THE PORTABLE SAWMILL IN FOREST MANAGEMENT

HERBERT O. FLEISCHER

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by Herbert O. Fleischer

University of Michigan
School of Forestry and Conservation
Ann Arbor

PREFACE

The primary purpose of this paper is to compare, on a financial basis, the portable sawmill with the customary type of stationary sawmill. This comparison has been worked out by applying actual cost figures to a hypothetical forest property.

Cost figures used here have been assembled from various sources and are not supposed to be typical of any single forest property; rather, they are average figures susceptible to much wider application than any specific figures for a single forest property might be.

The second part of the paper deals with the problem of portable mill moving. It attempts to analyze the economic principles which should form the basis for determining the frequency of mill moving in any given case.

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PART I

A Comparison of Costs and Profits under a Stationary and a Portable Mill Plan

INTRODUCTION

The Eastern Texas Land Company* owns a total of 129,280 acres of loblolly-shortleaf pine land bearing the following forest stands:

	Area, acres
Virgin timber	26,880
Culled areas	11,520
Second growth areas, 25 % restocked	38,912
Second growth areas, less than 25% restocked	26,368
Old field merchantable stands	14,848
Old field nonmerchantable	10,752
Total	129,280

A map of the total holdings and distribution of the types is shown on page 4.

* Hypothetical; basic data from D. M. Matthews, unpublished.

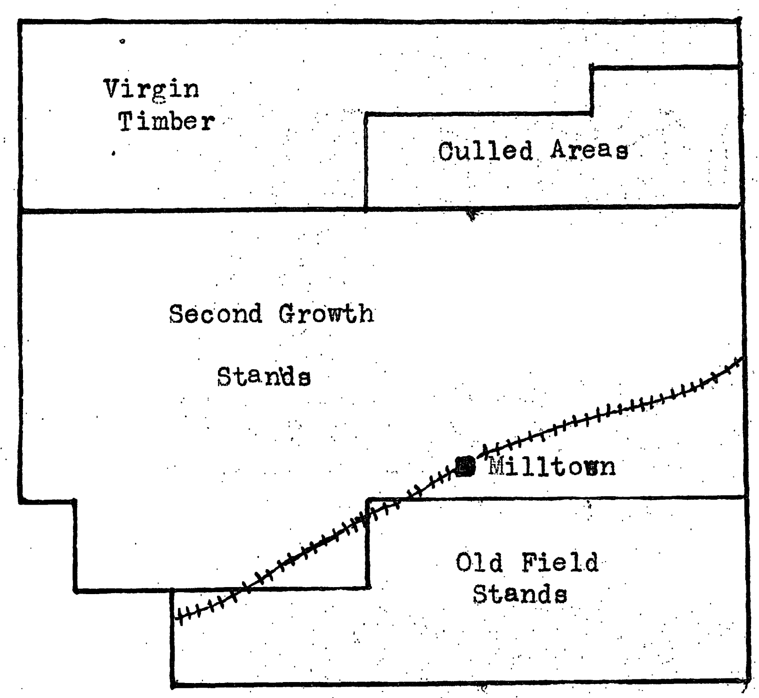

Figure 1. Map of the Lands of the Eastern Texas Land Company

Scale: 1 inch = 4 miles.

The Company proposes to exploit these lands under a sustained yield plan of management since the wide distribution of age classes and types seems to make this procedure practicable. A cruise has been made of the area and the information obtained in this way is to be used as the basis for a preliminary management plan for the entire property.

The question then arises as to what is the most profitable method of milling the output. It is possible to introduce a number of portable sawmill units to work in the woods, together with a concentration yard which is located at the village which is to be the headquarters of the Company. These sawmills and the accessory equipment will be of such design that the lumber produced will be of the same quality as that produced be a stationary mill. Alternatively, a large stationary mill can be located in the above-mentioned village. Log transportation is to be by truck.

The valuation of the forest property under the management plan finally adopted and the milling plan which seems most profitable will form the basis of the corporate organization which is proposed for the handling of the property.

THE SILVICULTURAL BASIS OF THE FOREST MANAGEMENT PLAN

Composition and character of the stands. Loblolly and shortleaf pine often make up the entire forest stand in eastern Texas, shortleaf predominating on the drier sites and loblolly on the moist sites. Minor associates, when present, include hawthorn, persimmon, black gum, post oak, red oak, and red gum. The forests exist as uneven-aged stands. In competing with each other neither of the pine species has a distinct advantage, since loblolly grows fast in youth but decreases in rapidity of growth as it grows older, whereas shortleaf increases but slowly in rate of growth but maintains its maximum growth rate to an old age. The composition of the forest, with regard to these two principal species, will therefore not change without human interferance. Under management, however, loblolly will be favored, since it puts on the most rapid growth at an early age. For our purposes the hardwoods may be disregarded, since they are few and of low quality; they will be cut for what they are worth, in the hope of eliminating them eventually.

Growth. Loblolly and shortleaf pine in the South are known to be fast-growing species adapted to sustained yield forest management. Growth data presented here for the area under consideration are for stands which are understocked; the growth rates are, however, not thought to be excessive. According to Reynolds* mature trees up to 24 inches in diameter can be grown in 70 years on good sites. Our data, presented in table 1, indicate that shortleaf pine up to 14 inches in diameter and loblolly up to 20 inches can be grown in 70 years.

R. Reynolds, unpublished.

Age	Average diameter growth in 10-year period, inches		Actual diameter, inches, at 10-year intervals	
	Loblolly	Shortleaf	Loblolly	Shortleaf
10	2.54	1.70	3.3	2.7
20	2.97	1.84	5.84	4.4
30	3.00	1.97	8.81	6.24
40	2.93	2.06	11.81	8.21
50	2.70	2.18	14.74	10.27
60	2.40	2.20	17.44	12.45
70	2.08	2.20	19.84	14.65
80	1.76	2.20	21.92	16.85
90	1.48	2.20	23.68	19.05
100	1.22	2.20	25.16	21.25
110	1.02	2.20	26.38	23.45
120	-	-	27.40	25.65

Table 1. Growth rates of loblolly and shortleaf pine at various ages, collected on the Company property.

Figure 2 is a graphic presentation of the data shown in table 1 and serves to correlate growth in a ten year period with diameter instead of with age.

The actual rate of growth in the forest can be maintained at any desired level by regulating the density of the stands. We shall seek to maintain the growth rate as given in table 1 by keeping the basal area at about 100 square feet per acre. Studies by Paul (6)

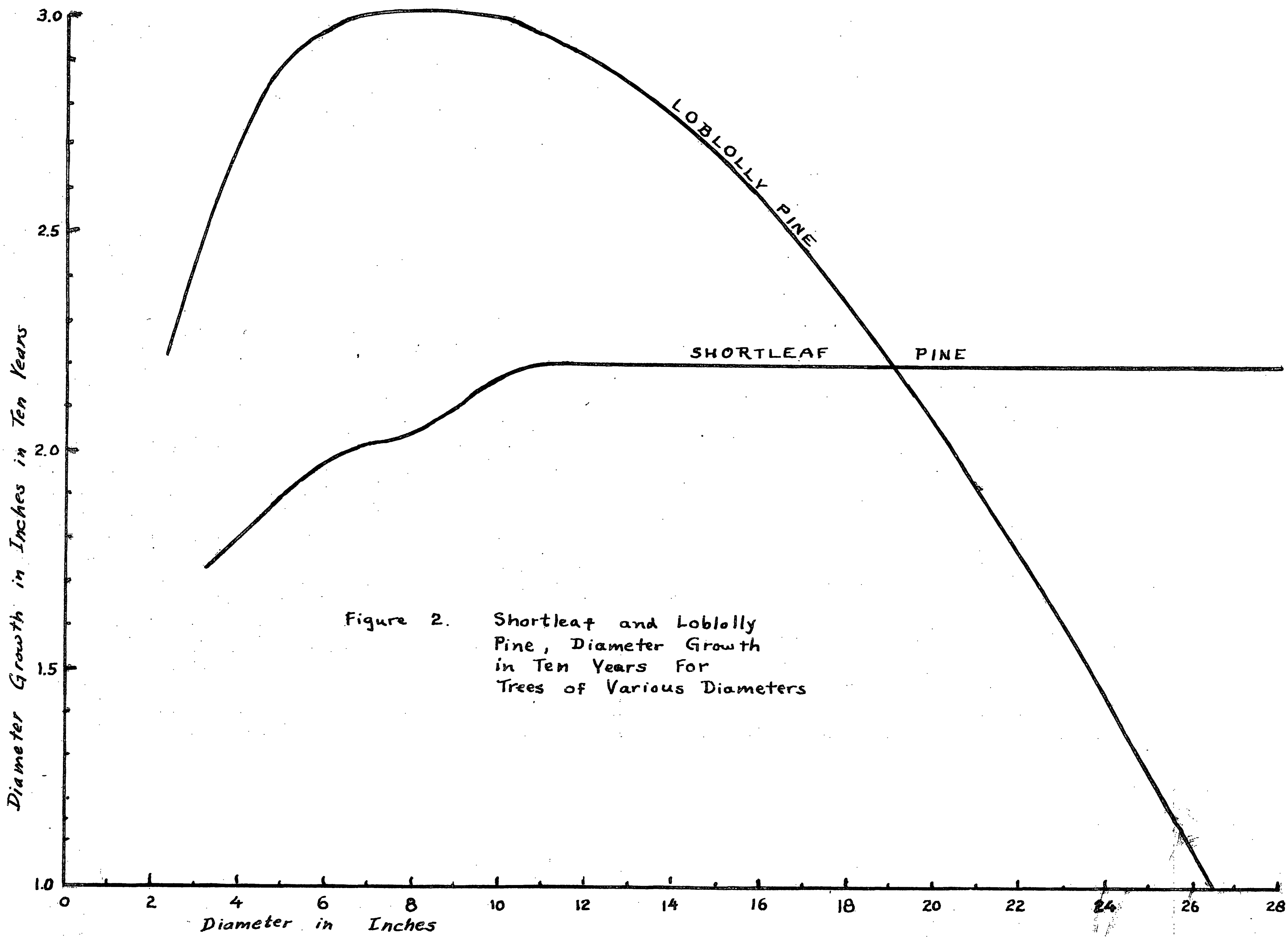

Figure 2. Shortleaf and Loblolly Pine, Diameter Growth in Ten Years For Trees of Various Diameters

indicate that this moderate rate of growth ~~is~~ sustained over a period of years will produce uniformly grained wood with a maximum amount of summerwood. This produces wood of high quality.

Tolerance. In any forest the character of the management plan will be profoundly influenced by the relative tolerances of the various species composing the forest stand. Chapman's (1) study on the recovery and growth of loblolly pine after suppression shows that suppressed trees will quickly recover and put on diameter growth at a rapid rate, although height growth is retarded. Trees $4\frac{1}{2}$ inches in diameter, suppressed 63 years, grew faster in diameter when released than trees never suppressed. In height growth they progressed only one half as fast as younger trees. Chapman concluded that diameter growth after release depends on the relative length of the surviving crown. Shortleaf pine is considerably more tolerant than loblolly.

In growth predictions, therefore, it is possible to deal with trees of ~~this~~ these species as though they had not been suppressed. This will be necessary in our problem with trees six inches and over in diameter, since we must try to bring them through the rotation as crop trees, or at least as thinning material, because of the present understocked condition of the stands. Suppressed trees four inches and less, however, are not regarded in the growth predictions, since faster growing young trees will undoubtedly replace them as crop trees within the present rotation.

Regeneration. Shortleaf pine is the most abundant reproducer in mixed stands, since it has unusual ability to grow under severe competition. Advanced reproduction of loblolly is likely to be confined to openings created in the stand. It becomes necessary, therefore, to make cuttings in such a way as to remove groups large enough to favor the loblolly pine.

Under ordinary management the procuring of reproduction need not be a problem. Both loblolly and shortleaf are good seed producers and both are not exacting in their seedbed requirements, although loblolly requires moister conditions than shortleaf. Because of their ability to coppice following a fire shortleaf and the hardwoods predominate after a fire.

Fire Protection. A system of fire protection will be part of the management plan of the forest. The problem is not great. Slash decomposes rapidly and presents no fire danger after three or four years. Lopping and scattering will reduce this by a year, but is not essential.

Other Injury. Both loblolly and shortleaf pines have deep taproots and are not subject to windfall. Diseases and insects are also not serious. Rot is present almost solely in trees damaged by fire and can therefore be eliminated. The southern pine beetle and the Nantucket tip moth are the only insects which will probably be encountered, both on loblolly and slash. Neither of them kills the trees, and need not cause great alarm. (8)

Mortality. Mortality due to all causes is taken together as an average figure and applied to the growth predictions. However, it is assumed that the mortality figure will be greatly reduced or even entirely eliminated from the stands after the first selective cutting has been made. For this reason growth predictions after cutting do not contain a deduction for mortality.

Table 2 shows the mortality percentages in a single year and for a ten year period. It is based on 555 plots taken in average shortleaf-loblolly stands.

Table 2. Mortality per cent in average shortleaf-loblolly pine stands *

Diameter Class	Mortality % in 1 year	Mortality % for 10-year period
2	.40	3.7
4	.34	3.0
6	.30	2.8
8	.27	2.6
10	.26	2.8
12	.28	3.3
14	.34	4.1
16	.43	5.0
18	.56	6.4
20	.72	8.2
22	.92	10.0
24	1.12	11.7
26	1.34	13.7
28	1.56	15.8
30	1.80	--

VOLUME TABLES

Volume tables were made for the property for each of the two pine species, and are of two types: for virgin stands; and for second-growth stands. The volumes given in the basic data were curved as shown in figure 3. Volumes were then reassembled into tabular form and are given in table 3. The International Rule was used.

In applying the volume tables weighted values were used where both species had been thrown together in the growth predictions. Virgin stands, after the first selective cutting, were treated as second growth.

* Source: D. M. Matthews.

Figure 3. Graphic volume table, showing board foot volumes (International Scale) of virgin and second growth loblolly and shortleaf pines.

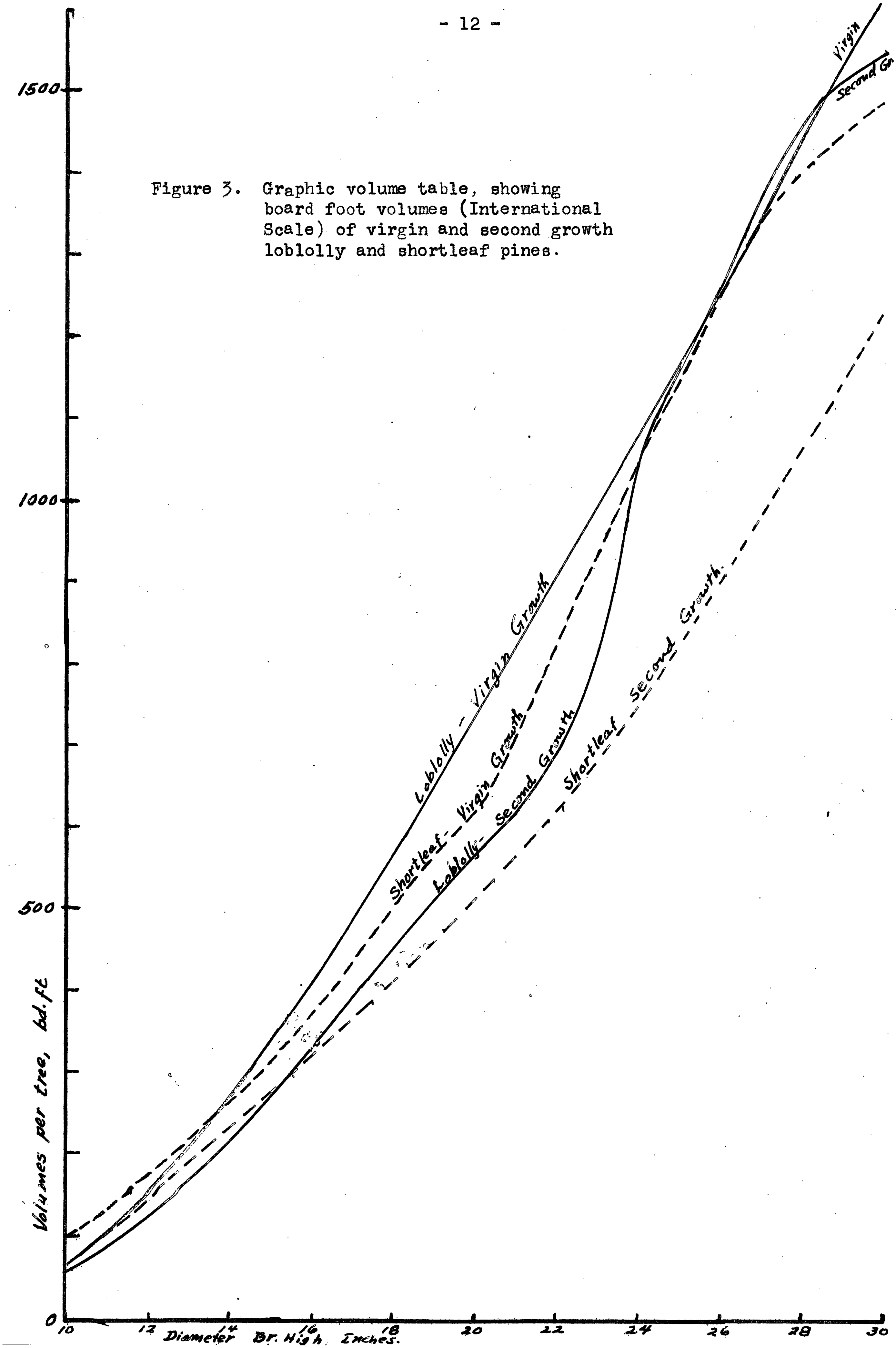

Table 3. Volume tables for the property, International Rule.

