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A COMPARISON OF THE COSTS OF OPERATION OF THE MOTOR BUS, BIRNEY
SAFETY CAR AND TROLLEY BUS ON THE LOCAL TRANSPORTATION
ROUTES IN PASADENA

By

Douglas A. Stromsøe

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I - INTRODUCTION

With the installation by the Pacific Electric Railway of a bus system in Pasadena to supplant most of its trolley lines, the problem of the comparison of the costs of the two systems naturally presented itself. The study here undertaken was originally started as just a comparison of the motor bus and Birney Safety Car, but as the work progressed it seemed advisable to include the trolley bus as well - a method of transportation that is comparatively new as far as development is concerned, but which seems to be finding increasing favor in the East.

II - SCOPE OF STUDY

The Pacific Electric Railway proposes to establish nine bus routes, lettered from A to I, supplanting existing rail routes and extending to other regions not hitherto served. Three of the rail routes will be retained, numbered in this study Routes, 1, 2 and 3, and upon these three routes Birney Safety Cars are to be operated. This makes a total of twelve routes and each of these twelve is here considered with respect to all three systems of transportation.

It might be well to mention here one of the advantages of the bus system - that of being able to experiment on a certain route to determine whether it would be

profitable, before any expensive equipment is installed, such as rails and trolley wires. In this way, shifts may be made from time to time in the streets operated upon, until the best route is found. Thus an initial bus route, such as those here presented, may be entirely different after a few months of operation. However, in the present study it is assumed that these routes as selected by the Pacific Electric under advisement of the City of Pasadena represent the best routes that could be picked and that any future rail development would be along the same streets. A rail route, however, would perhaps be somewhat shorter than a bus line serving the same territory due to the elimination of loops, and allowance has been made for such a contingency.

Another consideration is that in the case of two or three rail lines using the same street (as Colorado Street) for a portion of their distances, the entire initial cost of the rails on the portion common to two or more lines should not be charged to each. To do so, however, is on the side of safety.

The Pasadena Short Line and the Oak Knoll are interurbans and although they handle local traffic in Pasadena they must be run anyhow, and a study of their operation as relating to local traffic need not be considered here.

The lengths of the rail lines were found by scaling from a map and the lengths of the bus lines were taken from

Pacific Electric data.

It is assumed that the average speed of buses will be nine miles per hour and that of the cars and trolley buses ten miles. This is due to the fact that the buses must draw up to the curb to discharge and take on passengers, and that the electric motored vehicle will have a little faster pick-up than the motor bus.

The comparison is made on the basis of equivalent service by each system. The short or rush-hour headway is assumed for five hours each day, with double that headway (or half the service) for the remaining fifteen hours of the twenty hours daily operation. (See data sheets).

III - UNIT COSTS

An examination of the various items affecting the cost of operation of a bus or car show that some of these items are constant regardless of the number of car miles operated, while others vary with the number of miles of travel. Because of this fact the best way to compare costs is by a study of curves showing the variation for each mode of transportation, of the cost per car mile with respect to the total car miles operated. Since the number of car miles operated is based on the headway maintained, a knowledge of the demands of service will make these curves of value in showing just which system would be cheapest in operation on a given route -

not only at present but also when increased service will increase the car miles operated.

In compiling a list of expenses of operation two authorities were used - Thirlwall in "Bus Transportation" (Sept. 1922) and the Interstate Railroad Commission figures on the comparison of costs of operation of several trucks tested under its supervision. Where sufficient data was lacking approximations were made of some of the costs. This is warranted as long as these figures remain comparable for the three systems of service.

The fixed costs in dollars per car mile are:

	<u>BIRNEY CAR</u>	<u>TROLLEY BUS</u>	<u>MOTOR BUS</u>
1. Power (@\$.015 per K.W.Hr. cost \$.025 per car mile)	\$.0250	\$.0250	
2. Gasoline (7.9 mi. per gal. @20¢)			\$.0253
3. Lubricants (400 " " " @ 70¢)	.0006	.0006	.0018
4. Tires (\$300 per six with 12000 mile life)		.0167	.0167
5. Repairs	.0170	.0170	.0350
6. Maintenance of Way	.0180		
7. Drivers' Wages	.0289	.0289	.0289
8. Superintendence	.0035	.0035	.0022
9. Garage (Thirlwall gives costs per mile of track for car barns, substations, etc.-See formulae below)			.0029
10. Insurance			

	BIRNEY CAR	TROLLEY BUS	MOTOR BUS
(a) Fire & Theft	\$.0024	\$.0024	\$.0024
(b) Collision	.0026	.0026	.0026
(c) Property Damage	.0014	.0014	.0014
(d) Liability	.0112	.0112	.0112
11. Administration	.0039	.0039	.0025
12. Depreciation	.0150	.0150	.0400
Bus: Initial Cost \$8,000, life 200,000 miles.			
Birney Car & Trolley Bus: Initial Cost \$6,000, life 400,000 miles.			
13. Miscellaneous (3%)	<u>.0039</u>	<u>.0039</u>	<u>.0052</u>
TOTAL	\$.1334	\$.1321	\$.1781

The costs here tabulated are incorporated in the formulae deduced below.

IV - DEVELOPMENT OF FORMULAE

A. FOR MOTOR BUS

Let. b = number of buses required.
 c = total cost per car mile in dollars.
 h = maximum headway.
 l = one way length of route.
 m = number of bus miles operated per year.

1. Interest on Bus Investment
 $.06 \times 8000 = \$480$ interest per bus per year
Then $\frac{480b}{m} =$ cost per bus mile.

2. Interest on garage investment

Investment = \$1000 per bus

Interest = $.06 \times 1000 = \$60$ per bus per year.
Then $\frac{60b}{m} =$ cost per bus mile

3. Garage Depreciation.

Garage life assumed as fifty years

$$\frac{1000}{50} = \$20 \text{ cost per bus per year}$$

Then $\frac{20b}{m} = \text{cost per bus mile.}$

The total cost per bus mile for the Motor Bus = $c =$

$$.1781 + \frac{480b}{m} + \frac{60b}{m} + \frac{20b}{m} = .1781 + \frac{560b}{m}$$

B. FOR BIRNEY CAR AND TROLLEY BUS.

Let. b_1 = number of cars or buses required.

c_1 = total cost per car mile in dollars for Birney Car.

c_2 = total cost per car mile in dollars for Trolley Bus.

h = maximum headway.

l_1 = one way length of route.

m_1 = car miles operated per year

1. Interest on Car or Bus Investment

$.06 \times 6000 = \$360$ interest per car per year.

Then $\frac{360b_1}{m_1} = \text{cost per car mile.}$

2. Interest on Shop, Distribution and Transmission, and Generating and Sub-Station investments.

Shop Investment	\$2000 per mile
Distrib. & Transm.	" "
Investment	6500 " "
Generating & Sub-Sta-	
tion Investment	4500 " "
Total	\$13000 " "

Interest = $.06 \times 13,000 = \$780$ per mile per year

Then $\frac{780l_1}{m_1} = \text{cost per car mile}$

3. Depreciation of Shops, Sub-Station, etc.

Assumed life = 50 years

Cost per year per mile = $\frac{13,000}{50}$ = \$260

Then $\frac{260}{m_1} l_1$ = cost per car mile.

