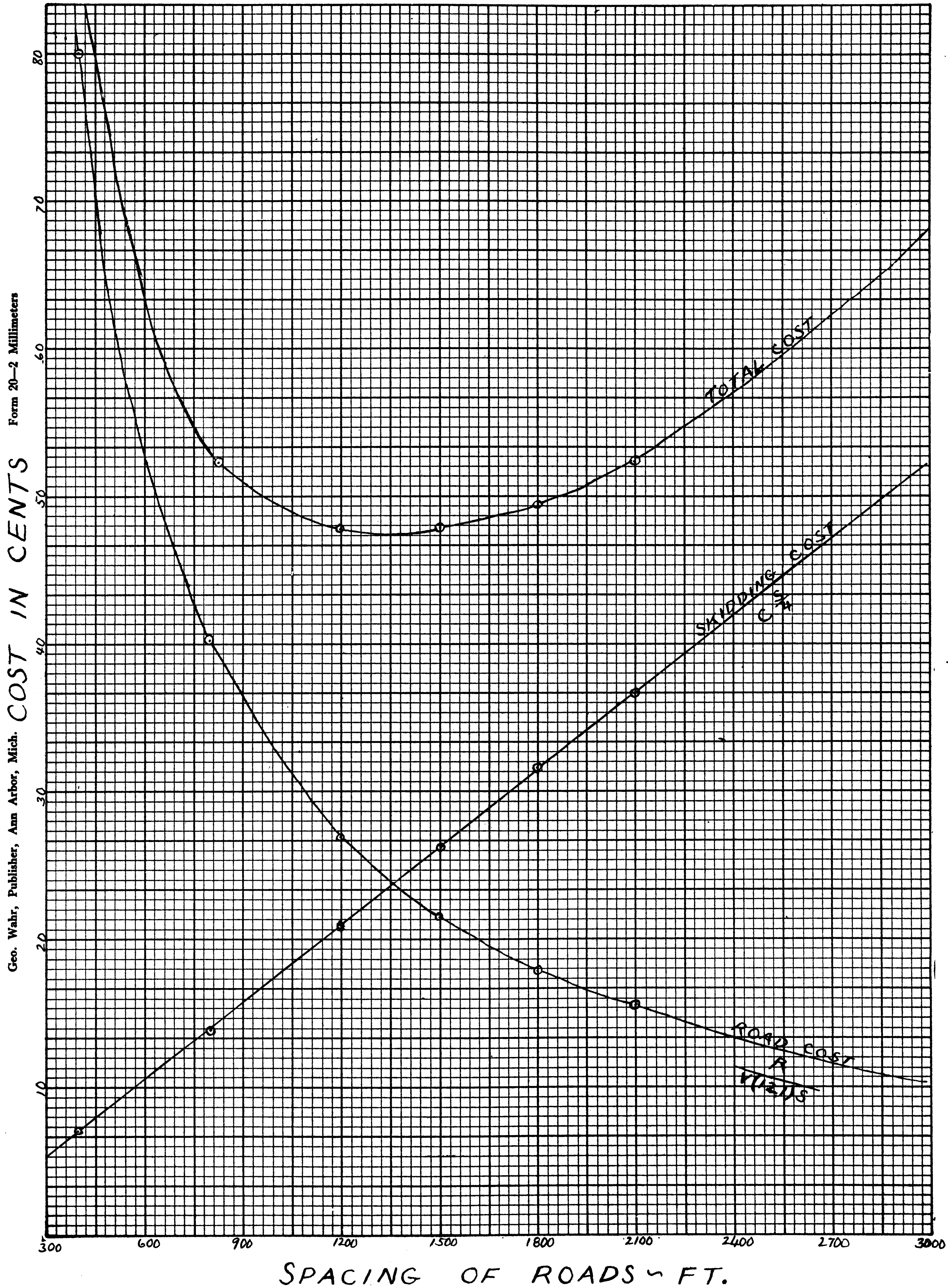


FIGURE VII



COST IN CENTS
80
70
60
50
40
30
20
10
300
600
900
1200
1500
1800
2100
2400
2700
3000
SPACING OF ROADS ~ FT.
TOTAL COST
SKIDDING COST
ROAD COST
Geo. Wahr, Publisher, Ann Arbor, Mich.
Form 20—2 Millimeters

$$C\frac{S}{4} = \frac{R}{V(12.1)S}$$

$$CS = \frac{4R}{V(12.1)S}$$

$$S^2 = \frac{R}{VC(3.025)} = \frac{.33\ R}{VC}$$

$$S = \sqrt{\frac{.33\ R}{VC}}$$

Checking this formula against the spacing already proven by the graph to be most economical (13.6 stations), we have the following values:

R = 1300¢ x 52.8 = 68,600¢ = road cost per mile

V = 17.5 M b.m. = volume per acre

C = 7.03¢ = variable cost per M b.m. per 100'

$$S = \sqrt{\frac{(.33)(68,600)}{(17.5)(7.03)}} = \sqrt{184} = 13.6 \text{ stations}$$

This simply means that if we can put the cat roads 1360 feet apart (roughly, once through a forty), the sum of our skidding and road costs will be at a minimum. Here again, although we come out with an exact figure, in the woods this distance is used only as a guide. By referring to the graph, we see that total costs are not raised more than 5¢ per M b.m. if we put the roads as close together as 900 feet or as far apart as 2000 feet. The use of the formula will prevent major errors in planning, however, and is especially useful when the operations move into a new timber type, or a new region, of radically differing costs or volumes, Experience often is of little help in making decisions in such a case, and use of the formula may save costly experimenting.

Figure VI represents 960 acres in a river bottom where such planning could be used. The main haul road is already built and follows the stream. The problem is to plan spurs from this road so as to realize maximum economy on the whole section and a half.

The 360 acres south of the road in section four will be planned first. The spacing of cat roads can be found by the formula.

$$S = \sqrt{\frac{.33\ R}{VC}} = \sqrt{\frac{.33 \times 68,600}{17.5 \times 7.03}} = \sqrt{184} = 13.6 \text{ stations}$$

However, there is only one mile of timber face to be tapped. If we use a 1,360-foot spur spacing, the planning will not come out even. The best thing we can do is to put in four roads, $5280 \div 4 = 1320$ feet apart, instead of 1360 feet. This will have very little effect on total cost.