Diameter	Volumes in board feet			
	Loblolly		Shortleaf	
	Virgin	Second Gr.	Virgin	Second Gr.
10	74	62	100	73
12	160	125	176	148
14	275	217	263	234
16	415	327	374	323
18	569	452	500	415
20	731	564	623	515
22	912	685	792	625
24	1078	1050	1050	754
26	1248	1244	1245	907
28	1437	1455	1400	1055
30	--	1538	1600	1230

DETERMINATION OF THE PROFITABLE ROTATION

The probable most profitable diameter cutting limit, or the diameter which determines the rotation age, is derived by means of the calculation shown in table 3a. This is an attempt to apply approximate value figures to the stands under consideration in order to determine the value growth percent for the various diameters.

Columns 1 and two show present diameters and diameters in 10 years, after applying growth figures. Present and future volumes (the latter obtained from figure 3) are shown in columns 3 and 5. Values shown in columns 4 and 6 are taken from U. S. D. A. Tech. Bulletin 375, table 10, column 1. These values will naturally not apply directly to our operation, but will show relative trends and can therefore be used to compare values at various diameters.

Values in column 6, minus values in column 4, divided by 10, give the value growth per year, as shown in column 7. Value growth percent is then simply calculated by dividing the value growth (col. 7)

Table 3a. Preliminary calculation showing approximate growth percent used in deciding the probable most profitable cutting diameter limit * .

1 Present Diameter B. H.	2 Diam. 10 Years Hence	3 Present Volume per tree	4 Present Value per tree	5 Future Volume per tree	6 Future Value per tree	7 Value Growth per year	8 Value Growth per cent
1. Loblolly Pine							
14	16.76	217	.62	370	2.31	.169	27.2
16	18.56	327	1.77	480	3.79	.202	11.4
18	20.34	452	3.34	590	5.51	.217	6.5
20	22.06	564	5.12	690	7.29	.218	4.3
22	23.74	685	7.25	925	11.00	.375	5.2
24	25.44	1050	12.60	1200	15.40	.280	2.2
26	27.08	1244	16.40	1375	18.60	.220	1.3
2 Shortleaf Pine							
14	16.20	234	.67	330	1.83	.116	17.3
16	18.20	323	1.75	420	3.15	.140	8.0
18	20.20	415	3.07	525	4.78	.171	5.6
20	22.20	515	4.68	630	6.70	.202	4.3
22	24.20	625	6.62	760	9.10	.248	3.7
24	26.20	754	9.05	920	12.15	.310	3.4
26	28.20	907	11.92	1065	15.10	.318	2.7

* The stand data used in this table are for the second growth, more than 25 % restocked, areas (p. 26).

by the present value per tree; this figure is given in column 8, and represents the value growth percent per year, which will be maintained for a ten year period. The figures show, for example, that if we leave an 18-inch loblolly pine we shall obtain an average value growth of 6.5% over the following ten-year period; while if we leave a 20-inch loblolly we shall obtain a growth of only 4.3%. It is likely, then, that with a ten-year cutting cycle we shall not want to leave trees over 18 inches, since the actual return from leaving them is low.

By referring to table 1 we see that loblolly grows to 19.84 inches in 70 years, shortleaf to 14.65 inches. Therefore we choose a 70-year rotation, with a ten-year cutting cycle.

STAND PREDICTION

Reynold's Method* of applying growth data in the prediction of future stands was used. In all cases predictions were made by ten-year periods. Two-inch diameter classes were used throughout in the calculations. Stands were classified according to the basal area control method into ten-year age classes, on a 70-year rotation. (5)

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* R. Reynolds, unpublished.

THE FOREST STANDS AND THE PRESENT AND FUTURE CUTS

Virgin stands cover an area of 26,880 acres, located at some distance from the Milltown. Since these stands carry the greatest merchantable volume they must support the main cutting operations for the first cutting cycle. On all other stands the merchantable volume is at present so low that cutting operations would not be justified. Furthermore, the virgin stands have a high representation of shortleaf pine and hardwoods; rapidly running over this area during the first cutting cycle would make it possible to improve the condition of the stands and increase the representation of loblolly at once.

If the virgin stands are to support the entire mill output for the first ten years of operation the cut must be fairly heavy. If the stand is classified by the basal area control method, on the basis of a 70-year rotation and a 10-year cutting cycle, the cut received by taking the oldest age class will not be sufficient. If, however, the two oldest age classes are taken, the cut will go down to 16 inches (table 4). This will leave trees 14 inches and up on the ground; the plan then is to return to this area in twenty years instead of ten for the second cut.

The present cut per acre under this plan is as follows:

Loblolly pine, 16" - 28"	4257 bd. ft.
Shortleaf pine, 16" - 28"	3660 bd. ft.
Total	7917 bd. ft.
Reduced 10 % for defect	7125 bd. ft.

This cut will cover annually an area of 2, 688 acres and will therefore yield an annual total cut of 19,152 M bd. ft. for the period. The cut is shown in detail in table 5.

Table 4. Stand table, average acre, shortleaf-loblolly virgin stand.

Diameter Class	Loblolly Pine			Shortleaf Pine			Hardwood		Dead Pine	Longleaf Pine	
	Main Stand	Sup. Stand	Total Volume	Main Stand	Sup. Stand	Total Volume	Main Stand	Sup. Stand		Main Stand	Sup. Stand
2	1.45	2.00		5.45	4.36		7.45	13.45		.18	.73
4	.18	.55		4.91	3.27		6.73	8.36		.73	1.82
6	.73	.91		6.91	3.09		4.36	5.27			.18
8	.55			6.18	.73		7.09	1.45	.18	.18	
10	1.09		81	7.64		764	3.82				
12	1.45		232	7.09		1248	1.45			.36	
14	2.91		800	2.91		774	1.64				
16	2.36		979	2.55	.18	954	.91	.18			
18	1.27		723	1.64		841	1.09				
20	.55		402	.73		491	1.27				
22	.18		164	.36		310	.18				
24	.73		786	.55		578	.18				
26	.55		686	.18		224	.18				
28	.36		517	.18		262			.18		
Total	14.36	3.46	5370	47.28	11.63	6446	36.35	28.71	.36	1.45	2.73

Total Pine Volume, 11,816 Bd. ft, reduced 10% = 10,634 bd. ft.

Assessed value, $30 per acre.
Total area, 26,880 acres
Total assessed value, $806,400

Table 5. Stand 1, virgin timber. Table showing the average cut per acre during the first ten years of operation.

Diam. Inches	Number of trees to be cut			Total B. A.	Volume, bd. ft., cut per acre		
	Lobl.	Shortl.	Total		Lobl.	Shortl.	Total
16	2.36	2.55	4.91	6.89	979	954	1933
18	1.27	1.64	2.91	5.15	723	841	1564
20	.55	.73	1.28	2.79	402	491	893
22	.18	.36	.54	1.42	164	310	474
24	.73	.55	1.28	4.02	786	578	1364
26	.55	.18	.73	2.69	686	224	910
28	.36	.18	.54	3.31	517	262	779
Total	6.00	6.19	12.19	26.27	4257	3660	7917

Total average cut per acre, 7917 ft., - 10% for defect = 7125 bd. ft.

The effect of making a heavy cut in the virgin stands will be seen after the stand has been predicted forward twenty years, as shown in table 6. In this prediction longleaf pine is thrown together with loblolly, since the two have similar growth habits. The growth rate used is that for a twenty year period, figured by interpolation from the growth curves in figure 2. The growth rates for the two main species of trees were then weighted according to the representation of each.

We find that even though we have cut to a diameter of 14 inches we again have 20-inch trees after 20 years. The stand can then be classified, as in table 7, in order to determine the oldest age class on the 70-10 plan. Of a total volume of 10,810 bd. ft. per acre we can cut the oldest age class, or 3,050 bd. ft.

The cut is as follows:

4.13 trees 18" in diam. ...... 1760 bd. ft.

2.33 trees 20" in diam.. ..... 1290 bd. ft.

Total cut per acre . . . . 3050 bd. ft.

Minus 10 % for defect . . . . 2745 bd. ft.

On 2,688 acres the annual cut from the twentieth year and on will therefore be 7,373 M. bd. ft. This cut is assumed to go on forever, although it is a conservative estimate, since the volume will increase as the condition of the stands improves and defect is eliminated.

Table 6. Prediction of the virgin stand, 20 years after cut

Diameter Class	Original Number of Trees			Weighted Growth Rate	Number in 20 yrs	B. A. sq. ft. in 20 yrs	Volume bd. ft. in 20 yrs
	Loblolly & Longl.	Shortleaf	Total				
2	1.63	5.45	7.08	2.03	N O	D A T A	--
4	.91	4.91	5.82	2.00	N O	D A T A	--
6	.73	6.91	7.64	2.15	6.87	.96	--
8	.73	6.18	6.91	2.20	6.03	1.63	--
10	1.09	7.64	8.73	2.29	6.49	3.56	600
12	1.81	7.09	8.90	2.32	6.68	5.27	1010
14	2.91	2.91	5.82	2.40	7.58	8.11	1850
16					8.58	12.02	3050
18					6.34	1121	3010
20					2.33	5.09	1290
Totals	9.81	41.09	50.90		50.90	47.85	10810

Table 7. Classification of stand from table 6.

Age group	B. A. % Distribution	Actual B. A. Sq. Ft.	Diameter Range, inches	Volume, Bd. Ft.
0 - 30	N O	D A T A		
31 - 40	23.5	11.24	6 - 14	2335
41 - 50	25.0	11.96	14-- 16	2,650
51 - 60	25.6	12.24	16 - 18	2,775
61 - 70	25,9	12.41	18 - 20	3,050
Totals	100 %	47.85		10,810

Culled stands cover an area of 11,520 acres; they are located near the virgin stands and will be cut immediately after the first ten-year cutting period in the virgin timber is completed. The present stand is shown in table 8. The stand is predicted forward for ten years, as shown in table 9, and classified as in table 10. The oldest age group shown in table 10 will be cut at this time. The residual stand is then again predicted forward ten years in table 11, and classified in table 12. The cut taken from the oldest age group in table 12 is assumed to go on forever, beginning in 20 years.

The cut beginning in ten years will take 2.45 trees from the 18 inch diameter class, table 9, and all trees above this diameter, and will yield a total volume of 3,704 bd. ft. per acre; allowing 10 % for defect the net yield is 3334 bd. ft., cut annually on 1,152 acres, giving an average annual cut of 3,840 M bd. ft. for ten years.

The cut beginning in twenty years takes 4.85 trees from the 18 inch class, table 11, and all trees above this diameter, and yields 3,702 bd. ft. per acre. Without deducting for defect, since we hope to have eliminated a great part of it by this time, we get an average annual yield of 4,270 M.bd. ft. from the area.

Table 8. Stand table, average acre of culled shortleaf-loblolly stands.

Diameter Class	Loblolly Pine			Shortleaf Pine			Hardwood		Dead Pine
	Main	Sup.	Volume	Main	Sup.	Volume	Main	Sup.	
2	3.56	.44		8.89	5.78		19.56	12.44	
4	1.33	.89		8.00	5.33		24.00	7.11	
6	4.89			10.22	3.11		15.11	3.11	.89
8	3.56			5.78	.44		4.44	.44	
10	2.67		198	6.22		622	6.22		
12	1.78		285	5.78		1017	4.00		
14	3.56		979	3.56		974	2.22		
16	.89		369	2.67		999	1.33		
18				.89		457	.44		
20				.44		296			
22							.44		
24				.44		462			
26				.44		584			
Total	22.24	1.33	1831	53.33	14.66	5348	77.76	23.10	.89

Total pine volume, 7179, reduced 10% for defect, = 6461 bd. ft.

Assessed value, $18 per acre.
Total area, 11,520 acres.
Total value of stands, as assessed: $207,360

Table 9. Culled Stands, composition in 10 years.

Diam.	Present Number		Number in 10 years *			B. A.	Volume in 10 years		
	Lobl.	Short.	Lobl.	Short.	Total	Sq. Ft	Lobl.	Short.	Total
2	3.56	8.89	2.30	1.57	3.87	.08			
4	1.33	8.00	2.06	7.79	9.85	.89			
6	4.89	13.33	.83	7.23	8.06	1.13			
8	3.56	6.22	2.91	12.70	15.61	4.11			
10	2.67	6.22	4.05	5.94	9.99	6.59	302	594	896
12	1.78	5.78	3.07	5.69	8.76	6.92	491	1000	1491
14	3.56	3.56	2.22	5.52	7.74	8.28	614	1452	2066
16	.89	2.67	2.87	3.59	6.46	9.04	1191	1342	2533
18		.89	1.92	2.36	4.28	7.58	1092	1180	2272
20		.44	.24	1.01	1.25	2.72	180	630	810
22				.49	.49	1.29		388	388
24		.44		.04	.04	.13		42	42
26		.44		.40	.40	1.47		498	498
28				.43	.43	1.84		602	602
30				.04	.04	.20		64	64
Total	22.24	56.88	22.47	54.80	77.27	52.27	3870	7792	11662

* After deducting mortality

Table 10. Classified stand per acre, culled areas in 10 years.

Age Group	B. A. % Distrib.	Actual B. A.	Number of Trees	Diam. Range, In.	Volume Bd. Ft.
0 - 20		N O	D A T A		
21 - 30	17.5	9.15	41.85	2 - 10	--
31 - 40	19.4	10.13	13.73	10 - 12	300
41 - 50	20.6	10.77	9.77	12 - 16	1240
51 - 60	21.1	11.03	6.82	16 - 18	6418
61 - 70	21.4	11.19	5.10	18 - 30	3704
Total	100	52.27	77.27		11662

Table 11. Culled Stands, composition in 20 years

Diameter Class	Number of Trees in	Basal Area Sq. Ft.	Volume per Tree	Total Volume
2	.70			
4	3.17	.30		
6	9.85	1.38		
8	7.66	2.07		
10	14.45	7.95	68	541
12	9.16	7.24	140	1282
14	9.66	10.34	228	2205
16	7.66	10.87	325	2520
18	6.77	11.99	430	2905
20	2.73	5.95	530	1448
22	.26	.69	650	169
Total	72.17	58.78		11070

Table 12. Classified stand per acre, culled areas in 20 years

Age Group	B. A. % Distrib.	Actual B. A.	Number of Trees	Diameter Range	Volume Bd. Ft.
0 - 30		N O	D A	T A	
31 - 40	23.5	13.81	38.51	2 - 12	915
41 - 50	25.0	14.69	15.42	12 - 14	2908
51 - 60	25.6	15.06	10.40	14 - 18	3545
61 - 70	25.9	15.22	7.84	18 - 22	3702
Total	100 %	58.78	72.17		11070

Second growth stands are treated in two groups, those with a stocking of 25 % or over, and those with less than 25% stocking.

Second growth areas with a stocking of 25 % or over cover an area of 38,912 acres. Their composition is shown in table 13. At present the total merchantable volume per acre is 6674 bd. ft. Since this is, however, scattered among areas which are less heavily stocked, it is not practibable to log the area at the present time. The stand is therefore predicted forward 10 years in table 14, and a total merchantable volume of 16,225 bd. ft. per acre is obtained at that time. The oldest age class as shown in table 15 will yield a cut of 5,495 bd. ft. per acre beginning in ten years; minus 10 % for defect leaves a net cut of 4,946 bd. ft.

In table 16 the residual stand is predicted forward another ten years, and the cut to be obtained for the cycle beginning in twenty years is shown in the classified stand table, table 17, to be 7,145 bd. ft. In this case there will be no deduction for defect.

The total cut from the area will therefore be:

for the cycle beginning in ten years: 4,946 ft. x 3,891 acres :

19,245 M bd. ft. per year

for the cycle beginning in twenty years: 7145 ft. x 3891 acres :

27,801 M bd. ft. per year

Table 13. Stand table, Average acre of shortleaf-loblolly second growth, more than 25 % stocking.

Diameter Class	Shortleaf Pine			Loblolly Pine			Hardwood		Dead Pine
	Main Stand	Sup. Stand	Total Volume	Main Stand	Sup. Stand	Total Volume	Main Stand	Sup. Stand	
2	0.90	12.00		2.71	23.10		11.87	21.94	
4	4.39	12.77		10.19	7.74		3.48	9.42	.39
6	11.74	8.90		16.77	5.03		10.45	5.94	.26
8	12.00	1.03		11.61	1.42		6.58	.65	.26
10	8.13	.26	626	11.74	.65	728	4.52	.13	.26
12	5.16		764	11.87		1484	2.71	.13	
14	1.03		238	6.19		1343	1.42		.13
16	.39		126	2.58		844	.52		
18	.39		162	.90		407	.77		.13
20	.13		67	.39		220	.39		
22				.13		89	.26		
24							.26		
26	.13		118				.13		
28							.13		
30				.13		200			.13
Total	44.39	34.96	2101	75.21	37.94	5315	43.49	38.21	1.56

Total pine volume, 7416 bd. ft., reduced 10 % for defect, = 6674 bd. ft.

Assessed value, $15 per acre.
Total Area, 38,912 acres.
Total assessed value for stands, $583,680

Table 14. Second growth, 25 % and over stocking, 10-year prediction.

Diam.	Present No.		No. after 10 years			B. A.	Volume in 10 years		
	Lobl.	Sh.	Lobl.	Sh.	Total	sq. ft	Lobl.	Sh.	Total
2	2.71	0.90		.16	.16	0			
4	10.19	4.39	1.65	1.16	2.81	.25			
6	21.80	20.64	7.38	4.17	11.55	1.62			
8	13.03	13.03	13.42	15.50	28.92	7.80			
10	12.39	8.39	15.30	12.10	27.40	15.08	950	880	1830
12	11.87	5.16	12.20	7.65	19.85	15.70	1525	1130	2655
14	6.19	1.03	12.00	5.09	17.09	18.30	2725	1189	3914
16	2.58	.39	7.75	1.39	10.14	14.20	2860	449	3309
18	.90	.39	3.95	.42	4.37	7.75	1785	174	1959
20	.39	.13	1.34	.36	1.70	3.71	756	186	942
22	.13		.50	.14	.64	1.69	342	875	1217
24			.10	.01	.11	.35	105	8	113
26		.13							
28				.10	.10	.43		105	105
30	.13		.11	.01	.12	.59	169	12	181
Total	82.31	54.58	76.70	48.26	124.96	87.47	11217	5008	16225

Table 15. Classified stand table for table 14.