4. Interest on Track Investment

Cost per mile of track = \$50,000

Interest = .06 x 50,000 = \$3,000 per year per mile.

Then $\frac{3,000}{m_1} l_1$ = cost per car mile

5. Track Depreciation

Assumed that track last 30 years under a 2 minute headway of 20 hours per day, then life in car miles = $30 \times 20 \times 12$ trips per hour $\times 365 = 13,140,000$ miles.

Then cost per car mile per mile of track =
 $\frac{50,000}{13,140,000} = \$.0190$

and cost per car mile for route = $.0038 l_1$

The total cost per car mile for the Birney Car = $c_1 =$
 $.1334 + .0038 l_1 + \frac{360b_1}{m_1} + \frac{260}{m_1} l_1 + \frac{780}{m_1} l_1 + \frac{3000}{m_1} l_1 =$

$.1334 + .0038 l_1 + \frac{360b_1 + 4040}{m_1} l_1$

The total cost per car mile for the Trolley Bus = $c_2 =$

$.1321 + \frac{360b_1}{m_1} + \frac{260}{m_1} l_1 + \frac{780}{m_1} l_1 = .1321 + \frac{360b_1 + 1040}{m_1} l_1$

In order to find b , b_1 , m and m_1 , of the formulae above:

Let. s = average speed in miles per hour

l = one way length of line

h = regular headway in minutes

$\frac{h}{2}$ = rush hour headway in minutes.

$$\text{Time for one round trip} = \frac{2 \times 60}{s} l = \frac{120}{s} l$$

The buses required for rush hour service are those required for the line. Extra buses cannot be changed from route to route, because rush hours will occur at about the same time on all lines.

$$b = \frac{120}{s} l \times \frac{2}{h} = \frac{240}{s \cdot h} l$$

This must be a whole number to substitute in the formula for c , as a fraction of a bus cannot be used.

$$\text{Since } s = 9 \text{ miles per hour for Bus then } b = \frac{26.67}{h} l$$

$$s = 10 \text{ miles per hour for Birney Car and Trolley Bus}$$

$$\text{and } b_1 = \frac{24}{h} l_1$$

Let. h = regular headway in minutes

$$\frac{h}{2} = \text{rush hour } " " "$$

n = number of hours per day of h headway

$$\frac{n}{3} = " " " " " \frac{h}{2} "$$

l = one way length of route

$$\text{Then } m = \left[\frac{60m}{h} + \frac{20n}{3} \times \frac{2}{h} \right] 2 \times 365 l = \frac{73,000 l n}{h}$$

But $n = 15$

$$\text{Therefore } m = \frac{1095000}{h} l$$

$$\text{and } m_1 = \frac{1095000}{h} l_1$$

Recapitulation of formulae developed:

Let. b = number of buses required.

b_1 = " " cars or Trolley Buses required.

c = total cost per bus mile for Motor Bus.

Let. c_1 = total cost per car mile for Birney Car.

Let. c_2 = " " " bus " " Trolley Bus.

h = maximum or regular headway in minutes

l = one way length of bus route.

l_1 = " " " car or trolley bus route.

m = number of bus miles per year.

m_1 = " " car or trolley bus miles per year.

MOTOR BUS

$$m = \frac{1095000}{h}$$

$$b = \frac{26.67}{h} l, \text{ where } b \text{ is a whole number.}$$

$$c = .1781 + \frac{560b}{m}$$

BIRNEY CAR AND TROLLEY BUS

$$m_1 = \frac{1095000}{h} l_1$$

$$b_1 = \frac{24}{h} l_1 \text{ where } b_1 \text{ is a whole number.}$$

$$c_1 = .1334 + .0038 l_1 + \frac{360b_1 + 4040}{m_1} l_1$$

$$c_2 = .1321 + \frac{360b_1 + 1040}{m_1} l_1$$

SAMPLE CALCULATIONS

$$l = 3.5 \text{ miles}$$

$$l_1 = 3.4 \text{ miles}$$

$$h = 60 \text{ minutes}$$

$$m = \frac{1095000 \times 3.5}{60} = 63875 \text{ car miles.}$$

$$m_1 = \frac{1095000 \times 3.4}{60} = 62050 \text{ car miles}$$

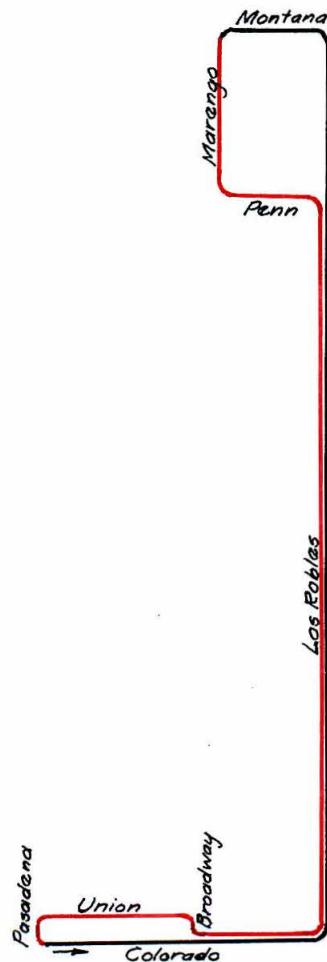
$$b = \frac{26.67 \times 3.5}{60} = 2 \text{ buses}$$

$$b_1 = \frac{24 \times 3.4}{60} = 2 \text{ cars or trolley buses.}$$

$$c = .1781 + \frac{560 \times 2}{63875} = \$.1956 \text{ per bus mile}$$

$$c_1 = .1334 + .0038 \times 3.4 + \frac{360 \times 2 + 4040 \times 3.4}{62050}$$
$$= \$.3793 \text{ per car mile.}$$

$$c_2 = .1321 + \frac{360 \times 2 + 1040 \times 3.4}{62050}$$
$$= \$.2006 \text{ per bus mile.}$$