The next question is whether the depth of the timber belt is sufficient to pay for the construction of these four roads on the 1320 foot spacing. We have about 2000 feet of timber from the main road to the boundary line of the property. Is this enough to make roads pay, or would it be cheaper to skid direct? Obviously, we could get an answer by adding up the total cost under each of the possible plans. However, it is possible to develop a short formula which will give us the answer without all this calculation. At some timber depth (D) the costs under either plan will be the same. That is, the cost with direct skidding will equal the cost with cat roads.

If we set this up as an algebraic equation, we can separate the D and express it in terms of the other variables. Using the same symbols and formulas as before, we have

$$C\left(\frac{D}{2}\right) = C\left(\frac{S}{4}\right) + \frac{R}{V(12.1)S} + H\,\frac{D}{2}$$

But we have seen that $C\,\frac{S}{4} \quad \frac{R}{V(12.1)S}$, if the proper road spacing is used. We may therefore restate the equation:

$$C\left(\frac{D}{2}\right) = 2\,\left(C\,\frac{S}{4}\right) + H\left(\frac{D}{2}\right)$$

$$C\,\frac{D}{2} - H\,\frac{D}{2} = 2C\left(\frac{S}{4}\right)$$

$$\frac{D}{2}(C - H) = C\left(\frac{S}{2}\right)$$

$$D(C - H) = CS$$

$$D = \frac{CS}{C - H}$$

Applying this formula to conditions in section four (Fig. VI), we have the following values:

C = variable skidding cost = 7.03¢ per M b.m. per sta.

S = economic spacing = 13.2 stations

H = cost of hauling on cat roads = 1.64¢ per M b.m. per sta.

$$D = \frac{(7.03)\ (13.2)}{(7.03)-(1.64)} = \frac{92.7}{5.39} = 17.2 \text{ stations}$$

That is, if the timber is 1720 feet deep, costs will be the same whether we skid direct or use cat roads. At timber depths greater than this, roads will definitely pay; at depths less than this they will cost more to build than they save on hauling. The timber in section four is 20 stations deep, so it will pay to build spur cat roads at the spacing we already figured, 1320 feet.

The next consideration is planning in section three. Here, obviously, it will pay to at least run cat roads back from the main haul road. But another possibility presents itself. Will it pay to run a truck road across the section and run spur cat roads east and west from this? The low cost truck road costs $3000 a mile, and we would need at least a mile of such road. Can we save $3000 in transportation costs by shortening the average roading distance?

We can use the same approach as in section four. The economic truck road spacing is:

$$S = \sqrt{\frac{.33\ R}{VC}} = \sqrt{\frac{(.33)(300{,}000¢)}{(17.5)(1.64¢)}} = \sqrt{3{,}440} = 58.6 \text{ stations}$$

$$D = \frac{CS}{C - H} = \frac{(1.64)(58.6)}{(1.64)-(0.178)} = \frac{96}{1.46} = 65.8 \text{ stations}$$

In other words, the breakeven point comes at 6,580 feet of timber depth. We have only 5,920 feet of timber, so costs would be slightly in favor of roading direct rather than to a spur truck road. We can prove this by total cost comparisons.

If we roaded direct to the main haul road, we would use a 1,320-foot spacing for the cat roads. Cost per M b.m. would be:

$$F_S + C_S\left(\frac{S}{4}\right) = 42.2 + 7.03\left(\frac{13.2}{4}\right) = 42.2 + 23.2 \quad = 65.4¢ \text{ skidding}$$

$$F_R + C_R\left(\frac{D}{2}\right) = 11.5 + 1.64\left(\frac{59.2}{2}\right) = 11.5 + 48.5 \quad = 60.0¢ \text{ roading}$$

$$\frac{R}{V(12.1)S} = \frac{68{,}600}{17.5(12.1)13.2} = \frac{68{,}600}{2{,}795} \quad = 24.5¢ \text{ road building}$$

$$F_H = 34.3 + 18 \quad = \underline{52.3¢} \text{ loading}$$

202.2¢ total cost aboard trucks

If we build a spur truck road, and road the logs east and west to it, instead of directly to the main haul road, the distances involved become:

S_c We have 5,920 feet average distance from main haul road to the back of the property. The nearest we can get to the optimum cat road spacing of 1,360 feet is $59.2 \div 4 = 1480$-foot spacing.

D_R The maximum roading distance will be the distance on either side of the spur truck road, or 2640 feet.

D_T The truck hauling distance will be 59.2 stations.

S_T The actual width served by the truck road will be 5280 feet.

Other costs will be the same as before.

$$F_S + C_S\left(\frac{S_c}{4}\right) = 42.2 + 7.03\left(\frac{14.8}{4}\right) = 42.2 + 26.0 = 68.2¢ \text{ skidding}$$

$$F_R + C_R\left(\frac{D_R}{2}\right) = 11.5 + 1.64\left(\frac{26.4}{2}\right) = 11.5 + 21.6 = 33.1¢ \text{ roading}$$

$$\frac{R}{V(12.1)S} = \frac{68,600}{17.5(12.1)14.8} = \frac{68,600}{3,140} = 21.9¢ \text{ cat roads}$$

$$F_H = 34.3 + 18 = 52.3¢ \text{ loading}$$

$$H\left(\frac{D_T}{2}\right) = 0.178\left(\frac{59.2}{2}\right) = 5.27 = 5.3¢ \text{ truck hauling}$$

$$\frac{T}{V(12.1)S_T} = \frac{300,000}{17.5(12.1)52.8} = \frac{300,000}{11,200} = 26.8¢ \text{ truck road}$$

207.6¢ total cost per M b.m. aboard trucks at main haul road

It will cost 5¢ per M b.m. more to operate over a truck road than to skid direct. The plan for section three, therefore, will be to put four cat roads, about 1320 feet apart, north from the main haul road. Conditions would have to vary only a little from those set up, however, to make the spur truck road pay. If the volume per acre rose as much as 4 M b.m., we could afford to build the spur.

$$S = \sqrt{\frac{.33 \times 300,000}{21.5\ (1.64)}} = \sqrt{2800} = 53 \text{ stations}$$