Age Group	B. A. % Distr.	Actual B A.	Number of Trees	Diameter Range	Volume Bd. Ft.
0 - 20	N	O	D A	T A	
21 - 30	17.5	15.30	53.66	2 - 10	680
31 - 40	19.4	16.97	26.70	10 - 12	2425
41 - 50	20.6	18.02	19.52	12 - 14	3569
51 - 60	21.1	18.46	15.04	14 - 16	4056
61 - 70	21.4	18.72	10.04	16 - 30	5495
Total	100 %	87.47	124.96		16225

Table 16. Second growth, ≠ 25 % and over stocking, 20-year prediction

Diameter Inches	Number of Trees in 20 Years	B. A. Sq. Ft.	Volume per Tree, weighted	Total Volume
2	.03			
4	.13	.01		
6	2.25	.31		
8	8.06	2.18		
10	25.73	14.17	65	1670
12	26.42	20.90	135	3575
14	21.12	22.60	225	4750
16	18.92	25.50	325	6150
18	10.47	18.52	450	4710
20	1.79	3.91	564	1090
Total	114.92	108.10		21945

Table 17. Classified stand table for table 16

Age Group	B. A. % Distrib.	Actual B. A.	Number of Trees	Diameter Range	Volume Bd. Ft.
0 - 30	N	O	D	A T	A
31 - 40	23.5	25.4	47.22	2 - 12	3165
41 - 50	25.0	27.0	29.23	12 - 14	5190
51 - 60	25.6	27.7	22.07	14 - 16	6445
61 - 70	25.9	28.0	16.40	16 - 20	7145
Total	100 %	108.1	114.92		21945

Second growth stands with a stocking of less than 25 % cover an area of 26,368 acres. Table 18 gives the composition of the stands and shows that the merchantable volume amounts to only 2967 bd. ft. per acre, most of this being concentrated in trees of low diameter. After ten years, however, the stand advances as shown in table 19 to a total volume of 6303 bd. ft per acre. After classifying the stand in table 20 we find that the volume to be taken in the oldest age class amounts to 2078 bd. ft.; deducting 10 % for defect we get 1870 bd. ft. merchantable volume per acre. The annual cut covers 2637 acres, so that the total average annual volume cut from these stands will be 4,931 M bd. ft.

Table 21 shows the residual stand after it has been predicted forward another ten years. When this stand is classified in table 22 we obtain an average cut, in the oldest age class, of 3131 bd. ft. per acre. On 2,637 acres this amounts to a total of 8,250 M bd. ft. average annual cut beginning in twenty years.

Table 18. Stand table, average acre of shortleaf-loblolly second growth, less than 25 % stocking.

Diameter Class	Loblolly Pine Main Stand	Loblolly Pine Sup. Stand	Loblolly Pine Total Volume	Shortleaf Pine Main Stand	Shortleaf Pine Sup. Stand	Shortleaf Pine Total Volume	Hardwoods Main Stand	Hardwoods Supr. Stand	Dead Pine
2	9.98	12.74		6.27	7.31		16.00	16.54	.44
4	7.36	3.60		3.11	1.78		3.15	4.05	.10
6	9.09	1.33		4.25	1.43		10.96	2.62	.05
8	4.94	.35		3.11	.35		5.98	.89	.10
10	4.25	.05	264	2.81	.10	216	4.54	.25	
12	5.14		642	2.32		343	4.15	.35	.10
14	2.37		514	.74		171	2.62	.20	.10
16	1.23		402	.10		32	1.63	.15	
18	.79		357	.25		104	1.19	.05	
20	.40		226	.05		26	.25		
22							.05		
24							.25		
26							.10		
28									
30							.10		
Total	45.55	18.07	2405	23.01	10.97	892	55.97	25.10	.89

Total pine volume, 3297 bd. ft., reduced 10 % for defect = 2967 bd. ft.

Assessed value per acre, $8
Total area, 26,368 acres
Total assessed value = $210,944

Table 19. Second growth stands, less than 25 % stocking. Composition in ten years.

Diam. Inches	Present No.		No. after 10 Years			B. A.	Volume in 10 Years		
	Lobl.	Sh.	Lobl.	Sh.	Total		Lobl.	Sh.	Total
.2	9.98	6.27		1.11	1.11	.02			
4	7.36	3.11	6.50	5.26	11.76	1.06			
6	10.42	5.68	7.59	2.84	10.43	1.46			
8	5.29	3.46	7.76	5.42	13.18	3.56			
10	4.30	2.91	7.45	3.30	10.75	5.91	452	240	692
12	5.14	2.32	4.67	2.62	7.29	5.75	584	388	972
14	2.37	.74	4.81	2.22	7.03	7.53	1045	520	1565
16	1.23	.10	3.61	.09	3.70	5.18	1180	32	1212
18	.79	.25	1.66	.15	1.81	3.20	750	62	812
20	.40	.05	.94	.22	1.16	2.53	530	113	643
22			.37	.06	.43	1.13	254	37	291
24			.11		.11	.35	116		116
Total	47.28	24.89	45.47	23.29	68.76	37.68	4911	1392	6303

Table 20 Second growth stands, less than 25 % stocking. Classified stand table for stand in 10 years.

Age Group	B. A. % Distrib.	Actual B. A.	Number of Trees	Diameter Range	Volume Bd. Ft.
0 - 20					
21 - 30	17.5	6.59	37.37	2 - 10	68
31 - 40	19.4	7.31	12.26	10 - 12	943
41 - 50	20.6	7.76	8.53	12 - 14	1463
51 - 60	21.1	7.95	6.48	14 - 16	1751
61 - 70	21.4	8.07	4.12	16 - 24	2078
Total	100 %	37.68	68.76		6303

Table 21. Second growth, less than 25 % stocking, composition after predicting 20 years forward.

Diameter Inches	Number of Trees, 20 yrs.	B. A. Sq. Ft.	Volume per Tree, weighted	Total Volume
2	.20			
4	.91	0.08		
6	10.41	1.46		
8	8.64	2.33		
10	12.36	6.80	65	804
12	10.41	8.22	130	1355
14	9.40	10.07	220	2070
16	7.11	9.95	325	2310
18	4.33	7.65	450	1945
20	.87	1.90	564	491
Total	64.64	48.46		8975

Table 22. Second growth, less than 25 % stocking, classified stand table after predicting 20 years forward.

Age Group	B. A. % Distribut.	Actual B. A.	Number of Trees	Diameter Range	Volume Bd. Ft.
0 - 30					
31 - 40	23.5	11.39	33.43	2 - 12	919
41 - 50	25.0	12.12	13.85	12 - 14	2195
51 - 60	25.6	12.40	10.02	14 - 16	2730
61 - 70	25.9	12.55	7.34	16 - 20	3131
Total	100 %	48.46	64.64		8975

Old field stands exist in two age groups, the old field merchantable stands and the unmerchantable stands. The old field merchantable stands, the composition of which is shown in table 23, cover an area of 14,848 acres; the unmerchantable stands, of which there exist 10,752 acres, have a composition as shown in table 30. Most of the trees in the unmerchantable classes are less than six inches in diameter, hence only about 20 years old (table 1). Therefore they will not reach the status of crop trees for another 50 years. They are therefore disregarded in the growth predictions, which do not go beyond 30 years.

In the following treatment of the merchantable stands the trees are predicted ahead on a per acre basis as given in the original field data, but must later be prorated over the entire area of old field stands, since they exist in a scattered condition throughout the area, and all improvements, such as roads, must pass through areas of unmerchantable as well as merchantable timber.

In table 24 the old field merchantable stands, as shown in the previous table, are predicted forward ten years, after which time the oldest age class, as shown in the classified stand table, table 25, will be cut. The volume tobe cut in this class is 5,958 bd. ft., which after deducting 10 % for defect gives a net yield of 5,362 bd. ft. This volume is cut from 1485 acres annually for a period of ten years; hence the total annual yield will be 7,962 M bd. ft. for this area. When this volume is in turn prorated over the entire area of 25,600 acres of old field stands, the average yield per acre is only 3,110 bd. ft.

Table 23. Stand table, average acre of old field stands.

D. B. H Class	Loblolly Pine Main Stand	Sup. Stand	Total Volume	Shortleaf Pine Main Stand	Supr. Stand	Total Volume	Hardwood Main Stand	Supr. Stand	Dead Pine
2	.67	1.67			4.00		.33	5.00	
4	1.00	8.33		2.33	4.33		1.33	3.67	.67
6	20.00	15.33		10.33	7.00		2.00	3.00	.33
8	38.00	2.00		12.33	1.67		2.33	.33	.33
10	28.67	.33	1778	6.33	.33	4.87	.67		
12	17.00		2125	2.33		345	.33		
14	8.67		1881	.33		76			
16	1.67		546						
18	.67		303						
20	.33		186						
22	.33		224						
Total	117.01	27.66	7043	33.98	17.33	908	6.99	12.00	1.33

Total pine volume, 7951 bd. ft., reduced 10% for defect, = 7156 bd. ft.

Assessed value, $20 per acre
Total area, 14,848 acres
Total assessed value, $296,960

Table 24. Olf field merchantable stands, composition in ten years.

Diam. Inches	Present No. Lobl.	Present No. Sh.	No. after ten years Lobl.	No. after ten years Sh.	No. after ten years Total	B. A.	Volume in ten years Lobl.	Volume in ten years Sh.	Volume in ten years Total
2	.67	2.33		.41	.41				
4	1.00	13.85	.46	3.29	3.75	.34			
6	27.67	13.66	.83	12.28	13.11	1.84			
8	39.00	6.50	14.35	13.01	27.36	7.38			
10	28.83	2.33	31.80	6.19	37.99	20.90	1970	450	2420
12	17.00	.33	33.15	2.19	35.34	27.90	4150	324	4474
14	8.67		22.60	.47	23.07	24.65	4900	110	5010
16	1.67		12.38	.03	12.41	17.40	4050	30	4080
18	.67		4.21		4.21	7.45	1905		1905
20	.33		.95		.95	2.07	535		535
22	.33		.42		.42	1.11	288		288
24			.30		.30	.93	315		315
Total	125.84	39.00	121.45	37.87	159.32	111.97	18113	914	19027

Table 25. Old field merchantable stands in ten years, classified.

Age Group	B A. % Distrib.	Actual B. A.	Number of Trees	Diameter Range	Volume Bd. Ft.
0 - 20	N O		D A T A		
21 - 30	17.5	19.60	62.89	2 - 10	1160
31 - 40	19.4	21.71	32.90	10 - 12	2924
41 - 50	20.6	23.07	27.82	12 - 14	4040
51 - 60	21.1	23.62	20.96	14 - 16	4945
61 - 70	21.4	23.97	14.75	16 - 24	5958
Total	100 %	111.97	159.32		19027

At this point we run into our first problem of making thinnings in order to keep the stands at a reasonably rapid rate of growth. In table 25 we see that the merchantable stands have accumulated a fairly high basal area of 111.97 ft. Of this 23.97 ft. is removed in cutting the crop trees, leaving 88.0 ft. on the ground. If the supposed rate of growth would be continued in stands of this density we could expect, after ten years, a total basal area of 140.43 ft. per acre. However, we know that the growth rate would be considerably retarded in stands of this density, and that it is therefore necessary to make thinnings.

After we shall have predicted the stand ahead a second ten years our data will contain only trees in the four oldest age classes. We assume that if we have a basal area of about 90 ft. in these four classes we shall be able to get the desired growth. A simple proportion will therefore give us the desired basal area figure to which we must thin our stand before the final prediction: Present actual basal area is to the future basal area as x (the present basal area after thinning) is to the ~~present~~ future basal area desired, or

$$\frac{88}{140} = \frac{x}{90}$$, and x is 56.5 ft. of basal area.

Table 26 shows the calculation necessary to apply this figure. In the third column the desired basal area of 56.5 ft. is distributed according to the weighted percentages of basal area to be obtained in each age class in order to have a perfect distribution of trees. The number of trees required to make up this basal area is then determined, as given in the fourth column. This number, when subtracted from the actual number of trees in each class as shown in table 25, gives the number of trees to be taken from each class in thinnings. In table 27 these trees are distributed by diameters.

Table 26. Number of trees to be taken in thinnings, olf field merchantable stands, after first ten-year prediction.

Age Group	B. A. % Distribution	Desired B. A. Actual Sq. Ft.	No. of Trees Desired, Total	No. of Trees to remove in Thinnings
0 - 20	N O	D A	T A	
21 - 30	22.2	12.5	40.1	22.79
31 - 40	24.6	13.9	21.1	11.80
41 - 50	26.1	14.8	17.4	10.42
51 - 60	27.1	15.3	13.6	7.36
61 - 70	R E M O V E D	A S	C R O P	T R E E S

Table 27. Diameter distribution of the trees to be taken in thinnings, old field merchantable stands, after first ten-year prediction.

Diameter	Number before Thinning	Number taken in Thinning	Volume taken in Thinning	Number after Thinning
2	.41	.15		.26
4	3.75	1.36		2.39
6	13.11	4.75		8.36
8	27.36	9.90		17.46
10	37.99	13.71	996	24.28
12	35.34	13.02	1930	22.32
14	23.07	9.48	2220	13.59
16	3.54	--	--	3.54
Total	144.57	52.37	5146	92.20

Naturally the trees to be taken in thinnings will consist mostly of shortleaf pine. By removal of these trees the stands will be improved and the rate of growth, in general, improved. The volume removed in thinnings, 5146, is an impressive figure, yet the trees making up this volume are all in the low diameter classes; it is improbable, therefore, that the revenue received from them will be very great. In our future calculations we shall disregard this volume, on the assumption that the thinnings will just about pay their own way, or that if any excess revenue is received from them it will be used in other stand improvement work. This method of handling the thinning problem is considered to be conservative, for the expense of taking these trees at the time when the crop trees are removed will not be great, yet the improvement in the quality and quantity of the growth resulting from the operation will tend to make all future incomes from this area rise.

The residual stand after thinning is predicted forward another ten years in table 28, and classified in table 29. The volume taken in crop trees during the cutting period starting in twenty years will be 5,919 bd. ft. per acre. There will be no deduction for defect in these trees because of the stand improvement work. On 1485 acres the annual cut will be 8,790 M bd. ft.

A thinning operation will again accompany the removal of the crop trees.

Table 28. Old field merchantable stands, composition in 20 years.

Diam. Inches	Number of Trees	B. A. Sq. Ft.	Volume per Tree	Total Volume
2	.05			
4	.21	.02		
6	2.39	.34		
8	6.27	1.69		
10	12.57	6.91	62	778
12	19.36	15.28	125	2420
14	24.18	26.15	217	5240
16	18.47	25.85	327	6040
18	7.71	13.63	452	3485
20	.99	2.16	564	558
Total	93.20	92.03		18521

Table 29. Old field merchantable stands, in 20 years, classified.

Age Group	B. A. % Distrib.	Actual B. A.	Number of Trees	Diameter Range	Volume Bd. Ft.
0 - 30	N	O	D A	T A	
31 - 40	23.5	21.61	37.52	2 - 12	2781
41 - 50	25.0	23.00	22.11	12 - 14	4487
51 - 60	25.6	23.60	18.13	14 - 16	5334
61 - 70	25.9	23.82	14.44	16 - 20	5919
Total	100 %	92.03	92.20		18521

Table 30

////////

Assessedd value, $3.00 per acre.
Total area, 10,752 acres
Total assessed value, $32,256

SUMMARY OF CUTTING YIELDS FOR THE VARIOUS CYCLES

Since this report does not attempt to be a detailed management plan, but rather a simplified statement of the probable future timber and financial yield available from the property, a simple summary of the average composition and yield per acre for each of the ten-year cutting cycles is considered sufficient. During the first ten years of operation we shall be working only in the virgin stands, which are treated earlier in this report, and summarized in table 5, page 18.

During the second ten years of operation we shall not be operating in the virgin area, but shall cover all other areas in our logging operations. The old-field unmerchantable stands, although yielding no volume, must be included in the area to be covered, since they are scattered among merchantable timber. The total acreage to be covered annually will therefore be 10,240 acres. The average stand per acre, for the entire area to be covered, is shown in table 31. The table first shows the actual average number of trees per acre in the various stands to be covered, taken from previous tables; then these numbers are weighted in accordance with the percentage of total area occupied by each of the forest types. The total of this last set of figures, for the various diameters, gives the total number of trees, as an average for the entire area to be covered during the second cycle. Table 32 then summarized the average annual cut from each of the stands during the cycle, and gives the total annual cut, which amounts to 35,978 M bd. ft. When this figure is divided by the total acreage covered annually the average cut per acre is determined to be 3514.5 bd. ft. The distribution of this volume through the various diameter classes is given in table 33.

Table 31. Composition of the average cut per acre for total acreage covered during the second cutting cycle.

Diameter class, inch.	16	18	20	22	24	26	28	30	Total
Number of trees per acre, summarized from previous tables:									
Culled stands	--	2.45	1.25	.49	.04	.40	.43	.04	5.10
Second growth, 25 % restocked	3.00	4.37	1.70	.64	.11	--	.10	.12	10.04
Second growth, less than 25 % restocked	.61	1.81	1.16	.43	.11	--	--	--	4.12
Old field mercht.	8.87	4.21	.95	.42	.30	--	--	--	14.75
Old field unmercht.	--	--	--	--	--	--	--	--	--
Weighted percentage of number of trees given above:									
Culled, 11.5%	--	.28	.14	.06	--	.05	.05	.01	.59
Second gr., 25% restocked, 37.9%	1.14	1.66	.64	.24	.04	--	.04	.05	3.81
Second gr., less than 25% rest., 25.6%	.16	.46	.30	.11	.03	--	--	--	1.06
Old field merch., 14.5%	1.29	.61	.14	.06	.04	--	--	--	2.14
Old field non-mercht., 10.5%	--	--	--	--	--	--	--	--	--
Total average number per acre	2.59	3.01	1.22	.47	.11	.05	.09	.06	7.60

Table 32. Average total volume cut per year from each stand during the second cutting cycle.