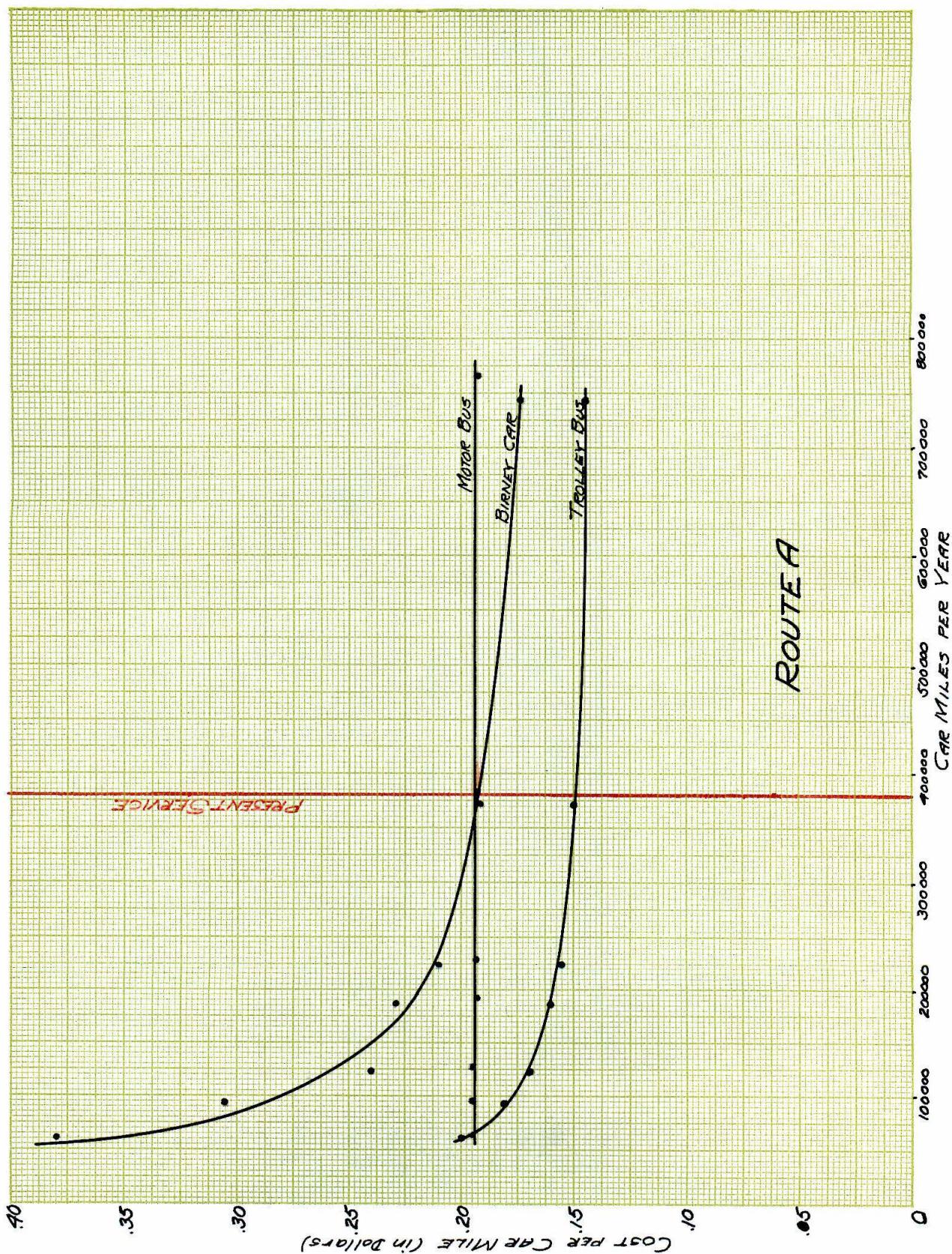


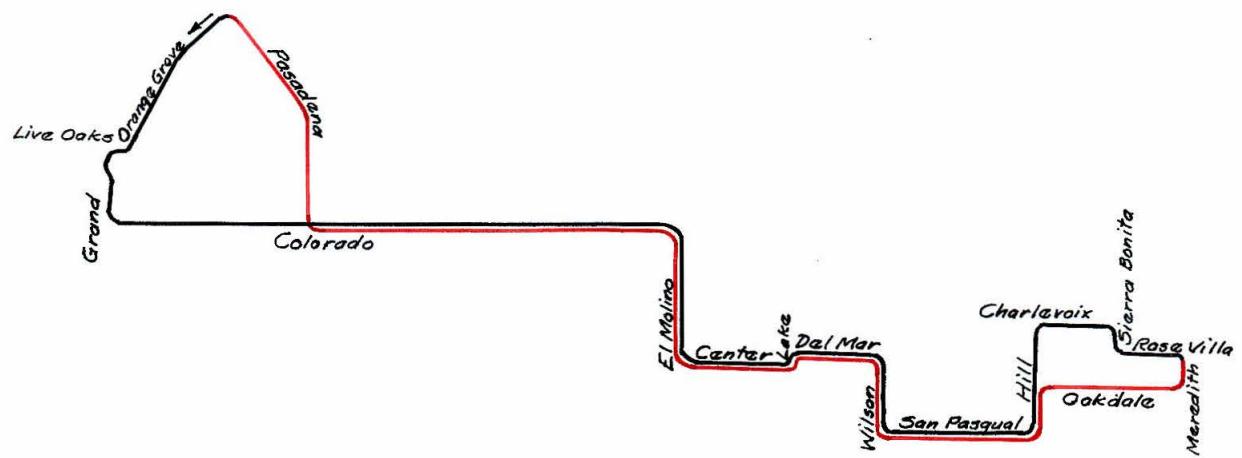
ROUTE A

— OUTBOUND
— INBOUND

ROUTE A

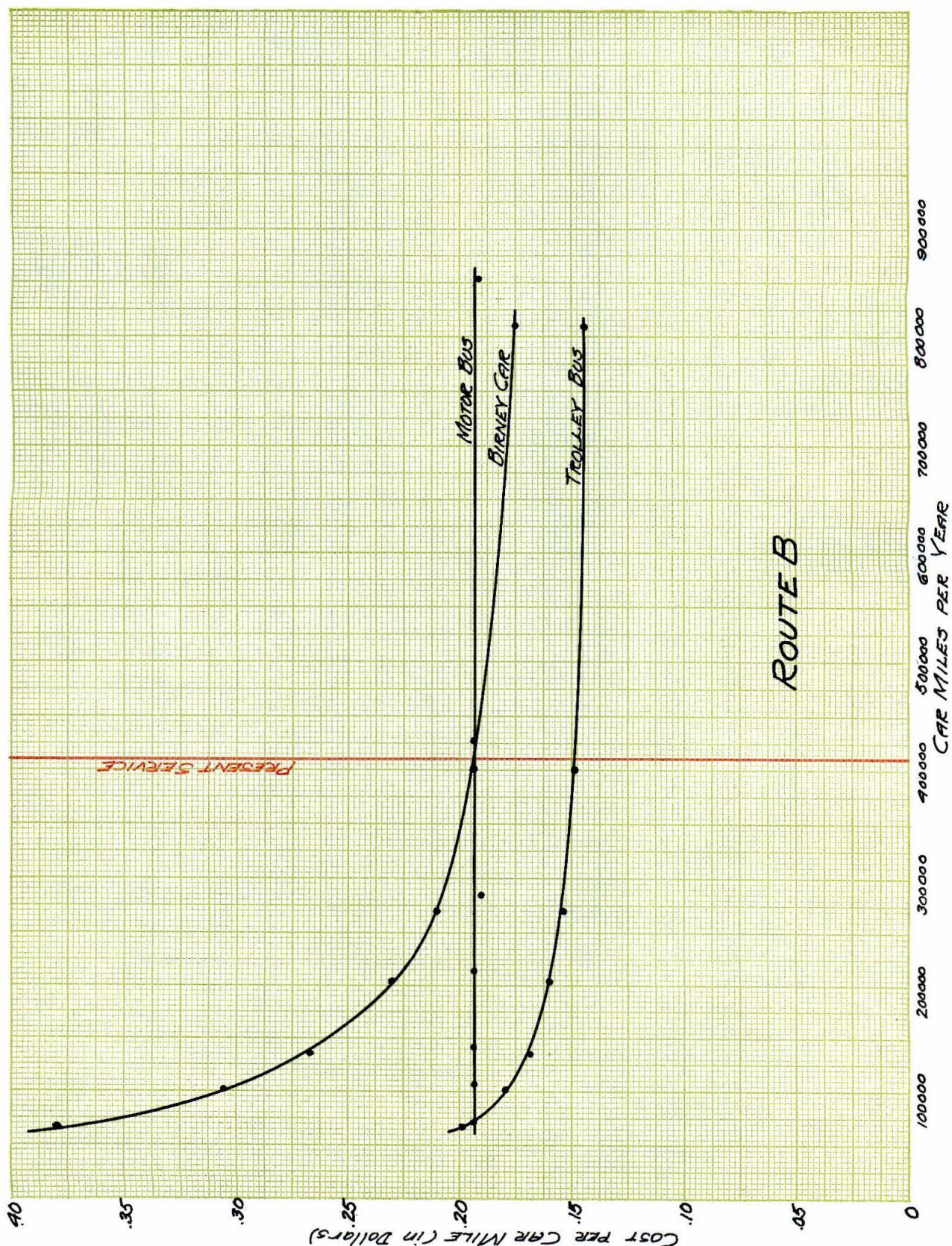
HEADWAY in minutes	LENGTH OF LINE in miles	CAR MILES PER YEAR		VEHICLES REQUIRED	Cost per car mile in dollars					
		Bus Bouverie Trolley Bus = M_1	Bus Bouverie Trolley Bus = M_2		Bus Bouverie Trolley Bus = C_1	Bus Bouverie Trolley Bus = C_2				
5 Hours 20 Minutes										
30	60	3.5	3.4	63875	62050	2	2	.1956	.3793	.2006
20	40	"	"	95813	93075	3	3	.1956	.3055	.1816
15	30	"	"	127750	124100	4	3	.1956	.2405	.1692
10	20	"	"	191625	186150	5	5	.1927	.2298	.1608
7.5	15	"	"	255500	248200	7	6	.1934	.2103	.1550
5	10	"	"	383250	372300	10	9	.1927	.1919	.1503