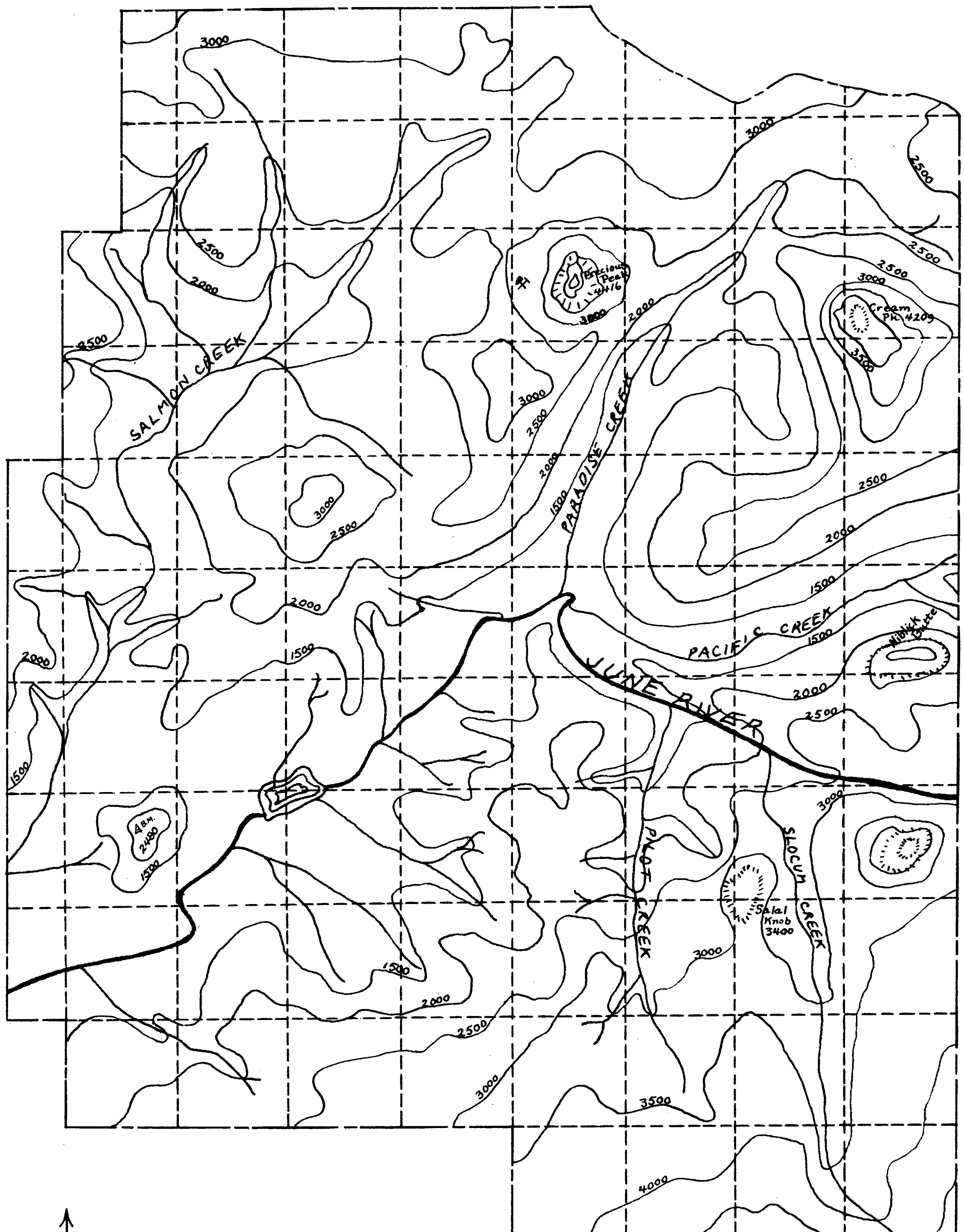
$$D = \frac{(1.64)(53)}{(1.64)-(0.178)} = \frac{87}{1.46} = 59.5 \text{ stations}$$

Similarly, if rough going raised the tractor roading cost to 2¢ per M per 100 feet, the spur would become possible. Or if we had 6,600 feet of timber to the north of the main haul road (instead of 5,920) it would again pay, even with all the other factors just as they are now.

<u>Operating plan for whole property</u> (Fig. VIII)

In planning for a large area here in the fir region, the topography will to a large extent control the road layout and therefore the plan of logging. It is obviously impossible to superimpose a rigid grid of roads on an area such as the one represented in Figure VIII. Nevertheless, it will be useful in planning to know the optimum level ground road spacings for each of the road classes we are to deal with. We can usually approximate proper road spacings even if we cannot attain them.

FIGURE VIII



ENTIRE OWNERSHIP

$$S = \sqrt{\frac{.33 \times 68,600}{17.5\ (7.03)}} = \sqrt{184} = 13.6 \text{ stations (cat road)}$$

$$S = \sqrt{\frac{.33 \times 300,000}{17.5\ (1.64)}} = \sqrt{3,440} = 58.6 \text{ sta. (low grade truck)}$$

$$S = \sqrt{\frac{.33 \times 500,000}{17.5 \times 0.178}} = \sqrt{63,000} = 230 \text{ sta. (20 m.p.h. truck)}$$

In a very large area of level ground, therefore, we would space 20 m.p.h. truck roads every four miles. Meeting these roads at right angles every mile would be low-grade truck roads. And finally, cat roads would discharge onto the 15 m.p.h. truck roads every quarter mile. Direct skidding would be to the cat roads, with average skidding distance about 340 feet. Obviously, wherever possible the cat roads would be so located as to pass close to any groups of especially high volume. This can usually be done without departing too far from the optimum spacing.

The only thing we can say definitely by inspection of the map is that a high grade, 20 m.p.h. road will be built along June River. The conventional principles of road location would be used. In general, the object will be to traverse the property with as few bridges and in as short a distance as possible (within the limits set by the maximum grade).

In any one of the tributary valleys the lengths of the various road standards would be determined by use of the principles set up in the plans for the 60-acre and the 960-acre areas. It will not be necessary to repeat the calculations here. The road would in all probability begin in any of the larger valleys as a 20 m.p.h. truck road, and in the lesser ones as a 15 m.p.h. road. The standard would be progressively lowered toward the end of the valley, until at the back end even the cat road would be discontinued. Once the use of the formulas is mastered, it only takes a short while to make a working plan for any given watershed.

Spurs from these main valley roads would be planned area by area, using the methods already outlined, as they came up to be logged. Over much of the property they can be put in at their optimum spacing or close to it, as was illustrated in the gently rolling area (Fig. VI). Where topography does not permit this, it will still be possible to choose whatever alternative will give the smallest costs by using the principles of cost analysis that have been set forth.

Several new problems may come up. The most important of these has to do with logging on a sustained slope. Roads in this case will be placed on the contours. Obviously, costs will be lower for downhill tractor hauls to these roads than for uphill ones. The question is, should we space our roads the same on such a slope as we would on level ground? And after spacing is decided, how much of our total production should go uphill and how much of it down? An approach to this problem is given by D. M. Matthews in "Cost Control in the Logging Industry," from which the following ideas are taken.