Culled stands	3,840 M bd. ft.
Second growth, 25 % restocked.	19,245
Second growth, less than 25 % restocked . .	4,931
Old field merchantable	7,962
Total annual cut	35,978 M bd. ft.

Average cut per acre:
35,978,000 ÷ 10,240 acres = 3514.5 bd. ft.

Table 33. Composition of the average cut per acre for total acreage coverdd during the third cutting cycle and beyond.

Diameter class, inches ⁄	16	18	20	22	Total
Number of trees per acre, summarized from previous tables					
Virgin stand	--	4.13	2.33	--	6.46
Culled stand	--	4.85	2.73	.26	7.84
Second growth, 25 % restocked	4.14	10.47	1.79	--	16.40
Second growth, less than 25 % restocked	2.14	4.33	.87	--	7.34
Old field merchantable	5.74	7.71	.99	--	14.44
Old field unmerchantable	--	--	--	--	--
Weighted percentage of the numbers of trees given above.					
Virgin, 20.8 %	--	.86	.48	--	1.34
Culled, 8.9 %	--	.43	.25	.02	.70
Second gr., 25 % restock., 30.1%	1.25	3.15	.54	--	4.94
Second gr., less than 25 % restock., 20.4 %	.44	.88	.18	--	1.50
Old field mercht., 11.5 %	.66	.89	.11	--	1.66
Old field unmercht., 8.3 %	--	--	--	--	--
Total average number per acre	2.35	6.21	1.56	.02	10.14

During the third ten-year cutting cycle and presumably for all cutting cycles thereafter the average cut per acre will be as shown in the lower line in table 33. This table is derived in a similar manner as table 31. The average annual cut from each of the stands is given in table 34. The total annual cut amounts to 56,484 M bd. ft. At this time the entire forest property will be covered ~~in~~ once during every ten-year cycle; hence the average area covered annually is 12,928 acres, and the average cut per acre is 4,379 bd. ft. The distribution of this volume through the various diameter classes is given in table 35.

Table 34. Average total volume cut per year from each stand during the third and all consequent cycle.

Virgin stand	7,373 M bd. ft.
Culled stand	4,270
Second growth stand, 25 % restocked	27,801
Second growth stand, less than 25 % restocked . .	8,250
Old field merchantable stand	8,790
Total	56,484 M bd. ft.

Average cut per acre:
56,484,000 bd. ft. ÷ 12,928 acres = 4379 bd. ft.

Table 35. Summary of the distributions of the volumes through the various diameter classes for each cutting cycle.

Diam. Class	First cutting cycle			Second cutting cycle			Third cycle, and beyond		
	Number of Trees	Volume	% of total volume	Number of Trees	Volume	% of total Volume	Number of Trees	Volume	% of total Volume
16	4.91	1933	24.4	2.59	844	24.0	2.35	766	17.5
18	2.91	1564	19.7	3.01	1290	36.7	6.21	2739	62.6
20	1.28	839	11.3	1.22	680	19.4	1.56	860	19.6
22	.54	474	6.0	.47	310	8.8	.02	14	.3
24	1.28	1364	17.3	.11	110	3.1			
26	.73	910	11.5	.05	60	1.7			
28	.54	779	9.8	.09	130	3.7			
30				.06	90	2.6			
Total	12.19	7917	100	7.60	3514	100	10.14	4379	100

AVERAGE ANNUAL DEPRECIATION AND THE FIXED INVESTMENT

Depreciation on all items of fixed investment is figured by the straight-line method. A separate calculation is required for each of the first three ten-year cutting cycles, since the volume of timber cut rises from about 20,000 M ft. per year for the first cycle to 36,000 M during the second cycle and to 56,000 M during the third cycle and supposedly beyond.

Items such as the stationary sawmill, which as a matter of policy are depreciated over a period of twenty years, will naturally appear in two successive ten-year depreciation sheets. The depreciation, however, remains constant over the entire twenty-year period, instead of allowing a residual value of one-half the original value at the end of the first ten years and then charging this into the second sheet.

The stationary mill plan. The stationary sawmill to be built in the milltown at the present time is to be capable of handling 70 M bd. ft. per day; at three hundred days a year the annual output will therefore be 21,000 M bd. ft. The estimated cost of a plant to handle this timber is as follows:

Sawmill	$175,000
Planing mill	30,000
Dry kiln	24,000
Rip mill	12,000
Buildings and town	110,000
Total	$351,000

During the second cutting-cycle the mill capacity must be expanded so as to accomodate 120 M ft. per day, or 36,000 M per year. It is estimated that the cost involved in increasing the mill capacity will mean an increase of about 75 % over the original fixed investment, or an expenditure of ~~$131,000~~ $263,250. This will bring the total expenditure for these items to date up to ~~$482,000~~ $614,000.

The expansion required at the beginning of the third cycle will bring the mill capacity up to 56,000 M per year; this will entail another investment similar to that made at the beginning of the second cycle, hence ~~$131,000~~ $263,250, bringing the total investment made during the three cycles up to ~~$613,000~~ $877,500.

<u>The cost of the truck and trailer units</u> to be used in hauling logs to the mill is estimated to be $850; this allows $650 per truck and $200 for the trailer. The trucks are estimated to have a life of four years, hauling 225 days a year.

The comparatively short hauling season is made necessary by the weather conditions in the southern pine region. For the wet season of three or four months hauling will probably not be possible in spite of the excellent road system planned for the property. Furthermore, trucks will be required to go directly into the woods to pick up logs at points where they are bunched by mules; such woods hauling will not be possible during the wet season. It is possible that the trucks can be kept busy during part of this period in hauling logs which are near enough to the road so that they can be bunched economically directly at the road instead of in the woods. However, this will depend upon local conditions and will not enter our calculations.

The normal capacity of a truck and trailer unit hauling 16 inch logs is about 800 bd. ft. (R. Reynolds; N. C. Brown). During the first cycle the average haul from the virgin timber to the mill will be about ten miles. It is estimated that trucks will be able to make six round trips a day. One truck and trailer unit will therefore haul 800 x 6 or 4,800 bd. ft a day; in a year of 225 days it will haul 1,080 ft. To haul 20,000 M ft. a year a fleet of 19 truck and trailer units will therefore be required. The initial cost of these trucks will amount to $16,150.

Depreciation on these trucks does not appear in the investment sheet, since it is charged in later as a variable production cost. The reason for this is that it is a variable cost required in calculating the average road spacing. Interest on the investment, however, is to be charged at this point.

During the second cycle the average hauling distance will be about 7 miles; trucks will be able to make about 8 round-trips a day. The average truck will therefore haul 6,400 ft. a day or 1,440 M ft. per year. Since the annual cut during this cycle is 36,000 M ft. 25 truck units will be required, at a cost of $21,250.

During the third cutting cycle, with an average hauling distance of about 6 miles, ten trips a day per truck will be possible. The average truck will therefore haul 8,000 ft. a day or 1,800 M ft. a year, and 32 trucks will be required. The cost of these units will be $27,200.

Roads, as a matter of general policy, are included as a charge per thousand board feet and will appear later under the production cost calculations. Since the roads planned under this system are estimated to cost $750 per mile, it will be possible to build a very good road system without an extra charge for "main line" roads. At the start of the logging operations, however, it is necessary to build a tap road nine miles in length from the mill to the virgin timber area. At $750 a mile this road will cost $6,750, and appears at this figure in the investment sheet. This road is not depreciated but will be used throughout the life of the company. As a fixed investment it is charged with interest.

Other roads appearing later as a charge per thousand bd. ft. are not charged with interest, even though it is hoped that they will be used again during later cutting cycles; they do not appear in the investment sheet.

During the second cutting cycle it may also be necessary to build a certain amount of tap-line roads in order to reach certain forest stands before others. It is estimated that the mileage of these roads will not exceed 15 miles; hence at $750 per mile the sum of $11,250 is allowed for this item; this sum however will not be expended in a single year, but over a period of ten years. At 5 % interest, and using the formula

$$Co = a \frac{1.0p^n - 1}{.0p \times 1.0p^n}$$

the initial charge for this road, as appearing in the fixed investment for the second cutting cycle, is $8,686.

At the time of the third cutting-cycle it will not be necessary to build any further tap-line roads. Interest, however, will continue on the 25 miles of road built previously at $750 per mile, or on $18,750; hence this figure appears under the fixed investment for the third and consequent cycles.

Table 36, 37, and 38 show the average annual depreciation and the fixed investment for the various cutting cycles. Figures appearing in these tables, other than those explained above, are self-explanatory.

Table 36. Stationary mill, average annual depreciation and fixed investment for the first ten-year cycle.

Item	Initial Cost	Years in use	Residual Value	Aver. An. Deprec.	Fixed Investm.
Sawmill, planing mill kiln, etc.	351,000	20	--	17,550	184,275
Truck and trailer units, 19	16,150	4	--	--	8,968.75
Tap-line road	6,750	indefinitely		--	6,750
Mule teams, 10	4,000	5	--	800	2,400
Saws, axes, etc., $650 twice annually	1,300	1	--	1,300	650
Tractor and grader	3,000	5	600	480	2,040
Office fixtures and supplies	2,500	10	--	250	1,375
Total	$384,700			$20,380	$206,458.75

Table 27. Stationary mill, avergge annual depreciation and fixed investment for the second ten-year cycle.

Item	Initial Charge	Years in use	Residual Value	Ave. An'l Deprec.	Fixed Investm.
Investment in sawmill, etc., carried over	--	--	--	17,550	184,275
Cost of increasing mill, etc., capacity	263,250	20	--	13,162.50	138,206.25
Truck units, 25	21,250	4	--	--	13,281.25
Tap-line road, first nine miles	---	--	--	--	6,750
Tap-line road, new, 15 miles	8,686	--	--	--	8,686
Mule teams, 18	7,200	5	--	1,440	4,320
Saws, axes, etc., $1300 twice annually	2,600	1	--	2,600	1,300
Tractor and grader	3,000	5	600	600	2,040
Office fixtures and supplies	5,000	10	--	500	2,750
Total	$310,986			37,732.50	361,608.50

Table 38. Stationary mill, average annual depreciation and fixed investment for the third and subsequent ten-year cycles.

Item	Initial Charge	years in use	Residual Value	Av. An'l Deprect	Fixed Investm.
Investment in sawmill, etc., carried over	--	--	--	13,162.50	138,206.25
Cost of increasing mill, etc., capacity	263,250	20	--	13,162.50	138,206.25
Truck units, ~~20~~ 32	27,200	4	--	--	17,000
Tap-line road system, 24 miles	--	--	--	--	17,900
Mule teams, 28	11,200	5	--	2,240	6,720
Saws, axes, etd., $1,950 twice annually	3,900	1	--	3,900	1,950
Tractor and grader	3,000	5	600	480	2,040
Office fixtures and supplies	7,500	10	--	750	4,125
Total	$316,050			33,695	326,247.50

Under the portable mill plan of operation a concentration yard will be necessary at the milltown to handle the raw product delivered from the sawmills in the woods. The number of portable mill units will vary from one ten-year cutting cycle to the next, depending upon the volume of timber to be cut; the fixed investment required for work in the woods is therefore figured on the basis of the sawmill unit. This is done in table 39.

Sawmill costs were obtained from a reliable source in itemized form. The sawmill used will be of the semi-portable bandmill type, capable of cutting lumber equal in quality to that produced at a stationery mill. The output per mill per 10-hour day is 16 M ft. The initial cost of such a mill is as follows:

Power unit	$2,700
Initial installation charge	300
Saw	480
Mandrel, carriage, feed	4,250
Conveyors, belting	1,000
Deck equipment	300
Lumber dollies	20
Tools	20
Water tanks	50
Pump and line	200
Total	$9,320

The useful life of this portable mill is 10 years, and the residual value 10 %. The initial installation charge for this mill unit is $1,100; mill moving will, however, cost only $800. Since mill moving will be treated as a production cost per M ft., $800 must be subtracted from the initial $1,100, leaving the $300 for installation as shown in the above itemized list.

Hauling logs to the mill will be accomplished by mules and trucks. It is estimated that one truck and trailer unit, costing $850, will be able to supply 16 M ft. of logs per day to a mill located in the woods; logs will first be bunched in the woods by two mule teams. Saws, cant hooks, etc., are allowed for at the same rate as in the stationary mill investment; the investment, however, is divided between five mill units (as will be shown later), and will therefore be only $300 per mill.

Table 39. Portable mill, average annual depreciation and fixed investment per mill unit for a ten year period.

Item	Initial Charge	Years in use	Residual Value	Av. Anl. Deprec.	Fixed Investm.
Mill and equipment	9,320	10	932	838.80	5,545.40
Truck and trailer	850	4	0	--	531.25
2 mule teams	800	5	0	160	480
Saws, axes, etc., $150 twice annually	300	1	0	300	150
Camp outfit	25	1	0	25	25
Total	$11,295			$1,323.80	$6,731.65

To allow for weather not suitable to woods work, we assume a working year of only 250 days for each portable mill unit.. The annual output per mill will therefore be 4,000 M bd. ft. The number of mill units required during each cutting cycle and the average annual depreciation and fixed investment for these units is shown in table 40.

Table 40. Number of mill units required, average annual depreciation, and fixed investment for each cutting cycle.

	First cycle	Second cycle	Third cycle and thereafter
Average annual output, M ft	20,000	36,000	56,000
Output per mill unit	4,000	4,000	4,000
Number of mill units required	5	9	14
Initial cost	$56,475	101,655	158,130
Average annual depreciation	$6,619	11,914.20	18,533.20
Fixed investment	$33,658.25	60,584.85	94,243.10

Concentration Yard.

All investment charges which have not been included as items directly related to the portable mill unit as shown above, are included in the concentration yard investment.

A problem which generally faces every owner of a portable mill is that the lumber produced is of low quality. Furthermore, the output is periodic, the grading of lumber is poor, and the variety of products is low; the treatment which the lumber receives after being sawn is generally not comparable to that received by the stationary mill output. The first of these problems can be overcome by planning on using only a high-grade bandmill which can turn out lumber equal in quality to that produced by a stationary mill. The introduction of the concentration yard to handle the output of many portable mills will overcome the other difficulties. Here the lumber can be graded and sorted; by handling the output of many mills through the concentration yard market demands can be met efficiently and regularly.

In the concentration yard planned for this property the investment in planing mill, kiln, rip mill, building and town, etc., will be equal to that provided for the stationary mill. The lumber produced at this plant will therefore be inferior in no way to that produced at a stationary mill, and will bring comparable prices.

The investment in stationary improvements for the first ten-year period is as follows (compare page 46):

Planing mill	$30,000
Kiln	24,000
Rip mill	12,000
Buildings and town	110,000
Filing room	1,000
Total	$177,000

The investment required to expand the capacity of the plant from 20,000 M ft. per year to 36,000 M ft. per year in the tenth year is figured in the same way as that required for the stationary mill; namely, by allowing 75 % of the original cost, or $132,750, for expansion. At the beginning of the third cycle in the twentieth year of operation a similar investment will be made to expand the capacity of the plant so as to handle 56,000 M ft. per year.

<u>Trucks</u> which will haul the boards from the sawmills to the concentration yard are included in the concentration yard investment. The average load for a $1\frac{1}{2}$-ton truck costing $650 is 3,500 ft. of lumber. During the first ten year period, with the average haul of ten miles as also in the case of the stationary mill, six round trips per day will be possible. When hauling 225 days a year each truck will therefore

deliver 4,720 M bd. ft., and a total of four trucks will be required.

During the second cycle the average trip will be 7 miles and the number of round trips will be 8 per day. Each truck will haul 6,300 M ft. a year, and 6 trucks will be required to haul 36,000 M ft. a year. During the third cycle and thereafter the average haul will be 6 miles and ten round trips a day will be possible, each truck therefore hauling 7,800 M ft. a year; seven trucks will therefore deliver the annual output of 56,000 M bd. ft. Depreciation is again figured as a cost per mile.

Other items, namely the tractor, the charge for the tap-line road construction, and the office fixtures and supplies, are identical to the charges allowed in the stationary mill investment sheets.

Tables 41, 42, and 43 show the average annual depreciation and the fixed investment for the concentration yard during each cycle.

Table 41. Concentration yard, average annual depreciation and fixed investment for the first ten-year cycle.

~~Planing mill, kiln, town, etc.~~	Initial Charge	Years in use	Residual Value	Av. Anl. Deprec.	Fixed Investm.
Planing mill, kiln, town, etc.	177,000	20	--	8,850	92,925
Trucks, 4, @ $650	2,600	4	--	--	1,625
Tractor	3,000	5	600	480	2,040
Main or tap-line road	6,750	indefinitely		--	6,750
Office fixtures and supplies	2,500	10	--	250	1,375
Total	$191,850			$9,580	$104,715

Table 42. Concentration yard, average annual depreciations and fixed investment for the second ten-year cycle.

Item	Initial charge	Years in use	Residual Value	Av. Anl. Deprec.	Fixed Investm.
Investment in planing mill, etc., carried over	--	--	--	8,850	92,925
Cost of doubling capacity of yard	132,750	20	--	6,637.50	69,693.75
Six trucks @ $650	3,900	4	--	--	2,437.50
Tractor and grader	3,000	5	600	480	2,040
First 9 miles of tap-line road	--	--	--	--	6,750
Fifteen miles of new tap-line road	8,686	--	--	--	8,686
Office fixtures and supplies	5,000	10	--	500	2,750
Total	$153,336			$16,467.50	$185,282.25

Table 43. Concentration yard, average annual depreciation and fixed investment for the third and subsequent cycles.