2.5	5	"	"	766500	744600	19	17	.1920	.1730	.1451

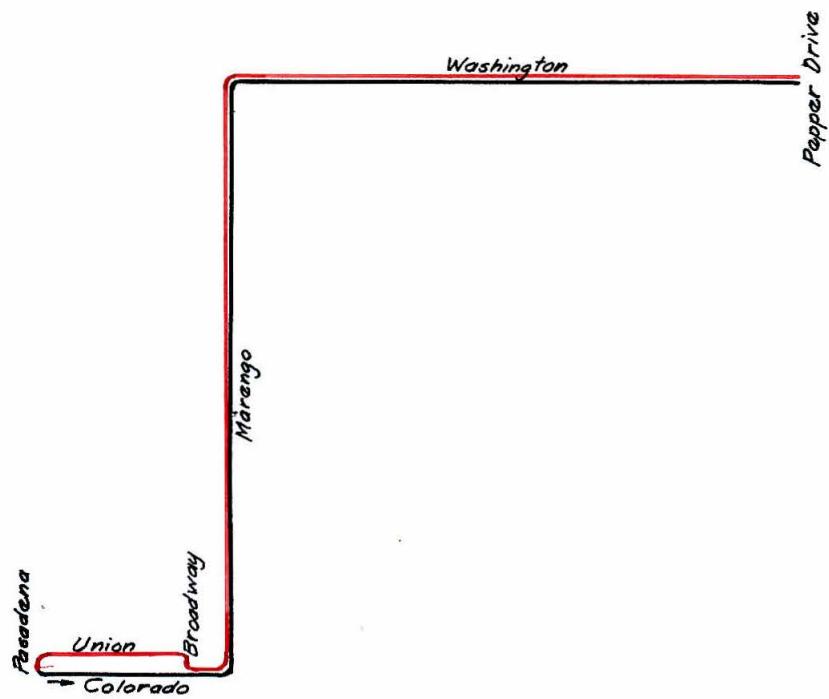




ROUTE B

HEADWAY in minutes		LENGTH OF LINE in miles		CAR MILES PER YEAR		VEHICLES REQUIRED		COST PER CAR MILE in dollars		
5 Hours	20 Hours	Bus	BIRNEY CAR TROLLEY BUS	Bus	BIRNEY CAR TROLLEY BUS	Bus	BIRNEY CAR TROLLEY BUS	Bus	BIRNEY CAR	TROLLEY BUS
		= 1	= 1_1	= m_1	= m_1	= 6	= D_1	= C_1	= C_1	= C_2
30	60	3.9	3.7	71175	67525	2	2	.1938	.3802	.1997
20	40	"	"	106763	101288	3	3	.1938	.3064	.1807
15	30	"	"	142350	135050	4	3	.1938	.2668	.1686
10	20	"	"	213525	202575	6	5	.1938	.2309	.1600
7.5	15	"	"	284700	270100	7	6	.1909	.2115	.1543
5	10	"	"	427050	405150	11	9	.1935	.1931	.1496
2.5	5	"	"	854100	810300	21	18	.1919	.1746	.1448