Usually an operation will not have separate figures on uphill and downhill skidding costs for various degrees of slope.

They must be determined, however, before an accurate analysis of skidding costs can be made. One approach to the determination of such data is to assume that the tractor uses the same gear ratio at all times in the woods, and that, therefore, the effect of variations in grade is to change the size of the load the cat can pull. The Caterpillar Tractor Company has prepared the tabulation shown in Table VIII, which shows the effect of grade on load. On a going operation which is making an analysis of its costs, of course these figures would be determined by field studies. For the purpose of illustrating the method of proper road layout, however, they will be used here without change.

Table VIII

Size of loads which can be skidded up and down grade, expressed in percents of loads skidded on level ground, D7 tractor

% grade	16" d.b.h.	20" d.b.h.	24" d.b.h.	28" d.b.h.	32" d.b.h.	36" d.b.h.
20	46%	45%	44%	44%	44%	44%
16	55	54	54	53	53	53
12	65	64	64	63	63	63
8	76	75	75	74	74	74
4	88	87	87	87	86	86
level	100	100	100	100	100	100
- 4	114	114	114	115	115	115
- 8	128	129	130	131	131	132
-12	143	145	146	148	149	150
-16	158	162	164	166	167	168
-20	175	181	184	186	188	190
-24	193	201	205	208	211	214
-28	211	222	225	230	234	239

For all practical purposes, the fixed per M cost can be assumed to remain unchanged with differences in slope. However, the above changes in load directly affect the variable skidding cost, which we called "C" in level ground skidding. If we increase the load 50%, variable skidding cost per M becomes $\frac{C}{1.50}$. If we decrease the load 25%, it becomes $\frac{C}{.75}$.

Once we have determined the costs per 100 feet per M b.m. for both uphill and downhill skidding, the total weighted skidding cost can be expressed as

$$Cu\left(\frac{PS}{2}\right)P + C\left(\frac{(1 - P)S}{2}\right)(1 - P)$$

where Cu = cost of uphill skidding per M per 100 feet

C = cost of downhill skidding per M per 100 feet

S = spacing of roads (or width served by each road)

P = the percentage of S hauled uphill

(1 - P) = the percentage of S hauled downhill.

To attain a minimum for the sum of uphill and downhill skidding cost, these two quantities must be equal. We can set them equal to each other in an algebraic equation. Then, since P is the variable in the cost, we can find the value of P which will give us minimum cost, by separating it out from the other factors.

$$Cu\left(\frac{PS}{2}\right) = \frac{C(1 - P)S}{2}$$

$$CuPS = CS - CPS$$

$$CuP = C - CP$$

$$P(Cu + C) = C$$

$$P = \frac{C}{Cu + C}$$

In other words, if we substitute the above value for P in $\frac{CuPS}{2}$ and in $\frac{C(1 - P)S}{2}$, these two values will then be equal. Furthermore, either one of them, unweighted, will be equal to the weighted total skidding cost for both uphill and downhill skidding.

We now have formulas for skidding cost that we can treat just as we did the one for level ground skidding in getting the optimum road spacing. We showed then that minimum cost came when the road construction cost equalled the skidding cost. Since we now have two expressions, each of which represents the average skidding cost, it follows that we can develop two expressions of the optimum road spacing. This is done below.

$$Cu\left(\frac{PS}{2}\right) = \frac{R}{V(12.1)S}$$

$$CuPS^2 = \frac{2R}{12.1(V)} = \frac{.165\ R}{V}$$

$$S^2 = \frac{.165\ R}{VCuP}$$

$$S = \sqrt{\frac{.165\ R}{VCuP}}$$ in terms of uphill skidding cost.

Or alternatively --

$$\frac{C(1 - P)S}{2} = \frac{R}{V(12.1)S}$$

$$C(1 - P)S^2 = \frac{2R}{V(12.1)} = \frac{.165\ R}{V}$$

$$S^2 = \frac{.165\ R}{VC(1 - P)}$$

$$S = \sqrt{\frac{.165\ R}{VC(1 - P)}}$$ in terms of downhill skidding cost.

Either formula will give the same answer. The only difference is that one is based on uphill and the other on downhill skidding cost.

As an illustration of the application of these methods, we could assume the following conditions to exist somewhere on the property:

A fairly well-sustained slope of 16%.

Average log, 1250 ft.b.m. or 36" diameter.

Contour truck roads are to be used, since obviously a truck could not work efficiently on a 16 per cent grade. The problem is how far apart these contour roads should be spaced.

The variable cost of roading to the truck roads on the level is 1.64¢ per M per 100 feet. Referring to Table VIII, we can compute uphill and downhill roading cost as follows.

Uphill: $Cu = \frac{1.64}{.53} = 3.1$¢ per M per 100 feet

Downhill: $C = \frac{1.64}{1.68} = 0.98$¢ per M per 100 feet

$$P = \frac{C}{Cu + C} = \frac{.98}{3.1 + .98} = \frac{.98}{4.08} = 24\% \text{ uphill}$$

$$S = \sqrt{\frac{.165\ R}{VCuP}} = \sqrt{\frac{.165 \times 300,000}{17.5 \times 3.1 \times .24}} = \sqrt{3,800} = 62 \text{ stations}$$

$$S = \sqrt{\frac{.165\ R}{VC(1-P)}} = \sqrt{\frac{.165 \times 300,000}{17.5 \times .98 \times .76}} = \sqrt{3,800} = 62 \text{ stations}$$

Truck roads, therefore, should be placed about a mile and a quarter apart. Cat roads will then be run out as spurs from the truck roads at their usual spacing, since the loads of the yarding tractors will be unchanged. If the cost of ground skidding were changed, of course the cat road spacing would be changed also. However, in this instance skidding tractors will be hauling on the contour and will handle substantially the same loads as on the level.

Other operating problems. Two major fields of planning have not even been touched on here. The first deals with the operation of a chance using power skidders or donkeys. The spacing of the landings and roads, the economic external yarding distance, and the computation of costs all present new problems. They can be attacked and solved by the same approach as we have used, but there is not time to go into them here. The subject is covered in "Cost Control in the Logging Industry," by D. M. Matthews.