~~Investment in planing mill, etc., carried~~	Initial charge	Years in use	Residual Value	Av. Anl. Deprec.	Fixed Investm.
Investment in planing mill, etc., carried over	[illegible]	--	--	6,637.50	69,693.25
Cost of expanding capacity of yard	132,750	20	--	6,637.50	69,693.25
7 trucks @ $650	4,550	4	--	--	2,843.75
Tractor and grader	3,000	5	600	480	2,040
Tap-line road, 24 mi.	--	--	--	--	18,000
Office fixtures and supplies	7,500	10	--	750	4,125
Total	$147,800			$14,505	$166,395.25

INVESTMENT IN LAND AND TIMBER

The present assessed value of the land and timber is, in this problem, assumed to be identical to the initial cost or the profit-bearing investment in land and timber. The values for the various stands are therefore taken from previous tables and summarized here, and will again appear later under the total investment.

Virgin stand (table 4)	$806,400
Culled stands (table 8)	207,360
Second growth, 25% + stocking (table 13)	583,680
Second growth, 25% - stocking (table 18)	210,944
Old field merchantable stands (table 23)	296,960
Old field unmerchantable stands (table 30)	32,256
Total value	$2,137,600

This value is not subject to any depreciation, nor need a sinking fund be set up to retire it, since in every case a sustained-yield operation is planned. It is possible that the actual value will rise above this figure in the future because of the increased productivity of the forest stands under proper management.

The probable increase in the tax rate which will result from the expected accretion in value is taken care of by the tax charge, page 64.

OPERATING COSTS AND WORKING CAPITAL

Operating costs include all those costs in the production of logs and lumber which have not been cited under the heading of average annual depreciation and fixed investment. For purposes of this study figures have been assembled from various sources and have been adjusted by means af an arbitrary index so as to be on a comparable level.

The chief sources of cost data have been: U. S. D. A. Tech. Bul. 375 (3); U. S. D. A. Tech. Bul. 337 (4); and an unpublished study of logging and milling costs in a portable sawmill operation in South Caro lina, made by the U. S. Forest Products Laboratory (2). The last-mentioned study was made in 1934, when labor costs and other prices were at a very low level; whereas the two former studies were made during the peak years before the depression of 1929. To obtain a sort of index to serve as a basis for comparing cost figures, costs for similar operations were first compared. It was found that the figures given in the F. P. L. study are, in general, only 40 % of those given in the two early bulletins. Felling and bucking in Bul. 375, for example, costs an average of 85 ¢ per M ft., whereas in the F. P. L. study the cost for the same operation is only 39¢, or 46 % of the former. The attempt is here made, therefore, to strike an average cost which will probably hold over long periods in the future by reducing figures used in the 1929 publications to 70 % of their stated level and stepping up the figures in the F. P. L. study from their 40 % level to the 70 % level.

In the following tables costs for felling and bucking and for loading are taken from table ~~24~~ 7, page 24, U. S. D. A. Tech. Bul. 375, reduced to 70 % of their original. Costs for "bunching" are the costs for bringing the logs together to points in the woods where they can be loaded directly onto the trucks which haul them to the mills; this is done by mules; the figures are taken from the F. P. L. study, stepped up from 40 to 70 %. Cost for "pond, sawmill, greenchain" in the case of the stationary mill are from table 7, Bul. 375, adjusted. Costs for milling in the case of the portable mill are from Table 6, U. S. D. A. Tech. Bul. 337; they are adjusted from the 100 % level to the 70 % level. These costs were chosen in this particular case because they are for a portable bandmill cutting 9 M ft. a day, which is the nearest approach to the bandmills cutting 16 M a day, used in this study, which was available. The figures for the stationary and portable mills are thought to be comparable after adjusting, since, as shown in tables 44 and 45 they run very close together; the portable mill being cheaper for logs 26 inches and under, and the stationary mill being cheaper for logs above this size.

For the various truck hauling operations costs were obtained from the F. P. L. study; all costs are of course adjusted as before.

Truck hauling in the woods (without roads) is figured on the following basis: trucks can haul 25 miles a day, 200 days a year carrying a load of 800 bd. ft. (logs). Total operating costs for gasoline, oil, tires, repairs, and license under these conditions amount to 14 ¢ per mile; wages per day for 1.62 men amount to $4.25, or 17 ¢ per mile; trucks and trailers costing $850 are depreciated over 800 days of 25 miles each, or 4 ¢ a mile; the total operating cost per mile therefore amounts to 35 ¢. Since trucks haul 800 bd. ft. per load the cost per M ft. per mile amounts to

Table 44. Stationary mill plan, variable operation costs.

Diameter:	Total	16"	18"	20"	22"	24"	26"	28"	30"
Fell and buck		.56	.54	.53	.53	.53	.63	.53	
Skid (bunching)		.77	.68	.63	.63	.63	.65	.70	
Load		.32	.26	.22	.18	.15	.15	.15	
Pond, sawmill, to greenchain		2.12	1.97	1.85	1.76	1.66	1.57	1.54	
Total	[illegible]	3.77	3.45	3.23	3.10	2.97	2.90	2.92	2.95*
Costs distributed according to percentages of volume cut per diameter class									
First cycle	3.32	.95	.68	.365	.186	.514	.334	.286	
Second cycle	3.40	.905	1.267	.627	.273	.092	.049	.108	.077
Third cycle	3.46	.66	2.16	.634	.009				

Table 45. Portable mill plan, variable operation costs.

Diameter	Total	16"	18"	20"	22"	24"	26"	28"	30"
Fell and buck		.56	.54	.53	.53	.53	.53	.53	
Skid (bunching)		.77	.68	.63	.63	.63	.65	.70	
Load		.32	.26	.22	.18	.15	.15	.15	
Milling		1.70	1.57	1.46	1.35	1.31	1.43	1.57	
Total		3.35	3.05	2.84	2.69	2.62	2.76	2.95	3.17*
Costs distributed according to percentages of volume cut per diameter class									
First cycle	3.01	.866	.601	.321	.162	.454	.318	.289	
Second cycle	3.03	.805	1.12	.551	.237	.081	.047	.109	.083
Third cycle	3.06	.586	1.91	.556	.008				

* Figures determined by curves.

44 ¢; allowing for the round trip the actual hauling cost is 87½¢ per M ft. per mile, or 1.6 ¢ per M per 100 ft.

When hauling logs by road trucks were found to make an average of 130 miles a day, at an operating cost of 12¢ a mile; wages at $4.25 a day as before amount to 3 ¢ a mile; depreciation on $850 for 800 days of 130 miles each amounts to 1 ¢ a mile; the total hauling cost is therefore 16 ¢ a mile, or 32 ¢ per round trip. With a load of 800 ft. the cost is 40 ¢ per M ft. per mile, or .76 ¢ per M ft. per 100 ft. of distance.

When hauling boards by road a truck costing $650 will carry 3500 ft. of lumber with an operating cost of 12 ¢ a mile; the wage for one man at $3.25 a day amounts to 2.7¢ per mile; depreciation on $650 for 800 days of 120 miles each amounts to 0.7 ¢ a mile; the total cost is therefore 15 ¢ a mile, or 30 ¢ for the round trip. This amounts to 8.6 ¢ per M ft. per mile.

The road systems for the two proposed methods of milling will be the same in both instances, for the reason explained in the second part of this study(page 102). The most economic road spacing is figured by the method developed by D. M. Matthews*, and will vary for each cutting cycle because of the different volumes cut; naturally the road spacing will also vary for each different stand on the property, but for purposes of this problem the average volumes cut during the different cycles, as summarized in table 35, page 45, will be used to obtain average spacings. Depreciation on trucks and the cost of road building, which are ordinarily classed under the "average annual depreciation and fixed investment" costs, are here treated under "operating costs" per M ft. cut because of the peculiarities of this method.

* D. M. Matthews, to be published.

The cost of building roads through the property is estimated to be about $750 per mile. Truck hauling of logs on the road costs 0.7¢ per M per 100 ft., and woods hauling costs 1.6¢ per M per 100 ft. (page 61). During the first 10-year cycle, therefore, when the volume cut per acre is 8 M ft., the average road spacing will be 4400 ft., and the cost of road building will amount to 17.6 ¢ per M, with the cost of woods hauling also 17.6 ¢ per M. During the next cycle the volume cut per acre is 3500 M ft. and the spacing is 6650 ft.; road building therefore costs 26.6 ¢ per M and woods hauling also costs 26.6 ¢ per M. During the third cutting cycle the average cut is 4400 M per acre, and the economic spacing is 5940 ft.; on this spacing the costs of road building and woods hauling would be equal at 23.8 ¢ per M. It is obvious, however, that at this time we are covering the same ground which had previously been cut over and which is therefore covered with a network of roads. In most cases the old road system will probably be used again, but occasionally it will be more economical to vary the old system be building extra roads. The charge allowed, therefore, either for the building of extra roads or for the extra cost of woods hauling to more than the "economic distance" is estimated to be about one-quarter the cost of building an entirely new road system. Therefore the cost of road building during the third cycle, and thereafter, becomes 6 ¢ per M ft. and the cost of woods hauling becomes 23.8¢ per M ft.

The spacing of portable mills along the roads can be calculated by similar methods in order to get the most economical total costs. The actual methods employed here are developed in the second part of this paper, and according to the formula presented on page 98 the most economic distances are: first cycle, 7500 ft., second cycle, 9250 ft., and third cycle, 8720 ft. When the mills are set up at these intervals the logs, after being hauled through the woods to the roads, must be hauled along the roads to the mills, and a corresponding charge for "road hauling" will enter the calculations. Mill moving amounts to $800 per set-up, as explained before (page 53); road hauling of logs costs 1.6¢ per M per 100 ft. (page 61). The charges for these items, which appear under the operating costs for the portable sawmills, therefore amount to the following: first cycle: mill moving, 13.1 ¢ per M, road hauling, 13.1 ¢ per M.; second cycle, mill moving 16.2 ¢ per M, road hauling 16.2¢ per M; third cycle and thereafter, mill moving, 15.3 ¢ per M, road hauling, 15.3 ¢ per M.

Under the stationary mill plan logs must be hauled by road, after being hauled through the woods as explained above, to the milltown at a cost of 40 ¢ per M ft. per mile(page 61). During the first cycle, with an average hauling distance of ten miles (page 48), the cost of road hauling will therefore be $4.00 per M; during the second cycle, with a haul of seven miles, it will be $2.80; and during the third and subsequent cycles, with a hauling distance of six miles, it will be $2.40 per M.

Other operating costs will be the same for the stationary mill and the portable mill. These costs are taken directly from table 7, U. S. D. A. Tech. Bul. 375 and are not adjusted because they do not fluctuate greatly. They are:

Supplies, repairs	$0.11
General expense	.22
Yards, kilns	2.25
Shipping	1.51
Planing mill	1.60

Selling	1.41
Insurance,/ on plant	.37
Taxes on plant and timber	.85
General expense	1.88
Insurance on lumber	.20
Taxes on lumber	.09
Discount on sales	.43
Allowance and adjustments	.13
Total overhead	$11.05

This method of treating the operating costs, namely as a cost per thousand board feet of output, assumes that the charges for the items involved will rise in direct proportion to the output. Thus in the tenth year of operation, when the output rises from 20,000 M ft. to 36,000 M ft., the estimated overhead charges will rise from about $230,000 per year to about $415,000 per year. This is admittedly only an approximation of the actual charges. Yet in the case of such items as taxes on plant and timber the probable future charges are so indefinite that this method of allowing for them, which will permit a tax charge of almost double its present amount as the value of the property increases under management, is justified.

Direct costs per M ft. of lumber are summarized in table 46.

For treatment under the costs per M ft. of lumber produced depreciation under the two plans of operation is summarized here from previous tables. To determine the charge per M the total annual depreciation during each cycle is divided by the annual cut in each case; this charge per M is then added to the direct costs in table 46.

1. Stationary mill plan

Depreciation on investment in mill and other improvements; first cycle (table 36):	$20,380	
Charge per M ft. cut		$1.063
Depreciation during second cycle (table 37)	37,732.50	
Charge per M ft		$1.05
Depreciation during third cycle (table 38)	33,695	
Charge per M ft		$0.60

2. Portable mill plan

Depreciation on sawmill units (table 40)	$6,619		
Depreciation on concentration yard (t.41)	9,580		
Total depreciation during first cycle		$16,199	
Charge per M ft			$0.845
Second cycle			
Depreciation on sawmill units (table 40)	$11,914.20		
Depreciation on concentration yard (t.41)	16,467.50		
Total depreciation during second cycle		$28,381.70	
Charge per M ft.			$0.79
Third cycle			
Depreciation on sawmill units (table 40)	$18,533.20		
Depreciation on concentration yard (t.41)	14,505		
Total depreciation during third cycle		$33,038.20	
Charge per M ft.			$0.595

Table 46. Total operating costs and depreciation per M ft. produced.

Item	Stationary Mill Plan			Portable Mill Plan		
	First Cycle	Second Cycle	Third Cycle	First Cycle	Second Cycle	Third Cycle
Variable operating cost	3.32	3.40	3.46	3.01	3.03	3.06
Woods hauling	.18	.27	.24	.18	.27	.24
Hauling logs on roads	4.00	2.80	2.40	.13	.16	.15
Hauling boards on road	--	--	--	.86	.60	.52
Spur road building	.18	.27	.06	.18	.27	.06
Portable mill moving	---	--	--	.13	.16	.15
Fixed operating costs and overhead	11.05	11.05	11.05	11.05	11.05	11.05
Depreciation	1.06	1.05	.60	.85	.79	.60
Total	19.79	18.84	17.81	16.39	16.13	15.83

<u>Working capital</u> can now be determined under the assumption that three months' product will at all times be tied up in the process of manufacture. For each of the total figures shown above in table 46 the calculation is as follows: Total operating costs and depreciation x total annual production x $\frac{1}{4}$ year = total average working capital.

Stationary mill plan:

First cycle: \$19.79 x 20,000 M x $\frac{1}{4}$ = \$98,900

Second cycle : \$18.84 x 36,000 x $\frac{1}{4}$ = \$169,470

Third cycle: \$17.81 x 56,000 x $\frac{1}{4}$ = \$249,340

Portable mill plan:

First cycle: 16.39 x 20,000 x $\frac{1}{4}$ = \$81,950

Second cycle: 16.13 x 36,000 x $\frac{1}{4}$ = \$145,170

Third cycle: 15.83 x 56,000 x $\frac{1}{4}$ = \$221,620

INCOME FROM LUMBER SALES

The first step in determining the income from lumber sales is to fix upon some average price of lumber which may be expected to hold for some time in the future. From a study by R. G. Richardson (7), showing lumber prices for loblolly and mixed southern pines over a period of years, it is seen that the prices for 1936 are half-way between the high prices of 1929 and the average low of 1931. In this study we have taken average lumber prices for 1936, based on the grades of lumber sawn from trees of various diameters, from table 5 of Richardson's paper (7). These are shown in table 47. For the various cycles these prices are then weighted in accordance with the percentage of lumber sawn from each of the diameter classes, the percentage figures being taken from table 35. A weighted average selling price for the lumber produced during each of the cutting cycles is thus obtained in table 47. From this are subtracted the total operating costs and depreciation obtained in table 46, and the residual figure shown the margin per M for interest on investment, risk, and profit in every case.

Table 47. Value of lumber obtained in each cutting cycle, and the margin remaining for interest on investment, risk, and profit.

Diameter Class	1936 value of lumber	Percentage of value obtained for lumber		
		1st cycle	2nd cycle	3d cycle
16	23.98	5.85	5.76	4.20
18	24.87	4.91	9.15	15.62
20	25.96	2.93	5.04	5.08
22	27.24	1.63	2.40	.08
24	28.24	4.89	.88	
26	29.17	3.36	.50	
28	29.91	2.93	1.11	
30	30.41*		.79	
Total		26.50	25.63	24.98

* Obtained by a curve.

(Continued)

Table 47 (continued)

	Value obtained from lumber sales		
	First cycle	Second cycle	Third cycle
Gross return from lumber	26.50	25.63	24.98
Stationary mill			
Operating costs and depreciation	19.78	18.83	17.81
Gross profit per M	6.72	6.80	7.17
Total gross annual profit	128,701.44	245,560.40	404,990.28
Portable mill			
Operating costs and depreciation	16.39	16.13	15.83
Gross profit per M	10.11	9.50	9.15
Total gross annual profit	193,626.72	341,791.00	516,828.60

TOTAL RETURN ON INVESTMENT

The total gross annual profit for each plan of operation and for each cutting cycle is summarized in table 47. This is the profit obtainable before paying interest on the investment, and a return for profit and risk. Table 48 therefore shows the total fixed investment in land, timber, and improvements under the two plans of operation for the various cutting cycles. The annual gross profit, as an annual per-cent return on this total investment, is to be taken as an indication of which plan of operation is the most profitable. Table 48 shows that for the stationary mill plan a return of 5.26% on the total investment can be expected during the first ten years of operation; this will rise to 9.2% during the second and to 14.9% during the third and subsequent cycles. Under the portable mill plan the return would be 8.2% during the first ten years, 13.5% during the second cycle, and 19.7% during the third and subsequent cycles.

Table 48. Total investment and the return for interest, risk, and profit.