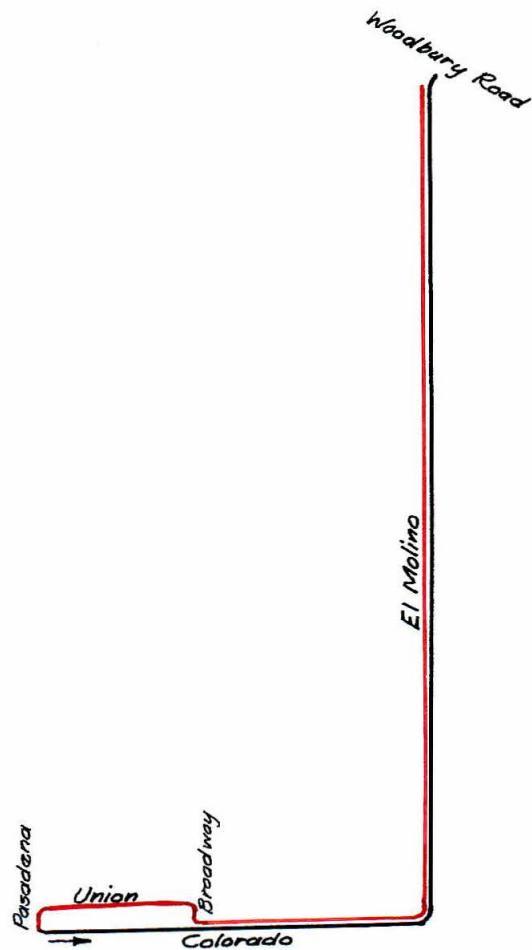
ROUTE C

— OUTBOUND
— INBOUND

ROUTE C

HEADWAY in minutes	LENGTH OF LINE in miles		CAR MILES PER YEAR		VEHICLES REQUIRED		COST PER CAR MILE in dollars			
5 hours	20 hours	Bus	Birney Car Trolley Bus	Bus	Birney Car Trolley Bus	Bus	Birney Car Trolley Bus	Bus	Birney Car Trolley Bus	
30	60	5.9	5.7	107675	104025	3	3	.1937	.3868	.1994
20	40	"	"	161513	156038	4	4	.1920	.3119	.1793
15	30	"	"	215350	208050	6	5	.1937	.2744	.1692
10	20	"	"	323025	312075	8	7	.1920	.2370	.1592
7.5	15	"	"	430700	416100	11	10	.1924	.2191	.1550
5	10	"	"	646050	624150	16	14	.1920	.2001	.1497
2.5	5	"	"	1292100	1248300	32	28	.1920	.1816	.1449