The other field of planning has to do with all the decisions that must be made which have nothing to do with the actual layout and planning of the transportation system. Choices must be made between alternative units of new equipment. Equipment already owned has to be put as much as is feasible on the particular jobs where it will perform most efficiently. Alternative plans of woods procedure and cutting policies present themselves. A choice exists as to thether the property should be classified under the forest tax law. The decisions that must be made are endless. Most of them can be logically approached in the same way we decided on the selection of road standards --

that is, by breaking the costs involved into their component unit costs, and then determining the most economical combinations of these unit costs.

As an example, such an approach can be made to the selection of trucks, and to their placement once they are on the job. If two makes of truck are available, one will be cheaper than the other on long hauls, and the other will be more efficient on short ones. At some length of haul, the use of either truck will be equally justified. Many an operator has kept close track of the total costs per M b.m. for several trucks on his own job, and based his choice for future purchases on the results. But if his show moves on to different operating conditions, he is at a loss as to how to apply his figures in the new show.

Truck costs are divided into two kinds. Certain fixed charges (like depreciation and the driver's wages) go on regardless of whether the truck is operating or not. Other charges are incurred only if the truck is running. When the truck is being loaded, fixed charges go right on and create what is known as the standby charge. When it is running, the cost incurred per M b.m. depends on its average round-trip speed.

In the hypothetical operation, costs have been determined to be as follows, and are repeated here for convenience.

	Chevrolet	Mack and Federal	Fageol Cummins
Standby charge per minute	2.4¢	3.9¢	6.0¢
Standby charge per M (3 min. per M)	7.2¢	11.1¢	18.0¢
Operating cost per hour	$3.08	$4.86	$7.09
Average load	3 M b.m.	5 M b.m.	10 M b.m.

We also saw that we could determine the hauling cost per M b.m. per mile by using the formula,

$$\text{Hauling cost per M b.m. per mile} = \frac{\text{Hourly cost x 2}}{\text{m.p.h. x load}}.$$

To illustrate the procedure, we will assume that we have Chevrolets and Fageols available, and want to properly distribute them on our job. The hauling is to be over the $3000 a mile roads, which permit round trip speeds of 15 m.p.h.

Using the hauling cost formula, we can develop the following costs per round trip mile:

Chevrolet --

$$\frac{3.08 \times 2}{15 \times 3} = \frac{6.16}{45} = 13.7¢ \text{ hauling cost per M b.m. per mi.}$$

Mack and Federal --

$$\frac{4.86 \times 2}{15 \times 5} = \frac{9.72}{75} = 13¢ \text{ hauling cost per M b.m. per mi.}$$

Fageol Diesel --

$$\frac{7.09 \times 2}{15 \times 10} = \frac{14.18}{150} = 9.5¢ \text{ hauling cost per M b.m. per mi.}$$

Now, say we wanted to know when to use the Chevrolet and when to use the Fageol diesel. Total hauling cost per M with either of them will be the standby charge per M b.m., plus cost per M b.m. per mile times miles hauled. Using symbols, we could say:

$$\text{Hauling cost} = F + NC$$

where F = standby charge per M b.m.

N = miles of haul

C = cost of hauling per mi. per M b.m.

We want to find the distance (N miles) where the costs will be equal whichever machine we use. This has been done graphically in Figure IX. The total cost lines for the two machines cross at 2.6 miles. For hauls shorter than this on the 15 m.p.h. road the Chevrolets are cheaper, and for longer hauls the Fageols should be used.

We could get the same answer by an algebraic approach. We are looking for the distance, N miles, at which the costs are equal for the two machines. If we set the two total cost formulas equal to each other and then separate N out from the other factors, the resulting equation will give us N in terms that we can easily determine. If we let F NC equal total costs for the Chevrolet, and F NC equal costs with the Fageol, the solution would take the following form:

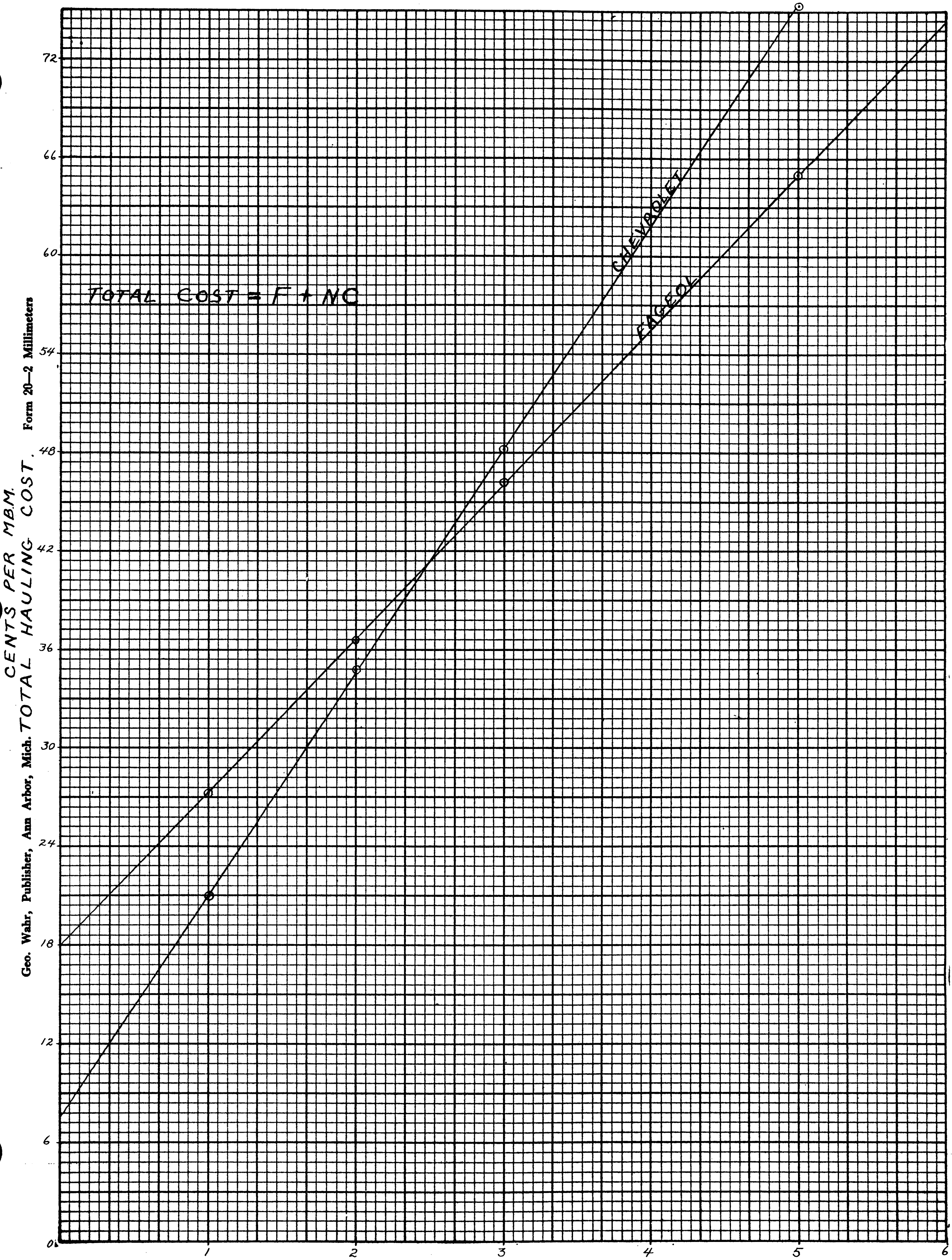
$$F_c + NC_c = F_F + NC_F$$

$$NC_c - NC_F = F_F - F_c$$

$$N(C_c - C_F) = F_F - F_c$$

$$N = \frac{F_F - F_c}{C_c - C_F}$$

FIGURE IX


TOTAL COST = F + NC
CHEVROLET
FAGEOL
CENTS PER M.B.M.
TOTAL HAULING COST.
LENGTH OF HAUL ~ MILES
0
6
12
18
24
30
36
42
48
54
60
66
72
1
2
3
4
5
6
Geo. Wahr, Publisher, Ann Arbor, Mich. Form 20—2 Millimeters

Substituting the values from our operation in this formula, we get the same breakeven point as we did graphically.

$$N = \frac{18¢ - 7.2¢}{13.7¢ - 9.5¢} = \frac{10.8}{4.2} = 2.6 \text{ miles}$$

To further illustrate the method, suppose we are considering all three of the trucks, and propose to buy several of whatever make we decide will be most economical for the external haul to the mill. This haul averages about 15 miles, according to the conditions we set up, over a road that permits average round-trip speeds of 20 m.p.h. Cost per M b.m. per mile will be found in the same manner as before.

Chevrolet --

$$\frac{3.08 \times 2}{20 \times 3} = \frac{6.16}{60} = 10.3¢ \text{ per M b.m. per mile}$$

Mack and Federal --

$$\frac{4.86 \times 2}{20 \times 5} = \frac{9.72}{100} = 9.7¢ \text{ per M b.m. per mile}$$

Fageol diesel --

$$\frac{7.09 \times 2}{20 \times 10} = \frac{14.18}{200} = 7.1¢ \text{ per M b.m. per mile}$$

Using these values, comparisons between the three trucks will take the following form:

Breakeven between Chevrolet and Fageol --

$$N = \frac{18 - 7.2}{10.3 - 7.1} = \frac{10.8}{3.2} = 3.4 \text{ miles}$$

Breakeven between Chevrolet and Macks --

$$N = \frac{11.1 - 7.2}{10.3 - 9.7} = \frac{3.9}{0.6} = 6.5 \text{ miles}$$

Breakeven between Macks and Fageol --

$$N = \frac{18.0 - 11.1}{9.7 - 7.1} = \frac{6.9}{2.6} = 2.7 \text{ miles}$$

These figures show that for hauls on the 20 m.p.h. road of 3.4 miles or over, the Fageol Diesel is superior to both the Chevrolets and the Macks or Federals. On hauls less than 3.4 miles, Chevrolets are cheaper than either of the others. Macks and Federals, therefore, should not be used at all on this job. Fageol Diesels should be used on the 15-mile haul to the mill. The large load they carry more than makes up for their high standby and operating charges. Chevrolets would be used on short interior hauls (moving equipment or men, for instance).

The same breakeven principle can be applied in the selection of loading equipment. We have assumed so far the use of a heel boom loader which cost $6.87 per hour, and which loaded at the rate of 3 minutes per M b.m. The company might have to purchase a new loading unit to handle an increased production. The question then would be whether to get a new heel boom loader or whether some other type with a lower hourly cost would pay. Say that a 30 H.P. gas donkey and crotch line is offered to them. It will load at the rate of only 7 minutes per M, but its machine rate is $5 an hour. How much production will justify the purchase of the speedier, but higher priced, heel boom?

Total loading cost has been shown to consist of two parts, the standby charge for the truck and the cost of the loading operation itself. The standby charge per M b.m. for the two loaders (assuming the use of the Fageols) will be 3 min. x 6¢ = 18¢ per M b.m. for the heel boom, and 7 min. x 6¢ = 42¢ per M b.m. for the crotch line. The cost per M b.m. of the loading operation itself will be in each instance the hourly cost of the loading machine divided by the hourly production. We can find the breakeven point by equating the two total costs:

$$18¢ + \frac{6.87}{\text{hourly output}} = 42¢ + \frac{5.00}{\text{hourly output}}$$

$$\frac{6.87 - 5.00}{\text{hourly output}} = 42¢ - 18¢$$

$$\frac{1.87}{\text{hourly output}} = 24¢$$

$$\text{Hourly output} = \frac{1.87}{.24} = 7.8 \text{ M b.m.}$$

In other words, if the operation is to load out 7.8 M b.m. or more per hour, it will pay to use the heel boom, regardless of the fact that it will be idle much of the time. The cost of this idle time will be more than made up for by the reduced standby charge on the trucks.

Another way of stating this same problem is to put it in the form of a breakeven formula very similar to the one used in truck selection.

$$n = \frac{F_H - F_C}{C_C - C_H} = \frac{6.87 - 5.00}{.42 - .18} = \frac{1.87}{.24} = 7.8 \text{ M b.m. per hour}$$

In this case the machine costs are fixed per hour, and the variable costs are the standby charges.

VALUATION OF PROPERTY

We have developed a method of planning for economic woods operation, and of easily estimating costs, whatever that plan may be. It is now possible to compare broadly differing plans in the light of the net incomes they produce. We can, for instance, compare the relative return from a plan liquidating in thirty as against twenty years, and bring into the calculation the fact that a dollar in the hand is worth two on the stump. Or we can compare a plan taking a larger volume per acre with one taking a smaller volume, recognizing the fact that the transportation layout will be different under the two plans, even though the annual production may be the same.