	First Cycle	Second Cycle	Third Cycle
Stationary Mill Plan			
Fixed investment (tables 36, 37, 38)	206,458.75	361,608.50	326,247.50
Investment in land and Timber (page 58 a)	2,137,600.00	2,137,600.00	2,137,600.00
Working capital (p. 66)	98,900.00	169,470.00	249,340.00
Total investment	2,442,958.75	2,668,678.50	2,713,187.50
Annual income for interest, profit, and risk (t. 47)	128,701.44	245,560.40	404,990.28
Income as a per-cent return on investment	5.26	9.2	14.9
Portable mill plan			
Fixed investment in mills (table 40)	33,658.25	60,584.85	94,243.10
Fixed investment in concentr. yard (tables 41, 42, 43)	104,715.00	185,282.25	166.395.25
Investment in land and Timber (p. 58 a)	2,137,600.00	2,137,600.00	2,137,600.00
Working capital (p.66)	81,950.00	145,170.00	221,620.00
Total investment	2,357,923.25	2,528,637.10	2,619,858.35
Annual income for interest, profit, and risk (T.47)	193,626.72	341,791.00	516,828.60
Income as a per-cent return on investment	8.2	13.5	19.7

CONCLUSIONS AND SUMMARY, PART I

From the purely financial standpoint we have shown by the preceding calculations that the portable sawmill plan is superior to the stationary mill plan for the particular property under consideration. So far we have based our conclusion entirely upon one final figure which represents the return on the average fixed investment. In concluding this study we shall therefore want to show just how the savings involved in the portable mill plan are effected; we shall also need to consider other less tangible advantages and disadvantages of the portable mill plan, which did not enter the previous calculations.

Table 48 clearly shows that in the portable mill plan the fixed investment is smaller while the gross income is larger. The reasons for the larger income go back directly to the operating costs under the two plans, as compared in table 46. This table shows that with the portable mill we save from 30 to 40 cents per M on operating costs, depending upon the size of the timber cut. The greatest saving, however, is attributable to hauling costs; under the stationary mill plan our total cost for hauling logs is $4.18; under the portable mill plan the cost of hauling logs is 31¢, and the cost of hauling boards is 86¢, thus giving a total hauling cost of $1.17; here is a saving of $3.01 in favor of the portable mill during the first cutting cycle. This saving drops to $1.77 and $1.49 during subsequent cycles. The charge for portable mill moving varies from 13 to 16 cents per M, and is the only charge which exceeds a similar charge under the stationary mill plan. Depreciation is lower for the portable mill by 21 cents during the first cycle, but this advantage is lost during the third and subsequent cycles after the stationary mill has been depreciated entirely. The total saving in operating costs varies from $3.41 during the first cycle to $1.98 during the third cycle.

Other advantages of the portable mill plan. To put the business on a running basis we shall require a certain investment at the present time. The initial cost of a stationary mill and other impoovements is $384,700, as shown in table 36. To this must be added the investment in working capital of $98,900, making a total amount of $483,600 which must be raised at once. For the portable mill plan the comparable costs are: portable mill units, $56,475; concentration yard, $191,850; and working capital, $81,950; giving a total of $337,275 which is required for immediate investment. Even disregarding the return obtainable on the investment there is a distinct advantage in having to raise about $150,000 less in the case of the portable mill than under the stationary mill plan.

Suppose, furthermore, that a period of depression should forse us to restrict the mill capacity. Under the portable mill plan one or moe mill units could shut down temporarily and the operating costs would fall directly; under the stationary mill plan the entire sawmill would have to continue in operation under the restricted output, and the operating costs per M would undoubtedly rise. Depreciation charges which would go on regardless of such a restriction would nevertheless be lower for the portable mills than for the stationary mill.

Another advantage of the portable mill which did not ente this study because of the lack of data is that the portable mill could afford to cut logs of poorer quality than those cut by the stationary mill, not only because operating costs are lower, but because a poor quality log would have to be hauled only a short distance to a portable mill, whereas hauling it a long distance to a stationary mill might not be economical. Silvicultural operations such as thinnings woudl be more profitable under the portable mill plan than under the stationary mill plan.

Disadvantages of the portable sawmill. Certain disadvantages of the portable sawmill can be overcome under a plan such as that proposed in this study. The portable mill need not produce lumber of poorer quality than that produced by the stationary mill if the facilities for drying, storing, grading, and sorting lumber are available. Through introduction of the concentration yard the marketing difficulties experienced by the average operator are overcome. As proposed in this plan, saws can be filed by an expert filer at the concentration yard at a cost not above that for the stationary plan.

Supervision of a number of mill units located at outlying points is admittedly more difficult than the supervision of a stationary mill. Yet a capable supervisory officer will nevertheless be required to inspect the woods operations which go on in the proximity of the portable mill, and the supervision of the mill will not be too great a burden to him.

The stationary mill requires but one or two good sawyers as compared to the five, eleven, or fourteen sawyers required by the portable mills which will be required under the proposed plan. Yet the cost of hiring these sawyers is reflected in the operating costs for the mills, and the savings effected by the portable mill are sufficient to overcome this disadvantage and still leave a balance in favor of the portable mill.

In this problem the portable mill is assumed to operate only 250 days a year, to allow for adverse weather conditions, whereas the stationary mill operates 300 days a year. Yet the cost of depreciation, as shown in table 46, is nevertheless lower per M ft. than under the stationary mill plan. Therefore this disadvantage is also overcome.

In view of all these considerations it seems, therefore, that the portable mill plan is superior to the stationary mill plan for the property which has been considered in this study.

PART II

Some Considerations in the Economic Location of Portable Sawmills

INTRODUCTION

The problem of how often a portable sawmill should be moved in order to obtain the most economical distribution of costs is one which confronts every portable mill operator. What are the factors which influence the decision which every operator must make, and how are these factors related? Economists have recognized the importance of choosing the proper location for a newly proposed industry and have stressed the importance of bringing production costs, especially transportation costs, into a proper equilibrium so that the total of all costs will be a minimum.

Economists point out, for example, that an industry which draws its raw materials from one direction and ships its products to a market located in the opposite direction might well be situated half-way between the source of the raw materials and the market, provided the shipping costs are thus brought into equilibrium and other factors have no influence. As soon, however, as the cost of shipping one of the factors becomes relatively larger than that of the other, the industry ought to shift in the direction of the more expensive factor in order to bring down the cost of its delivery.

In the lumber industry we must often deal with costs of a particular character not generally encountered in other industries. Each lumbering organization must plan a miniature transportation system of its own, the cost of which may make up a large proportion of production costs. In the process of moving a log from the stump to the mill the first step is to move the log to a point on the major transportation system; it is here that we encounter ~~operating~~ transportation costs which are not, like ordinary costs, related to distance, but are rather related to area.

A simple example might be that of skidding logs to a landing from where they are hauled by trucks. The landing serves as the central point of a large skidding area, and the cost of constructing it must therefore be prorated over area in order to obtain its cost per M b. m. Therefore as the average skidding distance increases, the cost of building the landing per M decreases as the square of the distance, since it is related to area. The cost of skidding, however, naturally increases in direct proportion to the skidding distance.

In an instance like the one mentioned here it will be necessary to bring the cost of building the landing into equilibrium with the cost of skidding in order to obtain minimum total costs per M. Much work in the analysis of area costs has been done by D. M. Matthews. In the following pages the attempt is made to apply similar principles of analysis to portable mill operations, with the purpose of establishing the proper relation between the cost of moving portable sawmills, which is a cost related to area, with the cost of bringing logs to the mills, a cost which for our purposes can be considered a straight-ling cost varying directly with distance.

THE MATHEMATICAL BASIS FOR THE MINIMUM COST ANALYSES

In this mathematical consideration of the cost relationships involved in portable mill moving we shall be dealing with costs which vary inversely at different rates. In the instances to be considered here one cost will be found to vary at a uniform or arithmetic rate, since it is related to distance, while the other cost will vary at a geometric rate since it is related to area; graphically costs of the first category will appear as straight lines and costs of the second type will appear as curves. Since they vary inversely, the curves representing these two types of costs will generally cross; a line representing the total of the two costs can be superimposed upon the two curves in a graph, and will show the point at which the total costs are at a minimum.

The general rule to be followed in determining the minimum point of the total of the two curves, when graphic methods are not employed, is as follows: where the slopes of the two inversely related curves, or the rates of change expressed as the differences between successive points on the two curves, are equal, the total of the two is at a minimum.

The reason for this relationship can be expressed simply without the aid of calculus. Suppose we are dealing with the two variants represented by the curves shown in figure 4. Curve A increases directly as five times x, where x is the horizontal axis: $y = 5x$. Curve B increases inversely as the square of the x axis; or, $y = (10 - x)^2$. Curve C shows the sum of the two curves and can therefore be represented by the formula $y = 5x + (10 - x)^2$.

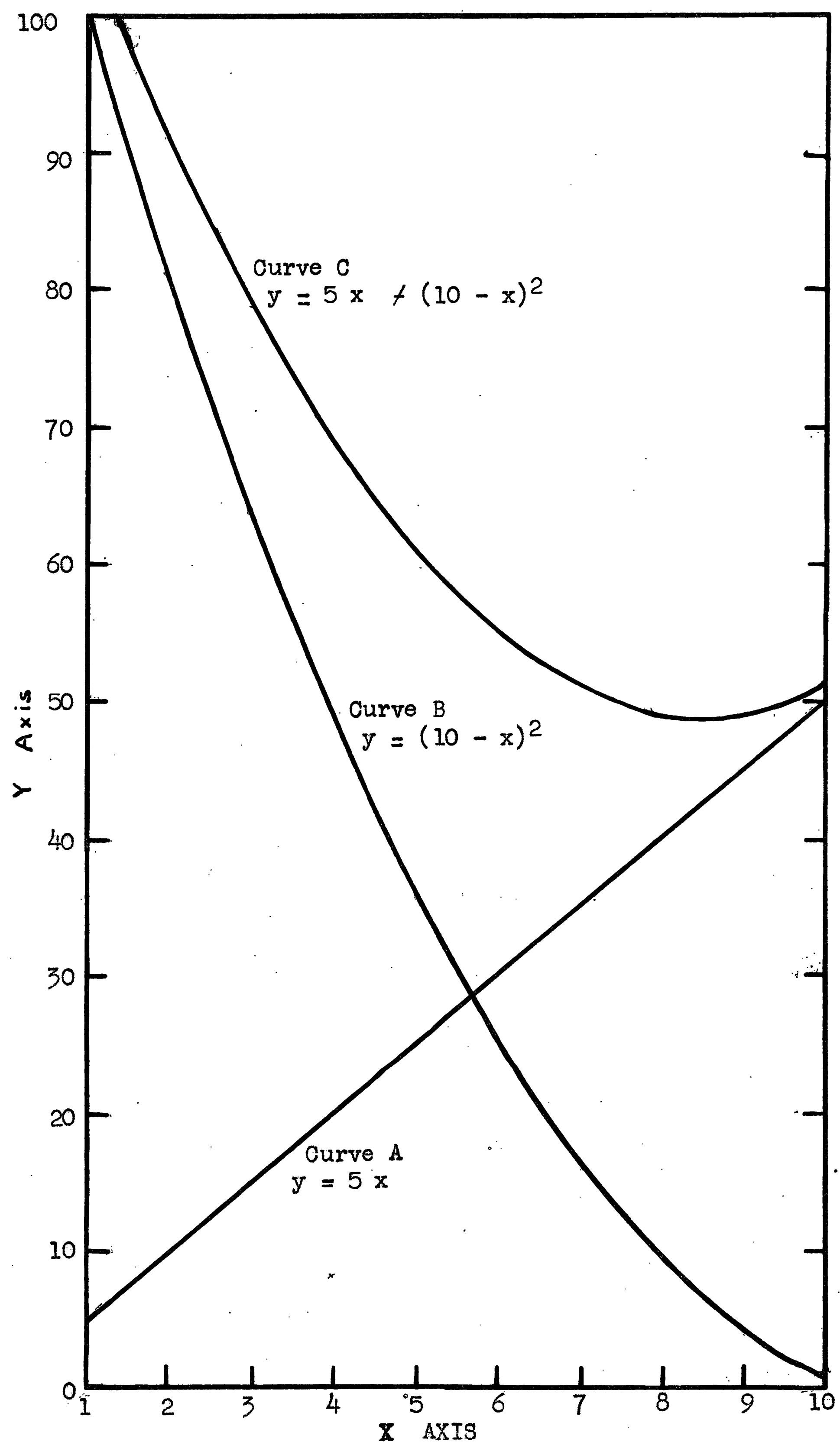

Figure 4. Graph illustrating the summation of two inversely related variables.

Curve C strikes its minimum at a point between 8 and 9 on the x axis. The following analysis will show that at this point the slopes of the two component curves are equal. Slopes of the curves are expressed as the difference between two successive figures.

x axis	Curve A	Slope of Curve A	Curve B	Slope of Curve B	Curve C
1	5		100		105
		5		19	
2	10		81		91
		5		17	
3	15		64		79
		5		15	
4	20		49		69
		5		13	
5	25		36		61
		5		11	
6	30		25		55
		5		9	
7	35		16		51
		5		7	
8	40		9		49
		5		5	
9	45		4		49
		5		3	
10	50		1		51

This tabulation shows that between points 8 and 9, where the slopes of curves A and B are equal, the minimum point on the summation curve, curve C, is attained.

The reason for this relationship is as follows: the minimum of the total of two component curves cannot be found at a point where one of the component curves is rising or falling faster than the other component curve. At point 5 on the x axis, for example, curve A is rising at a rate of 5 units per unit on the x axis; curve B is falling, however, at a rate of between 13 and 11 units per unit on the x axis; it is clear therefore that if we go farther to the right on the x axis the total of the two curves will be lower than at this point, since curve B has then had an opportunity to drop faster than curve A has risen.

In every case, therefore, where we are dealing with relationships of this kind, the minimum of the total of two curves is found at a point where the slopes of the two component curves are equal. This relationship is helpful in analysing various types of curves; it even allows the introduction of a constant in one or both of the curves, since the addition of a constant does not change the slope of a curve and hence the minimum point for the summation curve is not shifted.

Where we are dealing with specific types of curves other relationships may occasionally be found, although the fundamental rule still holds. Matthews has found*, for example, that where one of the component curves is a straight line and the other a hyperbola the minimum point of their shear equation will have the same abscissa as the actual point of intersection of the two component curves; i. e., the slopes of these two curves are equal at their point of intersection. This relationship holds only when there are no constant terms in either of the equations.

COSTS AFFECTING THE FREQUENCY OF PORTABLE MILL MOVING

Every cost which might possibly be affected by the frequency of mill moving must be given consideration in order to analyze its effect on the total of all costs. The costs which are involved in logging operations and which might be given consideration here can be grouped as follows: 1, road building; 2, felling and bucking; 3, skidding or bunching logs; 4, loading and scaling; 5, hauling logs to the mill; 6, milling; 7, hauling boards from the mill to the concentration yard; and 8, mill moving.

* D. M. Matthews, to be published.

In order to have all costs on a comparable basis we must express them as costs per thousand board feet / of lumber handled. When we express costs on this basis we can see at once that certain of the above groups of costs are not affected by the frequency of mill moving; namely, felling and bucking, loading and scaling, and milling (not including the cost of mill moving). For our purposes we can also consider the cost of hauling boards to the concentration yard constant, since the relatively small distance of moving the mill will have no effect on the average cost of this hauling. This leaves the following costs to be brought into equilibrium in the attempt to obtain the minimum total costs: road building, skidding and bunching, hauling logs, and mill moving.

LOGGING A SQUARE AREA FROM ONE MILL SET-UP

Let us disregard for the moment the question of road building and assume that we are dealing with a portable mill operating on a railroad flatcar and moving on the track, or that for other reasons we do not wish to use roads in our primary logging operations. As a matter of convenience we shall then want to skid or haul logs directly through the woods from all directions to the mill. Although a circle or hexagon might be the most economical skidding or hauling area in this instance, we nevertheless would most likely wish to operate over an area approximating a square if the country were flat enough. The problem presenting itself here is similar to that of bunching logs or skidding/ logs from a square area to a landing, and the following analysis could therefore be applied to such operations.

The costs which have not as yet been eliminated from consideration now fall into two inversely related groups: 1) cost of getting the logs to the mill, and 2) the cost of mill moving prorated on the basis of area served from one mill set-up. The cost of bunching, being less directly related to mill moving than the cost of hauling logs, can now be dropped from consideration, since if necessary it could be treated in a separate calculation.

Figure 5 illustrated the area from which logs would be hauled to the sawmill which is set up in the center of the area. The cost of moving the mill must be prorated over the entire area in order that it may be expressed as a cost per thousand board feet. The cost of hauling logs can be figured per thousand board feet as soon as we devise some method of calculating the average hauling distance.

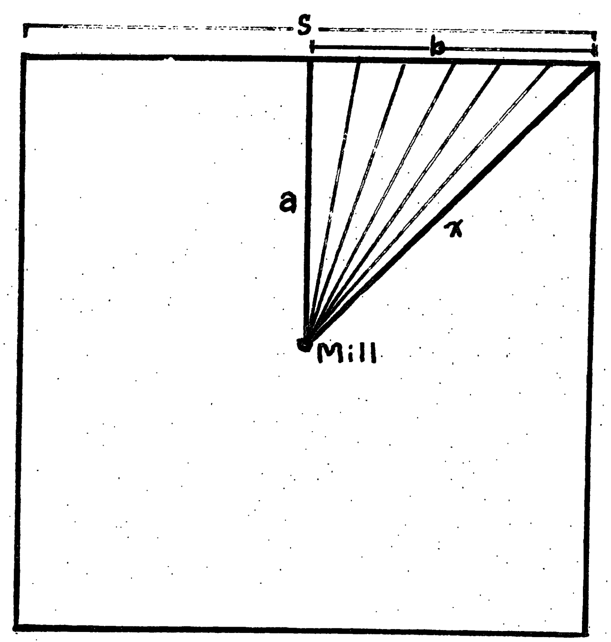

Figure 5. The area logged to the portable sawmill which is located in the center of the area.

The average hauling distance.

To find the average of the distances from the mill to the edge of the logging square we can apply the principle of the isosceles triangle. The maximum distance from the center of the square to the edge is that from the center to one of the corners, represented by the line x in figure 5. The minimum distance is that distance represented by a line running at right angles to one of the edges, from its middle point to the center of the square, as represented by line a. Since we are dealing with a square, line a is equal to the distance from the intersection of the edge of the square with line a to the corner of the square, as represented by line b, or a = b.