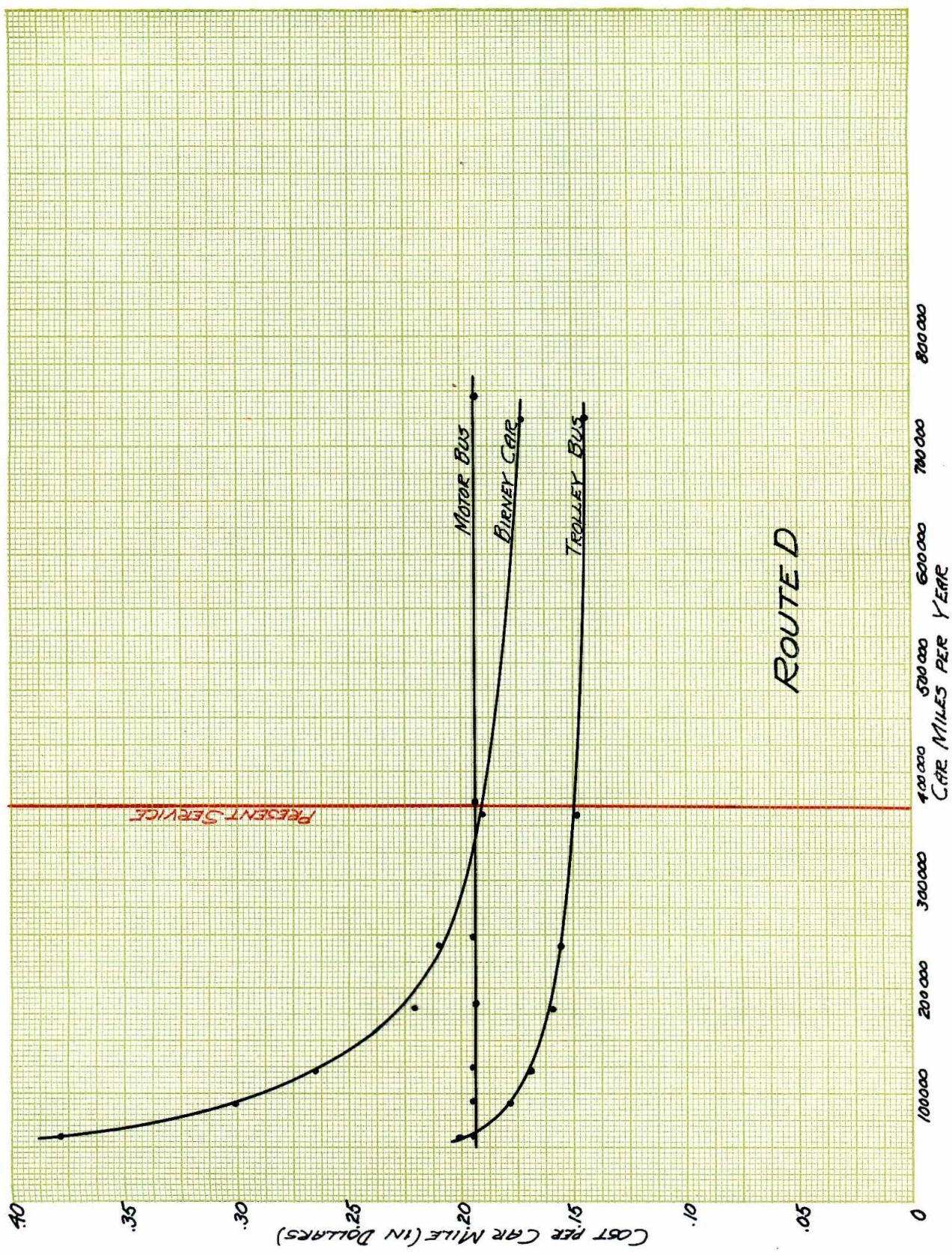


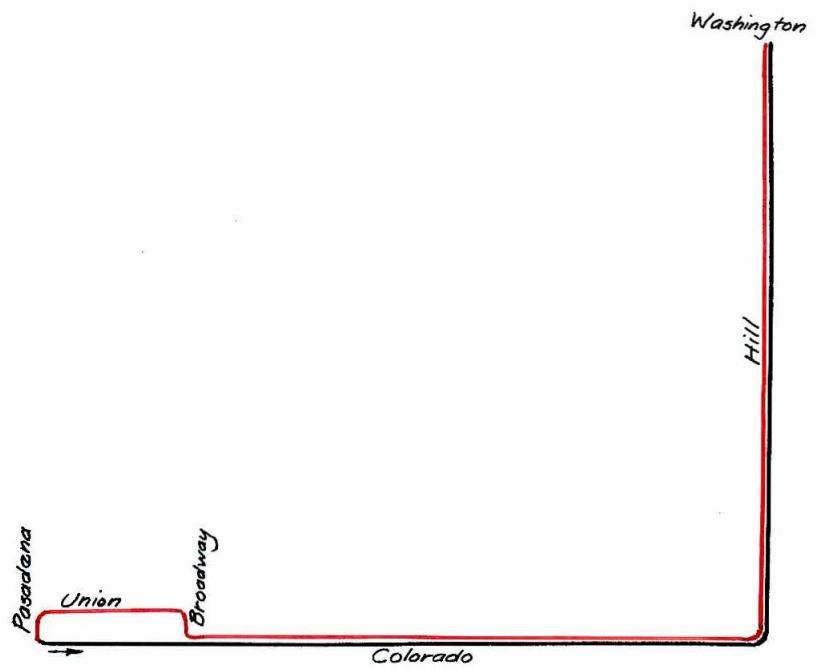
ROUTE D

— OUTBOUND
— INBOUND

ROUTE D

Passenger Miles per Year	Cost of Line per mile	Car Miles per Year	Vehicles Required	Cost per Car Mile in dollars		
				Bus	Birney Car Trolley Bus	Bus
300000000	\$10.00	300000000	60	60	60	60
200000000	7.10	200000000	40	40	40	40
150000000	5.50	150000000	30	30	30	30
100000000	4.00	100000000	20	20	20	20
7.50000000	3.00	75000000	15	15	15	15
50000000	2.00	50000000	10	10	10	10
2.50000000	1.00	25000000	5	5	5	5
1.25000000	0.50	12500000	2.5	2.5	2.5	2.5
0.62500000	0.25	6250000	1.25	1.25	1.25	1.25
0.31250000	0.125	3125000	0.625	0.625	0.625	0.625
0.15625000	0.0625	1562500	0.3125	0.3125	0.3125	0.3125
0.07812500	0.03125	781250	0.15625	0.15625	0.15625	0.15625
0.03906250	0.015625	390625	0.078125	0.078125	0.078125	0.078125
0.01953125	0.0078125	1953125	0.0390625	0.0390625	0.0390625	0.0390625
0.009765625	0.00390625	9765625	0.01953125	0.01953125	0.01953125	0.01953125
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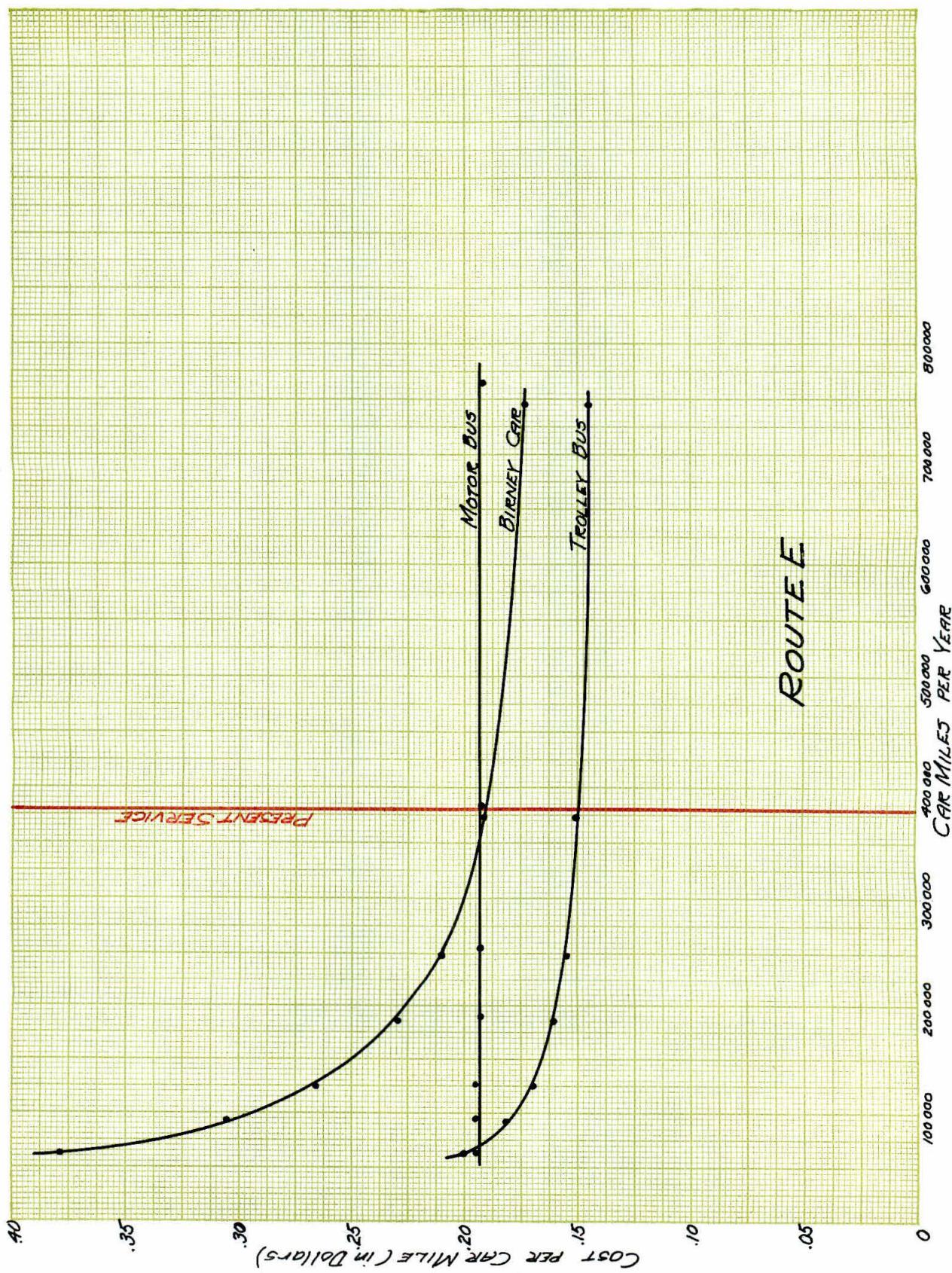


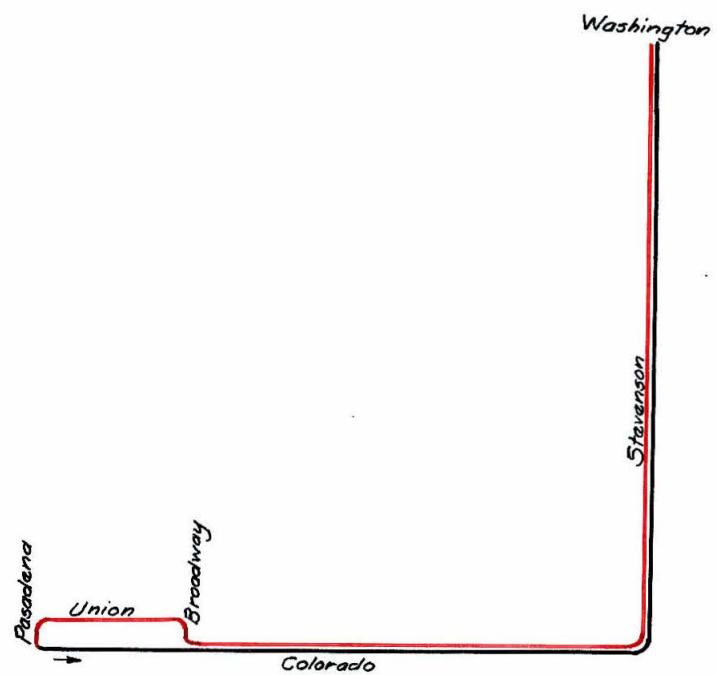
ROUTE E

— OUTBOUND
— INBOUND

ROUTE E

HEADWAY in minutes				LENGHT in miles		CAR MILES PER YEAR		VEHICLES REQUIRED		COST PER CAR MILE in dollars		
5 Hours	20 Hours	Bus	Automobile	Bus	Automobile	Bus	Birney Car	Bus	Birney Car	Trolley Bus	Trolley Bus	
30	60	3.5	3.4	63875	62050	2	2	.1956	.3793	.2007		
20	40	"	"	95813	93050	3	3	.1956	.3058	.1817		
15	30	"	"	127750	129100	4	3	.1956	.2659	.1693		
10	20	"	"	191625	186150	5	5	.1927	.2298	.1608		
7.5	15	"	"	255500	248200	7	6	.1934	.2107	.1550		
5	10	"	"	383250	372300	10	9	.1927	.1919	.1503		
2.5	5	"	"	766500	744600	19	17	.1920	.1730	.1451		