In essence, such comparisons are made in two steps. With any broadly outlined plan that may be considered, we first develop a reasonable operating plan, and from it the costs that can be expected under the plan. Then we evaluate what the succession of net annual incomes that will result from the plan is worth to us today, after allowing for all expenses, for normal business risk, and for a reasonable return on the investment involved. Whichever plan can show the greatest present day net value to us is obviously the one to adopt.

For the purpose of illustrating the procedure, the value of the hypothetical property will be determined under two widely differing cutting plans. The company so far has been assumed to be in effect highgrading the stand. That is, they are taking out only the high value species, and leaving a large volume of marginal species on the ground. This means that the logs removed necessarily carry all the fixed costs (such as depreciation). The management would be justified in wondering whether it might not be better to cut these low value species so that they would help bear the burden of fixed per acre and fixed per year charges. Wouldn't it be better to cut the whole merchantable stand (in this case down to 20") rather than to operate at what is now effectively a 48" limit?

It will be assumed that the following data are applicable. Comparable figures would be obtainable from any company's books.

Working capital	= $500,000
Logging plant and equipment	= $500,000
Debt incurred in acquiring and opening up tract	= $1,000,000
Interest rate on debt	= 6%
Administration and year-long supervision (per year)	= $55,000
Area of property, acres	= 53,440
Annual cut, M b.m.	= 100,000
Stand per acre	As in Fig. I

If production is to remain constant, the effect of raising the diameter limit is to increase the area covered each year, and therefore to decrease the life of the operation. In addition, the percentage distribution of species in the cut will be altered, and the per M b.m. selling price of the logs will be increased because of their larger average size. If we use 1931 prices as reported by Kirkland in "Selective Timber Management in Douglas Fir," the data pertaining to each of the proposed plans will be as presented in Table IX.

Table IX

Species	Volume cut per acre (M b.m.)	% of total cut	Average d.b.h. (in.)	Value per M b.m. on log market
	Highgrade to about 48" (as now) - Life 10 yrs.			
Fir	12.4	70.9	79	$14
Cedar	3.4	19.4	45	15
Hemlock	1.7	9.7	56	8
Total, or weighted ave.	17.5	100.0	70	$13.60
	Clearcut to 20" - Life 23 yrs.			
Fir	12.4	29.2	79	$14
Cedar	3.4	8.0	45	15
Hemlock	26.7	62.8	34	7
Total, or weighted ave.	42.5	100.0	48.5	$9.70

The first step in evaluating the property under either cutting practice is to fix an operating plan for it. It has already been decided that topography will force the construction of truck roads down the main valley bottoms, with tributary cat roads bringing logs down the slopes to landings on the truck roads. This plan is feasible over nearly all the area. A D8 can operate efficiently on favorable slopes as steep as 30%, and in very few places do slopes exceed this maximum. Where they do, cat roads can in some instances tap the area "the long way around," and in others it may be necessary to fall back on the use of power skidders or donkeys. Such occasional variations will not change the over-all plan for the area.

Obviously, it would be possible to draw up detailed plans for each watershed after the fashion of those described in earlier parts of this paper. When several plans are being considered, however, the labor involved in such a procedure would not be justified until the most economical plan had been decided upon. For the purpose of comparing the merits of alternative plans, it is possible to use average values and get an over-all average cost of production which is just as valid for the purposes of comparison, although of course it could not be applied in any individual forty or section. In this case it has been assumed that the truck roads go up the main stream bottoms on a 5% grade; cat roads come down to the truck roads on an average grade of 12%; and skidding tractors work on the contour. Reference to the map (Fig. VIII) will show that rarely do the machines work on exactly these grades. Over the area as a whole, however, the grades average themselves to about these figures, and calculations based on these average values will be accurate for the property as a whole.

We are now in a position to calculate production costs, using the formulas and methods that have already been described. A tractor-arch unit roading down a 12% grade carries 150% the level ground load.

$$\text{Variable roading cost} = \frac{1.64¢}{1.50} = 1.09¢ \text{ per M b.m. per 100 ft.}$$

Road spacing would be as follows:

Clearcut:

15 m.p.h. truck road -

$$S = \sqrt{\frac{.33R}{VC}} = \sqrt{\frac{(.33)(300,000)}{(42.5)(1.09)}} = \sqrt{2135} = 46 \text{ stations}$$

Cat road -

$$S = \sqrt{\frac{.33R}{VC}} = \sqrt{\frac{(.33)(68,600)}{(42.5)(7.03)}} = \sqrt{75.7} = 8.7 \text{ stations}$$

Highgrade:

15 m.p.h. truck road -

$$S = \sqrt{\frac{.33R}{VC}} = \sqrt{\frac{(.33)(300,000)}{(17.5)(1.09)}} = \sqrt{5180} = 72 \text{ stations}$$

Cat road -

$$S = \sqrt{\frac{.33R}{VC}} = \sqrt{\frac{(.33)(68,600)}{(17.5)(7.03)}} = \sqrt{184} = 13.6 \text{ stations}$$

Operating costs other than those which depend on the transportation system would be obtainable from nearly any operating company's books. In this hypothetical case they were drawn from the records of Company X, or from figures presented by Bruce Hoffman in "Problems of Private Forestry in the Douglas Fir Region." An attempt was made in all cases to keep them in line with average costs in the region. The calculation of the present value of the timber (stumpage value) would take the following form.

	Item	Group	per M b.m.
Selling price (Highgrading)			$13.60
Woods costs			
Group I - Direct operating costs			
Felling and bucking	= $1.90		
Ground skidding			
$C_S \frac{S}{4} = 7.03 \frac{13.6}{4}$	= .24		
Fixed cost	= .42		
Roading			
$C_R \frac{S}{4} = 1.64 \frac{72}{4}$	= .30		
Fixed cost	= .11		
Loading	= .52		
Truck haul (9.5¢ per M per mi.)(15 miles)	= 1.42	$4.91	
Group II - Fixed per acre			
Cat roads $\frac{68,600¢}{(17.5)(12.1)(13.6)}$	= .24		
Interior truck roads $\frac{300,000¢}{17.5(12.1)72}$	= .20		
Main haul road $\frac{500,000¢ \times 10 \text{ mi.}}{935,000 \text{ M}}$	= .05	.49	
Group III - Fixed per M			
Social security	= .20		
Industrial insurance and medical aid	= .07		
Supplies	= 1.00	1.27	
Group IV - Fixed per year			
Administration and year-long supervision $\frac{\$55,000}{100,000 \text{ M}}$	= .55		
Fire protection	= .20		
Timber tax	= .55		
Property tax	= .20		
Income tax	= .35		
Other tax	= .12	1.97	8.64