The average of the distances from the center of the square to its edge will be the average of lines a and x. In order to get this average distance in terms of one variable, we apply the Pythagorean theorem:

$$a^2 + b^2 = x^2 .$$

Since

$$a = b, \qquad a^2 + a^2 = x^2, \quad \text{and}$$

$$2(a)^2 = x^2;$$

Therefore

$$x = \sqrt{2(a)^2};$$

The average distance from the center to the edge of the square is

$$\frac{a + x}{2} .$$

Substituting a for x, we have the average distance in terms of a:

$$\frac{a + \sqrt{2(a)^2}}{2} .$$

The above equation represents the average of the maximum skidding distances. However, all logs do not come from the edge of the logging square, but are spread over the area. To find the average distance we must again base our calculations on the isosceles triangle used in the previous calcluations.

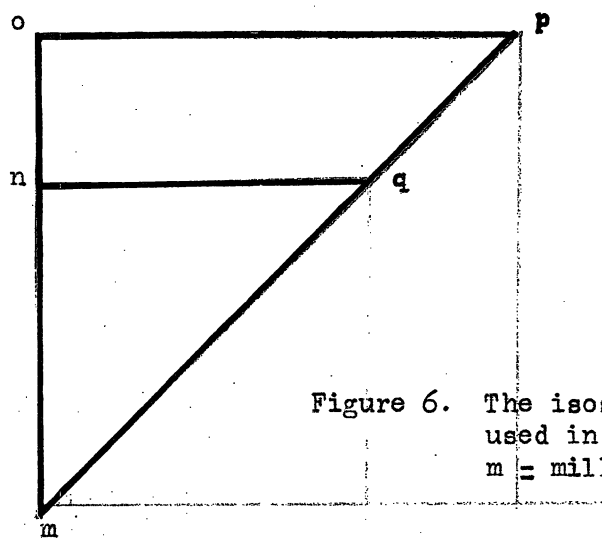

Figure 6. The isosceles triangle used in the calculations. m = mill location.

It will be seen from figure 6 that as we get farther from the mill, located at point m, the number of logs to be hauled from the area increases at a geometric rate with the area. Line o-p represents a portion of the edge of the logging square; line n - q will represent the average hauling distance from the area to point m, when prorated according to the number of logs coming from different portions of the area. This line will be the true average distance when the area m - n - q equals the area n - o - p - q.

Since we are dealing with isosceles triangles m-n = n-q, and m-o = o-p. The areas of these two triangles will therefore be $\frac{(m\ o)^2}{2}$ and $\frac{(m\ n)^2}{2}$. The area of the triangle m - n - q will equal the area of the figure n - o - p - q when the area of the triangle m - o - p ~~equal~~ minus the area of the triangle m - n - q equals the area of the triangle m - n - q. Hence

$$\frac{(m\ o)^2}{2} - \frac{(m\ n)^2}{2} = \frac{(m\ n)^2}{2}$$

and

$$\frac{(m\ o)^2}{2} = 2\ \frac{(m\ n)^2}{2}\ .$$

Cancelling and transposing we have,

$$(m\ n)^2 = \frac{(m\ o)^2}{2}$$

and

$$(m\ n) = \frac{(m\ o)}{\sqrt{2}}$$

Therefore

$$(m\ n) = \frac{(m\ o)}{1.41}$$

and, when (m o) equals unity,

$$(m\ n) = 0.707\ .$$

The ratio 1 : 0.707 expresses the relation between the distance from the center of the square to the edge and the distance from the center to the line which encloses half the area of the square. It is therefore a factor which can be applied to the formula developed on page 82, to convert the average maximum hauling distance into the true average distance. Applying this factor, we have the following formula to represent the average hauling distance for all the logs on the area:

$$\frac{a + \sqrt{2(a)^2}}{2}\ .707$$

When C is the cost of hauling logs, in cents per hundred feet of distance per M bd. ft., and a is expressed in hundreds of feet, the average cost of hauling, in cents per M bd. ft., is found by multiplying the above formula by C :

$$\underline{C\ (a + \sqrt{2(a)^2})\ .707}$$

The cost of moving the mill must now be calculated as a cost per thousand board feet. By construction (see figure 5) one side of the square logged to the mill is equal to 2 a ; the area of the square is therefore $(2\ a)^2$. When a is expressed in hundreds of feet, the resulting area will be expressed in units of 10,000 square feet. Since one acre contains 43,560 square feet it will contain 4.356 units of 10,000 square feet, and the area of the square, expressed in acres, is as follows:

$$\frac{(2\ a)^2}{4.356}$$

To determine the total volume of timber cut from the square whose area is found by the above formula, we need only multiply the area in acres by the average volume in acres. If V is the volume of timber per acre, in thousand board feet, the total volume on the area is:

$$\frac{(2\ a)^2\ V}{4.356}$$

In order to determine the cost of mill moving per thousand board feet, we now divide the total cost of mill moving, in cents, by the total volume cut on the area, as expressed by the formula above. When **M** is the cost of mill moving in cents, the cost of mill moving in cents per thousand board feet of timber cut therefore is:

$$\frac{M}{\frac{(2\ a)^2\ V}{4.356}}$$

which, simplified, becomes:

$$\frac{M\ 4.356}{(2\ a)^2\ V}$$

The balance of the costs of hauling logs to the mill and moving the mill is now attempted by setting the two above-mentioned formulae opposite each other in a simple break-even calculation. When all factors save the size of the area to be logged are known, the equation thus obtained will be useful in determining the size of the area to be logged in order to have the cost of hauling logs per M equal to the cost of mill moving per M. The equation is as follows:

$$\frac{C \left(a + \sqrt{2 (a)^2}\right) .707}{2} = \frac{4.356}{(2\ a)^2} \frac{M}{V},$$

where:

M = total cost of mill moving in cents,

a = half the distance of the side of the logging square, in hundreds of feet,

V = the volume per acre, in M bd. ft.,

C = the cost of hauling logs in cents per hundred feet of distance per M bd. ft.

The equation can be simplified as follows, in order to isolate a :
Multiply both sides of the equation by 2,
and divide both sides by .707 C:

$$a + \sqrt{2 (a)^2} = \frac{2\ M\ 4.356}{(2a)^2\ V\ C\ .707}$$

Simplify the $(2\ a)^2$ to $4\ (a)^2$ and multiply both sides by $(a)^2$:

$$a^2 \left(a + \sqrt{2 (a)^2}\right) = \frac{2\ M\ 4.356}{4\ V\ C\ .707}$$

The left side of the equation can be simplified to become:

$$a^2 (a + a \sqrt{2})$$

$$a^3 + (a^3 \sqrt{2})$$

$$a^3 (1 + \sqrt{2})$$

Then:

$$a^3 (1 + \sqrt{2}) = \frac{2\ M\ 4.356}{4\ V\ C\ .707}$$

and

$$a^3 = \frac{2 \quad M \quad 4.356}{4 \quad V \quad C \quad .707 \quad (1 + \sqrt{2})}$$

Simplifying the right side of the equation:

$$a^3 = \frac{8.712 \ M}{6.8268 \ V \quad C}$$

$$a^3 = \frac{1.276 \quad M}{V \quad C}$$

$$a = \sqrt[3]{\frac{1.276 \quad M}{V \ C}}$$

With the equation developed here it is possible to determine the size of the square required in order to have the cost of mill moving and the cost of hauling logs, both per M, equal. The answer, however, will be in terms of a, which is only half the length of one side of the square. If we wish to determine the size of the square in terms of its side, we must therefore multiply the answer by two; in other words, S = 2 a, where S is the length of the side of the square. The equation then becomes:

$$S = \sqrt[3]{\frac{1.276 \quad M}{V \quad C}} \times 2$$

where

S = the length of the side of the logging square, in 100 ft.,

M = the total cost of mill moving in cents,

V = the volume per acre, in M bd. ft.,

C = the cost of hauling logs in cents per hundred feet of distance, per M bd. ft.

The equation developed on the previous page is now ready for trial, using actual figures in place of the symbols. Let us use the data presented in the first part of this study of the portable mill, and solve for the size of the square to be logged. The data are as follows:

- S or 2 a = the length of the side of the square to be logged, in 100 feet, unknown, to be solved,
- M = the cost of moving the mill, in cents = 80,000 (page 53)
- V = the volume to be cut per acre, in M bd. ft. = 8 (the virgin stand, first cutting cycle, page 18),
- C = the cost of hauling logs through the woods, in cents per 100 ft. distance per M bd. ft. = 1.6 (page 61).

Substituting in the formula, we have:

$$S = 2 \sqrt[3]{\frac{1.276 \times 80,000}{8 \times 1.6}}$$

$$S = 2 \sqrt[3]{8,000}$$

$$S = 40$$

This answer tells us that the square to be logged if the cost of hauling logs per M is to be equal to the cost of moving the mill per M is 4000 ft. square.

This answer can be tested to see where the total minimum cost is obtained by actually calculating the cost of hauling and the cost of mill moving for squares of various sizes. These two items will then be totalled and the size of the most economical square to be logged to one mill set-up will be determined.

Table 49 shows the result of these test calculations. The first colums shows the length of the side of the square, in 100 ft., or S; column 2 shows the cost of mill moving per M, calculated by substuting the above figures in the formula shown at the bottom of page 85; the third column shows the cost of hauling per M, obtained by substituting the above figures in the formula at the bottom of page 84. The fourth column shows the total cost of hauling and mill moving, obtained by adding the figures in columns 2 and 3. (In these calculations S = 2 a, as explained on page 87; costs are in cents, distances in 100 feet.)

Table 49. Costs of mill moving and log hauling per M bd. ft. for logging squares of different sizes.

Length of Side of Square	Cost of mill moving per M	Cost of log hauling Per M	Total cost of mill moving & log hauling
10	435.6	6.8	442.4
20	109	13.7	122.7
30	48.5	20	68.5
35	35.5	23.8	59.3
40	27.2	27.2	54.4
45	21.4	30.6	52.0
50	17.4	34.1	51.5
51	16.7	34.7	51.4
52	16.1	35.4	51.5
55	14.4	37.3	51.7
60	12.1	40.8	52.9
70	8.9	47.5	56.4

This tabular statement of costs can also be expressed in graphic form, as shown in figure 7. Costs are shown on the ordinate, and the size of the square, expressed in terms of the length of its side, on the abscissa.

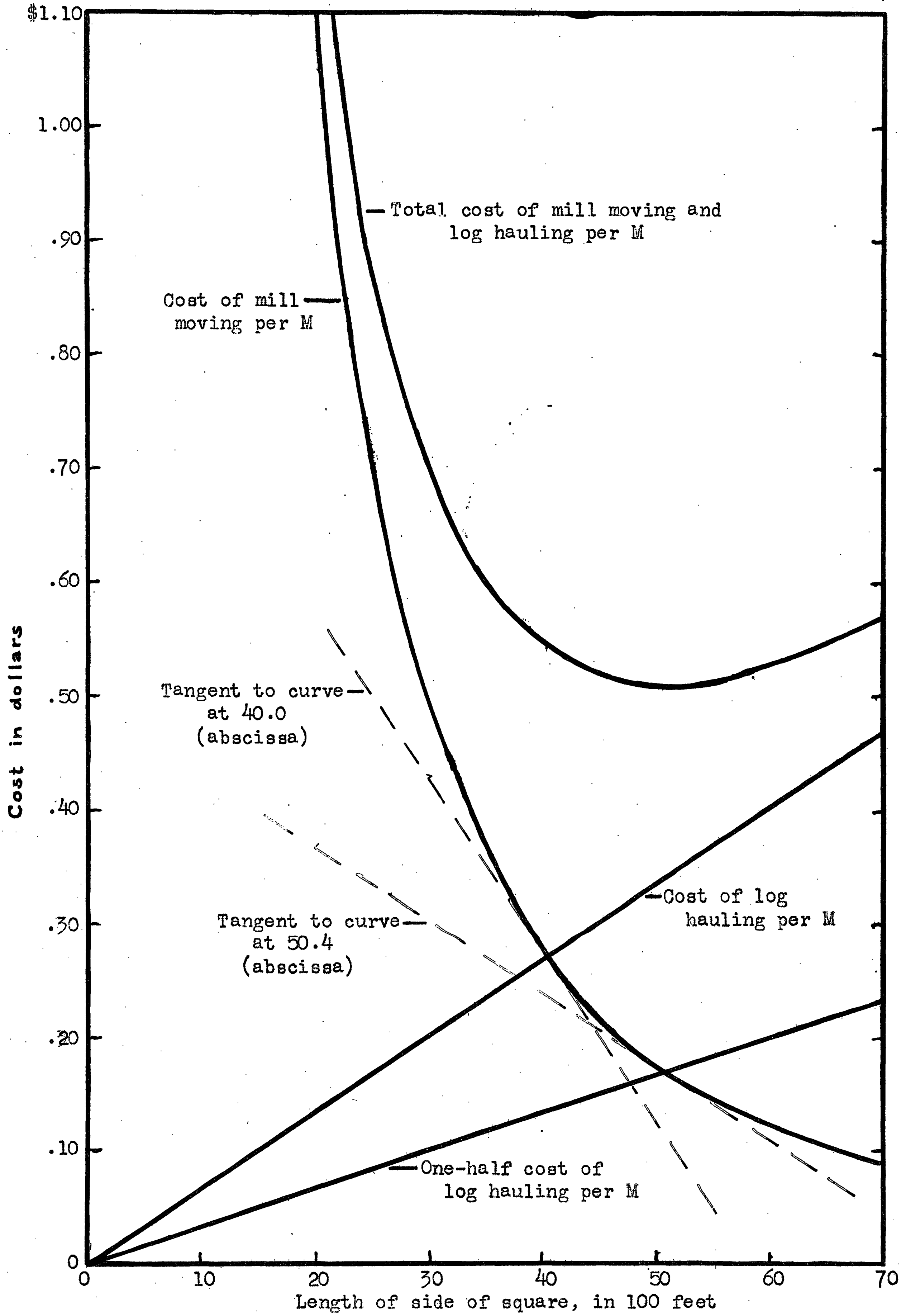

Figure 7. Costs of mill moving and log hauling per M b. m. for logging squares of various sizes.

This presentation of costs shows that when the logging area is 4000 feet square, as calculated on page 88, the costs of mill moving per M equals the cost of log hauling per M. The cost of log hauling rises at an arithmetic rate as the size of the square, hence the distance of the haul, becomes greater; the cost of mill moving falls at a geometric rate as the size of the square increases.

The minimum point on the total cost curve does not, however, fall at the point where the mill moving and log hauling cost curves cross, since figure 7 readily shows that at this point the slopes of the two component curves are not equal. We are not, therefore, dealing with curves similar to those discussed on page 79, where the slopes are equal at the point where their numerical values are equal. Hence the formula developed above to determine the size of the area to be logged from one mill-set-up will not hold without modification.

Examination of the curves in figure 7 will, however, show a different type of relationship. The slope of the curve representing mill moving costs can be shown at any point be drawing a line tangent to the curve at that point. A tangent to the mill moving cost curve at the point where the hauling cost curve crosses it clearly does not have the same slope as the hauling cost curve. However, a tangent having a slope equal to the slope of the hauling cost curve strikes the mill moving cost curve at point 50.4 on the abscissa. This, therefore, according to the relationship developed earlier in this paper, should be the point where the curve representing the total of the two cost curves is at its minimum; examination of the total cost curve will show this to be the case.

Furthermore, a curve drawn to represent one-half the hauling costs also crosses the mill moving cost curve at 50.4 on the abscissa. Therefore we have the following relation: the minimum total cost is found at a point where the cost of hauling logs to the mill is one-half the cost of moving the mill. On this basis we can therefore modify the break even formula which was used as the starting point for these calculations, as shown at the top of page 86, by dividing that side of the equation which represents hauling costs by 2.

The basic equation:

$$\frac{C\ \left(a + \sqrt{2\ (a)^2}\ \right)\ .707}{2} \leqq \frac{4.356\ M}{(2\ a)^2\ V}$$

then becomes

$$\frac{C\ \left(a + \sqrt{2\ (a)^2}\ \right)\ .707}{4} = \frac{4.356\ M}{(2\ a)^2\ V}\ ,$$

and the simplified form developed from the equation becomes:

$$S = 2\ \sqrt[3]{\frac{2.552\ M}{V\ C}}\ .$$

As on page 88 the proper figures can now be substituted in the equation, and the solution is as follows:

$$S \leqq 2\ \sqrt[3]{\frac{2.552\ \times\ 80{,}000}{8\ \times\ 1.6}}$$

$$S = 2\ \sqrt[3]{15{,}940}$$

$$S = 50.4$$

The proper size of the square to be logged is therefore one which is 5040 feet square. It has already been shown in table 49 and figure 7 that the minimum total costs are obtained when the area logged is of this size. The formula, therefore, is correct.

MILL MOVING WHEN A ROAD IS USED FOR HAULING LOGS

We have considered the problems involved in mill moving when a road was not used for hauling logs to the mill. Suppose, however, that we wish to use a road system for getting the logs out of the woods. The roads which will then be built will serve three purposes: 1) the mill will be moved on them; 2) logs will be hauled to the mill over them; and 3) boards will be hauled to the concentration yard on them. The area to be logged to the point at which the portable mill is set up would then resemble that shown in figure 8.