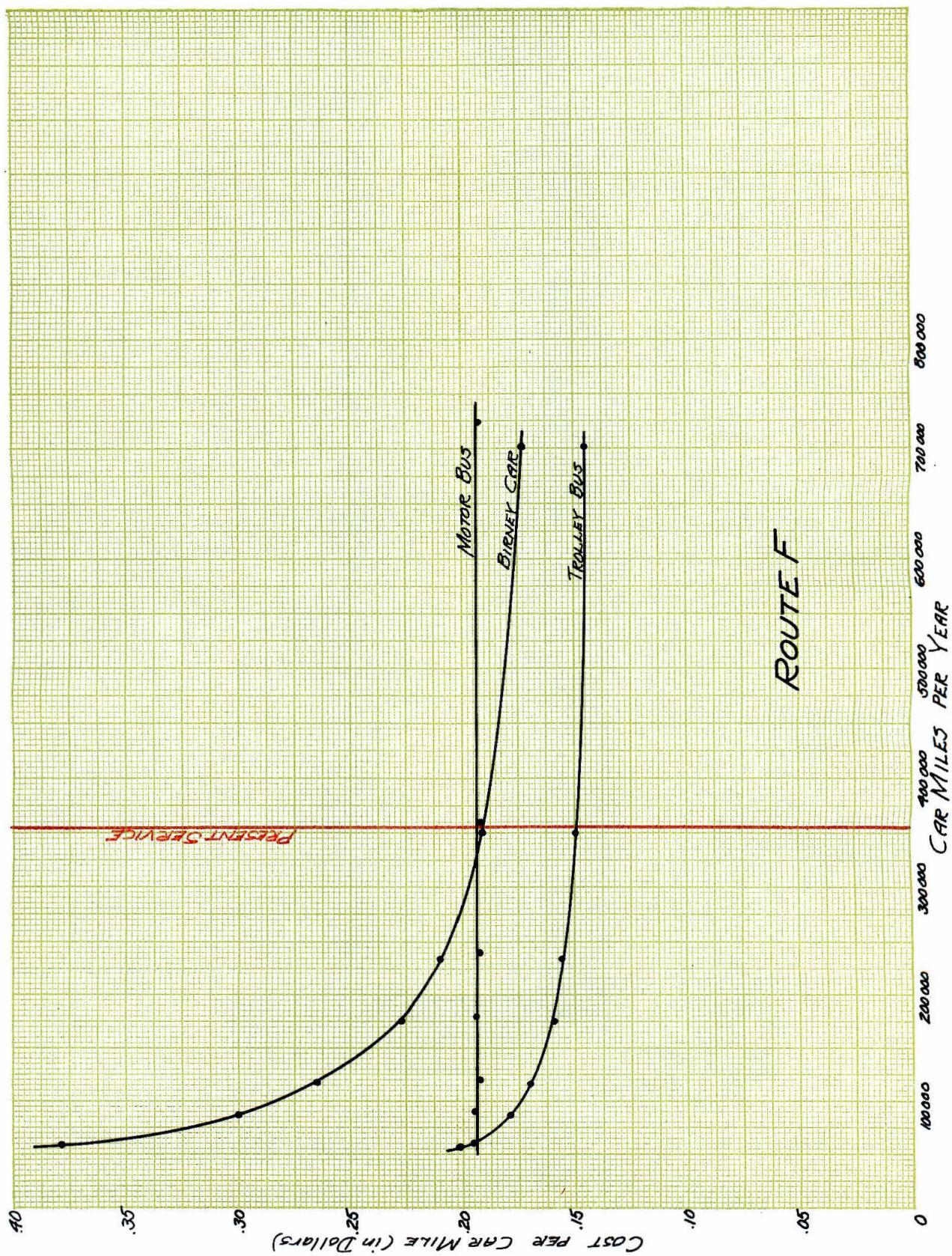


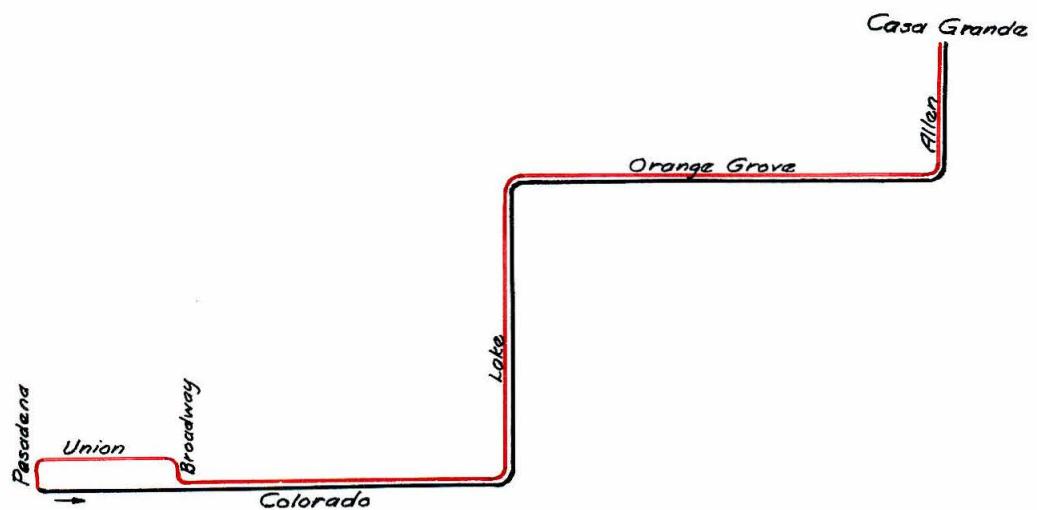
ROUTE F

— OUTBOUND
— INBOUND

ROUTE F

MILES OF ROUTE	DISTANCE IN FEET	CARS NEEDED PER YEAR		VEHICLES REQUIRED	COST PER CAR MILE in dollars			
		Bus	Bi-Mode Truck		Bus	Bi-Mode Car Truck 100 = m.	Bus	Bi-Mode Truck
30	60	3.3	3.2	60225	58400	2	2	.1967 .3793 .2014
20	40	"	"	90338	87600	3	2	.1967 .3014 .1783
15	30	"	"	120450	116800	3	3	.1920 .2655 .1698
10	20	"	"	180675	175200	5	4	.1946 .2276 .1593
7.5	15	"	"	240900	233600	6	6	.1920 .2102 .1556
5	10	"	"	361350	350400	9	8	.1920 .1907 .1498
2.5	5	"	"	722700	700800	18	16	.1920 .1723 .1451