Net to meet depreciation, interest, etc. $4.96

Gross Conversion $4.96

Depreciation per year(assuming that half of the equipment will last the life of the operation (10 yrs.) and half will last 5 yrs.)

$$\$250{,}000 \left(\frac{.06}{1.06^{10} - 1}\right) = \$250{,}000\ (.0759) = \$19{,}000$$

$$\$250{,}000 \left(\frac{.06}{1.06^{5} - 1}\right) = \$250{,}000\ (.1774) = 44{,}300$$

Retirement of debt

$$\$1{,}000{,}000\left(\frac{.06}{1.06^{10} - 1}\right) = \$1{,}000{,}000(.0759) = 76{,}000$$

Interest on working capital, plant and equipment, and debt

($2,000,000)(.06) =180,000

Annual cost $319,000

Capital costs per M b.m.

$$\frac{\$319{,}000}{100{,}000\ M} \qquad 3.19$$

Stumpage value per M b.m. $1.77

Annual stumpage income

(100,000 M)($1.77) =$177,000

There will, therefore, be a total net income of $1,770,000 over the course of ten years. However, we must allow for the fact that an income coming in the future is not worth its full value to us today. It must be discounted back to the present. If each income which is to come in the future is discounted back to the present, the net value of the stumpage to us today will be as follows:

$$\frac{(\$177,000)(1.06^{10} - 1)}{.06\ (1.06^{10})} = (\$177,000)(7.36) = \$1,303,000$$

This is the value of the property if everything goes as planned and we get the expected stumpage return every year. Many things may happen to disturb this flow of income, however. Market prices are apt to fall off. Labor costs (which constitute over half of the total cost of production) may rise generally over the whole region. A fire may destroy part or all of the property. To allow for these contingencies the potential worth of a property such as this is reduced by some percentage. In this case it seems fair to reduce it by 20 per cent, which is equivalent to multiplying it by a "factor of safety" of 80 per cent.

Present worth @ 6%	$1,303,000
Factor of safety	.8
Present worth, allowing for risk	$1,043,000

If we now repeat this valuation procedure for the other plan under consideration (clearcutting), we have a financial expression of the relative merits of the two plans.

				per M b.m.
Selling price (Clearcut to 20")				$9.70
Woods costs				
Group I - Direct operating costs, per M b.m.				
Felling and bucking	=	$1.90		
Ground skidding				
$7.03\left(\frac{8.7}{4}\right)$	=	.15		
Fixed cost	=	.42		
Roading				
$1.64\left(\frac{46.1}{4}\right)$	=	.19		
Fixed cost	=	.11		
Loading	=	.52		
Truck haul (9.5¢)(15 mi.)	=	1.42	$4.71	
Group II - Fixed per acre				
Cat roads $\frac{68,600}{42.5(12.1)8.7}$	=	.15		
Interior roads $\frac{300,000}{42.5(12.1)46.1}$	=	.13		
Main haul road $\frac{500,000¢ \text{ x } 10 \text{ mi.}}{935,000 \text{ M}}$	=	.05	.33	
Group III - Fixed per M				
Social security	=	.20		
Industrial insurance and medical aid	=	.07		
Supplies	=	1.00	1.27	
Group IV - Fixed per year				
Administration, engineer, etc.	=	.55		
Fire protection	=	.20		
Timber tax	=	.55		
Property tax	=	.20		
Income tax	=	.35		
Other tax	=	.12	1.97	8.28
Net to meet depreciation, interest, etc.				$1.42

Gross conversion $1.42

Depreciation per year (assuming that half of the equipment will last 5 yrs., one-fourth will last for 10 yrs., and one-fourth will last the life of the operation)

$$\$250{,}000\left(\frac{.06}{1.06^{5}-1}\right)=\$250{,}000\ (.1774)=\$44{,}400$$

$$\$125{,}000\left(\frac{.06}{1.06^{10}-1}\right)=\$125{,}000\ (.0759)=9{,}500$$

$$\$125{,}000\left(\frac{.06}{1.06^{23}-1}\right)=\$125{,}000\ (.0212)=2{,}650$$

Retirement of debt

$$\$1{,}000{,}000\left(\frac{.06}{1.06^{23}-1}\right)=\$1{,}000{,}000(.0212)=21{,}200$$

Interest on working capital, plant and equipment, and debt

$$\$2{,}000{,}000\ (.06)=180{,}000$$

Annual cost $257,750

Capital costs per M b.m. $\frac{\$257{,}750}{100{,}000\ M}$ 2.58

Loss per M b.m. $1.16

Because of the lower average market value of the cut, the hypothetical operation would lose money if it cut the low value hemlock. This justifies Company X's decision to cut only the highest present values out of their stands, which were similar to those dealt with here.

This example is typical of many problems that are best decided in the light of the dollar sign. The timber operator is primarily a businessman. The operating plan he will adopt is the one that means the most money in his pocket -- the greatest net income over the years. The approach just demonstrated gives a method of estimating such incomes. While the costs determined are averages, and cannot be applied to any specific portion of the property, they reflect fairly the relative values involved under the two plans. The comparative merit of the plans being considered is all that is wanted anyway. Obviously, this approach can be modified to aid in the decision of many major problems. We have applied it to alternative plans involving a marginal species. It could well be used to decide whether it would pay to shift from railroad to truck operation. It could be used to decide between a plan involving a light cut now but a heavier one later, and one involving a heavy current return with small hopes of ever returning.

This paper has been prepared to illustrate a method of approach to the problems that confront the logger in the northwest. It is frankly admitted that many of his problems have been only touched upon here; little more has been done than to point the way to a method of operations planning and of cost analysis which is applicable to his region. To completely cover the ground in these two phases of operation alone would take a paper twice the length of this one. To completely cover the field of cost interpretation and of the valuation of contrasting plans would take a book. But such determinations as have been described, if intelligently applied, are invaluable to the timber operator. Their use would take the function of planning out of the field of guess work and place it on an engineering basis. Experimentation with costs and methods would be reduced to a minimum.

It should be pointed out that a logging business cannot be run from an office desk, however. To be effective, the methods which have been described must be applied on the ground. Their use must be combined with logging experience and common sense if they are to work successfully. Granting accurate basic costs to start with, and common sense to temper the use of the values determined, an engineering approach like the one described should be an invaluable tool in the hands of the practical west coast logger. Granting that the values determined are used as guides rather than as definite figures to be rigidly adhered to, they should result in a more efficient, and a more remunerative, logging show.

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