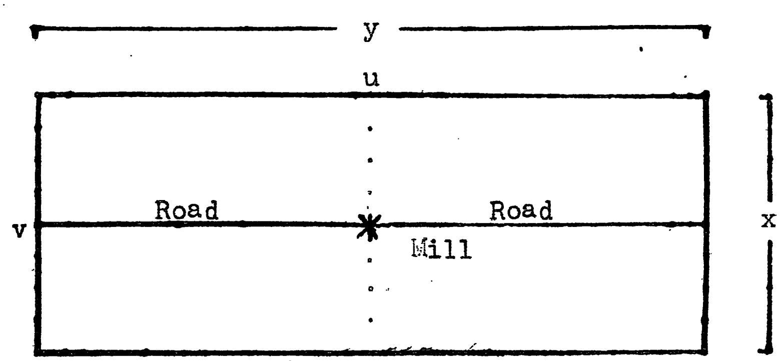

Figure 8. Area which might be logged to the portable mill set up in its center.

The road runs through the middle of the area and the mill is set up at its center.

The costs which must be considered in determining the most economical plan for moving the mill are: 1) cost of hauling logs through the woods; 2) cost of hauling logs on the road; 3) cost of road building; and 4) cost of mill moving. Again all costs must be figured on a thousand foot basis for purposes of comparison; costs will be figured in cents and distances in 100 feet.

Ordinary methods of arithmetic do not enable us to consider four variable costs in a single calculation. Therefore we must work with two variables at a time in the attempt to bring all costs into the proper proportion so that their total will be a minimum.

The relationship between the costs of woods hauling and road hauling will first be considered. Clearly those logs near the mill can most economically be hauled directly through the woods to the mill. If, however, hauling on the road costs less than hauling through the woods, other logs which are at some distance from the mill can be hauled more cheaply by moving them first directly to the road and then hauling them on the road to the mill.

The relationship between woods hauling and road hauling costs will determine the proportions of the rectangle to be logged, i. e., the ratio x : y in figure 8. For example, the cost of hauling a log from v on the road at the edge of the rectangle to the mill should equal the cost of hauling a log from u through the woods to the mill. If the cost of hauling from v to the mill were to be greater than the cost of hauling from u to the mill, then clearly the operator could get his logs to the mill cheaper by hauling logs through the woods from a point beyond u than by hauling from v, and the rectangle would be out of proportion if minimum costs were to be obtained.

The ratio of woods hauling costs to road hauling costs therefore is as 1 : 1, and a simple break-even calculation will establish the proper proportions of x - y. If y is the length of the long side of the rectangle and hence the length of the portion of the road within the area the average road hauling distance will be half the distance between one end of y and the mill, or $\frac{1}{4}$ y. Similarly the average woods hauling distance is $\frac{1}{4}$ x. If these distances are in 100 feet, and a represents the cost of woods hauling per 100 ft. per M and b represents the cost of road hauling on the road per 100 ft. per M, the break even calculation is as follows:

$$a \frac{1}{4} x = b \frac{1}{4} y$$

$$a x = b y$$

$$x = \frac{b y}{a} \qquad \text{or} \qquad y = \frac{a x}{b}$$

Either distance, x or y, can now be solved in terms of the other factor. For example, if y is 6,000 feet and the cost of road hauling per 100 ft. per M is 0.7 ¢ and the cost of woods hauling per 100 ft. per M is 1.6 ¢ :

$$x = \frac{0.7 \cdot 60}{1.6}$$

$$x = 26.2$$

In other words, when y is 6,000 feet, x should be 2,620 feet in order to obtain minimum costs for woods hauling and road hauling combined.

We shall next consider the relation between the cost of woods hauling and road building. D. M. Matthews* has shown that when the cost of skidding to a road, or in this case of hauling to a road, equals the cost of building the road per M the minimum total costs are obtained. Using the following symbols:

C = cost of skidding (or woods hauling) per M per 100 ft., in cents.

S = The economic spacing of roads, in 100 ft.

R = The cost of road building per mile, in cents.

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

the average skidding cost, in cents per M b. m. is:

$$C\, S\, \frac{1}{4}$$

* D. M. Matthews, to be published.

the road building cost in cents per M b. m. is:

$$\frac{R}{S} / \frac{12.1}{V} \; ,$$

and the economic spacing of the roads, in 100 feet, is:

$$S = \sqrt{\frac{4}{V}\frac{R}{C}} \; .$$

Again applying the same cost figures which we have used before, namely the costs which apply during the first cutting cycle of the portable mill operation, we have:

$\underline{C}$ = 1.6 = cost of woods hauling in cents per 100 ft. per M (= $\underline{a}$)

$\underline{R}$ = 75,000 = cost of road building in cents per mile

$\underline{V}$ = 8 = volume cut per acre, in M b. m.

and the formula for the economic spacing is:

$$S = \sqrt{\frac{4 \times 75{,}000 / 12.1}{8 \times 1.6}}$$

$$S = 43.8$$

In other words, when the spacing of the roads is 4,380 feet the costs of road building and woods hauling will be equal and their total will be a minimum. This can be checked by using the above formulae, substituting 43.8 for $\underline{S}$.

The cost of woods hauling then becomes:

$$1.6 \times 43.8 \times \tfrac{1}{4} = 17.5 ¢ \text{ per M}$$

and the cost of road building is:

$$\frac{75{,}000 / 12.1}{43.8 \times 8} \doteq 17.5 ¢ \text{ per M.}$$

Mill moving versus road hauling.

There is still another cost relationship which can now be determined, on the assumption that roads will be spaced on the economic distance of 4,380 feet: the cost of mill moving will be inversely related to the cost of hauling logs on the road. Given a strip of timber of a certain width, with a road running lengthwise through it, it is clear that, without drastic changes in the plan, the cost of road building per M and the average cost of hauling logs through the woods to the road are fixed. However, we can vary the spacing of the mill set-ups along the road. If we set up the mill at intervals of one mile along the road, the $800 moving charge will be spread over a strip of timber one mile long; the average road hauling distance will then be $\frac{1}{4}$ mile. If we set up the mill every half mile the cost of mill moving will effectively double, for it will amount to $1,600 per mile, while the average road hauling distance becomes 1/8 mile or half of what it was. There is therefore a direct inverse relation between the costs of mill moving and road hauling.

This is the same relationship which D. M. Matthews used as the basis for the economic spacing of a road calculation shown on the previous page. The cost of mill moving per M is found by dividing the total cost of mill moving by the area in acres ($\underline{x}\ \underline{y} \div 43,560$) times the volume per acre; the cost of road hauling per M is found by multiplying one-quarter of the length of the road within the area by the cost of road hauling per M per unit distance.

The following symbols are used, and with them are given the cost figures for the appropriate items, taken from the figures in the first part of this paper:

$\underline{M}$ = total cost of mill moving, in cents = 80,000

$\underline{V}$ = volume cut per acre, in M b. m. = 8 (first cycle)

$\underline{b}$ = cost of road hauling in cents per M per 100 ft. = 0.7

$\underline{x}$ = width of the area in 100 ft. = 43.8

$\underline{y}$ = length of the area in 100 ft., unknown.

The break-even calculation set up to solve for the unknown distance $\underline{y}$ is as follows:

$$\text{Cost of mill moving per M} = \text{Cost of road hauling per M}$$

$$\frac{4.356 \ M}{x \ y \ V} = \frac{b \ y}{4}$$

This can be simplified by cross multiplication:

$$4.356 \ M \ 4 = b \ x \ V \ y^2$$

and further:

$$y^2 = \frac{17.4 \ M}{b \ x \ V}$$

$$y = \sqrt{\frac{17.4 \ M}{b \ x \ V}}$$

When we now substitute the figures given above for the symbols we have:

$$y = \sqrt{\frac{17.4 \times 80,000}{43.8 \times 0.7 \times 8}}$$

$$y = 75$$

Given conditions as stated above, with roads 4,380 feet apart, the mill should be set up every 7500 feet in order to obtain the minimum of road hauling and mill moving costs.

This proposition can be tested by a simple check such as is shown in table 50. The column headed $\underline{y}$ gives various assumed distances between successive mill set-ups along the road. The next column gives the cost of mill moving per M, figured by the formula shown at the top of this page. The third column gives the cost of road hauling per M, also figured by the formula at the top of page 98. The last column gives the total cost per M for mill moving and road hauling. The minimum is found to occur when the spacing is 7,500 feet, for here mill moving and road hauling costs are equal at 13 ¢.

Table 50. Cost of mill moving and road hauling for various distances between mill set-ups.

y in 100 ft.	Cost of mill moving, cents	Cost of road hauling, cents	Total cost, cents
100	10	$17\frac{1}{2}$	$27\frac{1}{2}$
90	11	16	27
80	$12\frac{1}{2}$	14	$26\frac{1}{2}$
75	13	13	26
70	14	$12\frac{1}{4}$	$26\frac{1}{4}$
60	$16\frac{1}{2}$	$10\frac{1}{2}$	27
50	20	9	29

General conclusions.

We have now determined various relationships between the four costs which come into consideration in this mill moving problem. We have found that minimum total costs per M for the items involved are found:when:

woods hauling = road hauling

road hauling = mill moving

woods hauling = road building.

Since, in order to obtain minimum total costs, mill moving should be equal to road hauling, and road building should be equal to woods hauling, and woods hauling should equal road hauling, it follows that minimum total costs for the four items taken together are obtained when each factor equals each of the other three factors.

It will be practically impossible to obtain such an equitable balance of costs under actual field conditions. If we build a road at a certain cost per mile and build it at the economic spacing, and then use a mill which we move often enough so as to have the most economical distance between mill set-ups, it does not follow that the distance between mill- set-ups and the distance between roads will be in the proper relation. We have found, for example, that when the roads are spaced economically and the mills are moved at proper intervals so that the cost of mill moving per M equals the cost of road hauling per M, the rectangle to be logged is 4,380 feet wide and 7,500 feet long, and the costs per M are as follows:

mill moving	13 ¢ per M
road hauling	13
woods hauling	17½
road building	17½
Total	61 ¢ per M

We see at once from these figures that the proposition stated on page 95, that woods hauling costs must equal road hauling costs, does now hold when we try to equalize other costs. The reason for this becomes clear when we apply the simple ratio

$$a\ x = b\ y$$

explained on page 95. We find that when we apply this, the size of the rectangle to be logged would change considerably. With the costs as stated above, an area which is 4,380 feet wide should be 10,000 feet long, and inversely an area which is 7,500 feet long should be only 3,300 feet wide, in order that minimum costs for road hauling and woods hauling may be obtained. Using the methods developed above let us see what happens to our total costs when we are dealing with logging areas of these dimensions.

	Dimensions of area to be logged	
	4,380 x 10,000	3,300 x 7,500
	Costs per M b. m.	
Mill moving	10 ¢	17½ ¢
Road building	18	23½
Woods hauling	17	13
Road hauling	17	13
Totals	62 ¢	67 ¢

Immediately when the costs of woods hauling and road hauling become equal the costs of mill moving and road building get out of proportion.

These figures serve to show that no set rule for finding minimum costs can be applied when we are dealing with four variable costs. An analysis such as that given above will, however, yield figures which can be compared in the attempt to bring the total of all costs to a minimum. In the particular instance dealt with here, it would seem that the most economical area to log from a single mill set-up is a rectangle 4,380 feet by 7,500 feet. Yet to err on the side of making this area excessively large would not appreciably increase total costs. Moving the mill too often would be a more serious mistake, for the total costs might then rise sharply.

In general we can say that the economic spacing of the roads should be adhered to. If, upon analyzing the costs of mill moving and road hauling it is found that the cost of mill moving exceeds the cost of road hauling by a considerable amount, other methods can be applied to bring this cost down. For example, the mill could be set up half-way between to parallel roads; this would increase the road hauling charge by only a small amount proportional to the distance between the two roads, while the mill moving charge would be cut in half because the area adjacent to two roads could be logged to one mill site. Such an area is shown in figure 9.

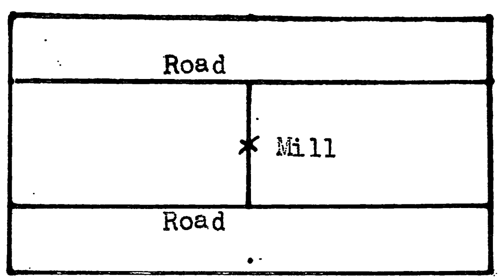

Figure 9. Area to be logged to a single mill site when the cost of mill moving is to be reduced, in proportion to other costs.

If, on the other hand, the opposite extreme prevails, namely, that the cost of mill moving is very low while the cost of building roads is very high, the cost of mill moving would be entirely out of balance with the cost of woods hauling, for the roads would have to be far apart. In such a case it might be wise to move the mill into the woods to a point where it would not pay to build roads, and do all the hauling directly through the woods to the mill, disregarding the road as channel for hauling logs. In this case the formula to find the economic size of a square area, developed in the first part of this paper, would apply. The entire road system would then serve only for hauling boards and for bringing the mill into the area, and would be only an incidental accessory to the logging operations.

Economic planning, with the aid of a few calculations such as those above, will prevent a prospective portable mill operator from purchasing the type of equipment not adapted to the prevailing conditions in the region. This study seems to show that a large portable mill/such as the one used in this study, which costs $800 to move, is adapted to a flat region where roads can be built anywhere at will. In rougher country where the cost of moving logs is high, a mill which can be moved cheaply and therefore often will save the operator a great deal of money in log hauling costs.

The most economical plan of operation will be one which has accomplished a balance of all the items which affect woods costs: the volume of timber cut per acre, the type of road, the cost of moving logs through the woods, and the size or type of mill.

SUMMARY , PART II

The problem of economically locating a portable sawmill is primarily one of moving it at proper intervals in order to obtain the proper balance of the costs related to the frequency of mill moving. In determining minimum costs we are generally dealing with sets of costs which are inversely related and which rise or fall at definite rates as conditions change.

When two inversely related costs are represented graphically the following general rule may be applied in order to obtain the minimum cost for the two related costs combined: where the slopes of two inversely related curves, or the rates of change expressed as the differences between successive points on the two curves, are equal, the total of the two is at a minimum.

When a portable mill is set up in such a way that logs will be hauled directly through the woods to the mill, without the use of roads, the area logged to a single mill-site will most likely be a square. In this case the costs which are inversely related, and which must be brought into balance in order to obtain minimum total costs are: 1) the cost of hauling logs to the mill, per M b. m.; and 2) the cost of moving the mill, per M b. m.

Certain formulae useful in the analyzation of costs involved in portable mill moving are developed. The symbols used in the formulae are as follows:

<u>M</u> = total cost of mill moving, per set-up, in cents;

<u>V</u> = volume of timber cut per acre, in M b. m.;

<u>C</u> = cost of hauling logs through the woods, in cents per 100 feet of distance per M b. m.;

<u>a</u> = one-half the length of the side of the logging square, in 100 feet;

$\underline{S}$ = total length of the side of the logging square, in 100 feet.

The formulae used for the cost calculations when the area to be logged to the mill-site is a square ~~is~~ are as follows:

Average cost of hauling logs through the woods to the mill: in cents per M b. m.

$$\frac{C \left(a + \sqrt{2 (a)^2} \right) .707}{2}$$

Average cost of mill moving in cents per M b. m.:

$$\frac{M \quad 4.356}{(2\ a)^2 \quad V}$$

The length of the side of the square to be logged from one mill site, when minimum costs are to be obtained; in 100 ft.:

$$S = 2 \sqrt[3]{\frac{2.552 \quad M}{V \quad C}}$$

When roads enter the picture and are used for the purpose of hauling logs, the area to be logged to a mill site which is located along the road becomes a rectangle. Logs are then hauled directly to the nearest point on the road and along the road to the mill. The minimum total cost for all costs related to the frequency of mill moving is obtained when the four following groups of costs are all equal:

mill moving per M b. m.,

road building per M b. m.,

woods hauling per M b. m.,

and road hauling per M b. m.

The following symbols are used in formulae which can be applied in analyzing the relationships between various groups of costs:

$\underline{x}$ = width of the rectangle to be logged, in 100 ft.;

$\underline{y}$ = length of the rectangle to be logged, in 100 ft.;

a = cost of hauling logs through the woods in cents per 100 ft. distance per M b. m.;

b = cost of hauling logs on the road in cents per 100 ft. distance per M b. m.; (= C in the calculation for economic road spacing);

S = economic spacing of roads in 100 ft.;

R = cost of road building in cents per mile;

V = volume cut per acre in M b. m.;

M = total cost of mill moving (per move) in cents.

When either the length or width of the area to be logged is known, the following formula can be used in order to find the unknown term, so that the rectangle will be of such proportions that the average road hauling cost equals the average woods hauling cost:

$$a\,x = b\,y.$$

In figuring the economic spacing of roads, that is, that spacing which is required in order that the cost of road building per M equals the cost of mill moving per M and that their total is at a minimum, the following formulae apply:

Average woods hauling cost; per M: (in cents)

$$C \; S \; \frac{1}{4}.$$

Average road building cost, in cents per M:

$$\frac{R \;/\; 12.1}{S \quad V}$$

The economic road spacing, in 100 feet:

$$\sqrt{\frac{4\,R}{V\,C}}$$

When the road spacing is set and it is desired to figure the economic spacing of the mill along the road in order that the cost of mill moving per M equals the cost of road hauling per M, the following formulae can be used:

Cost of mill moving in cents per M b. m.:

$$\frac{4.356}{x\ y}\ \frac{M}{V}$$

Cost of road hauling in cents per M b. m., average:

$$\frac{b\ \ y}{4}$$

Economic spacing of the mill along the road in order to obtain minimum total costs for mill moving and road hauling, in 100 feet:

$$y = \sqrt{\frac{17.4\ \ M}{b\ \ x\ \ V}}$$

Simple arithmetic means are not sufficient in order to determine the relationships between the four variable costs involved in this problem. The absolute minimum of total costs, attainable only when all four variable costs are equal, cannot be obtained when the type of road and the type of mill are not adapted to each other. Under ordinary conditions the size of the rectangle dealt with here can vary somewhat without having a serious effect on the total costs.

In general it is best to build roads on the economic spacing and then to choose mill sites at the most economical intervals along the roads. The principles underlying the choice of the most economical mill sites will vary with the conditions and must be analyzed for each operation according to the methods proposed in this paper.

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