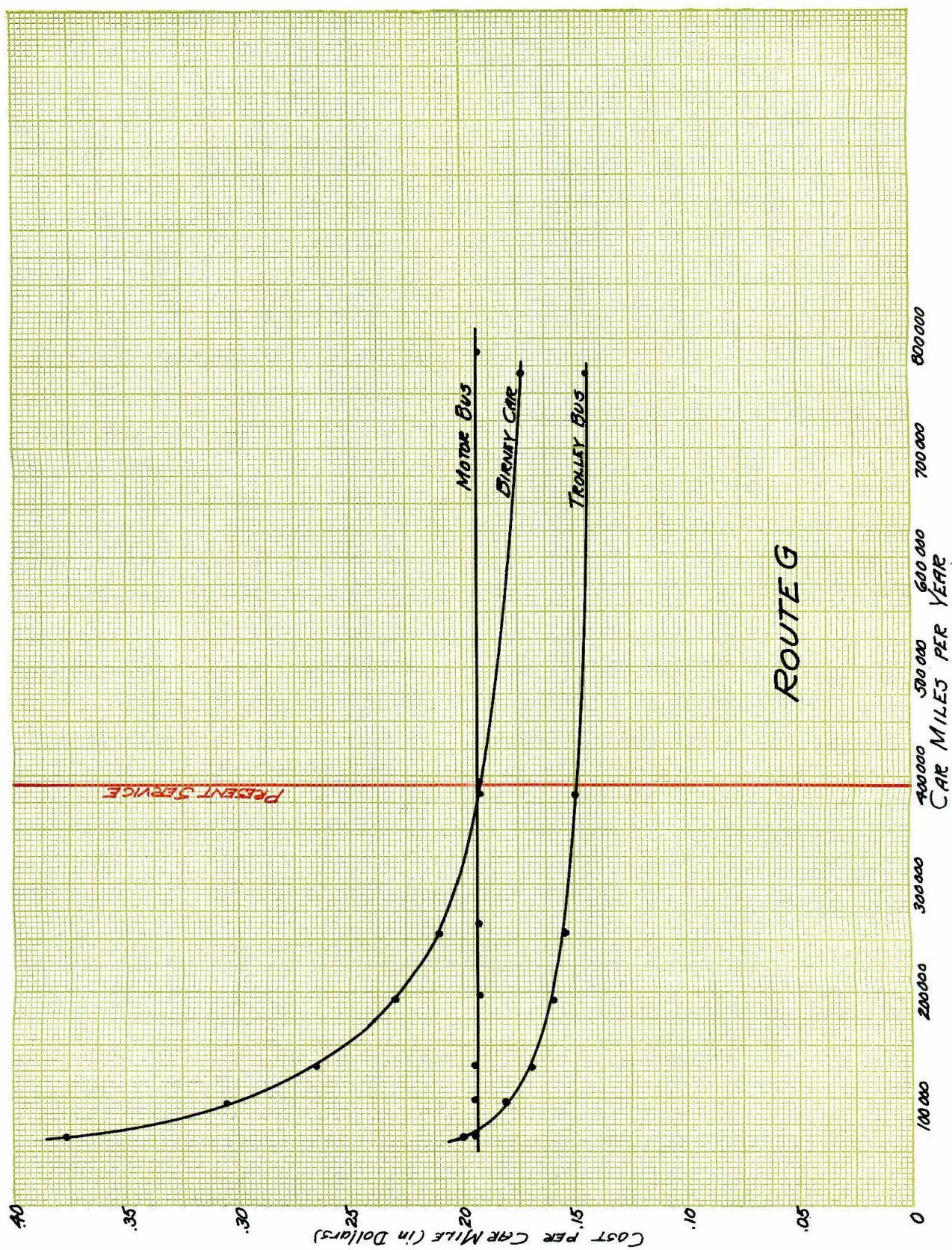


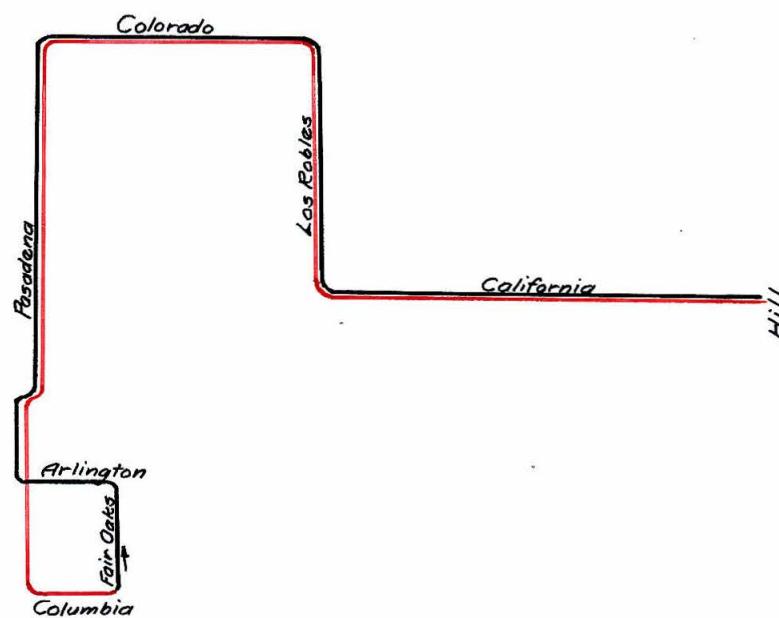
ROUTE G

— OUTBOUND
— INBOUND

ROUTE G

HEADWAY in minutes		LENGTH OF LINE in miles		CAR MILES PER YEAR		VEHICLES REQUIRED		COST PER CAR MILE in dollars		
5 Hours	20 Hours	Bus	Birney Car Trolley Bus	Bus	Birney Car Trolley Bus	Bus	Birney Car Trolley Bus	Bus	Birney Car Trolley Bus	Trolley Bus
30	60	3.6	3.5	65700	63875	2	2	.1951	.3793	.2004
20	40	"	"	98550	95813	3	3	.1951	.3055	.1814
15	30	"	"	131400	127750	4	3	.1951	.2658	.1690
10	20	"	"	197100	191625	5	5	.1923	.2299	.1605
7.5	15	"	"	262800	255500	7	6	.1930	.2105	.1548
5	10	"	"	394200	383250	10	9	.1923	.1920	.1500
2.5	5	"	"	788400	766500	20	17	.1923	.1731	.1448



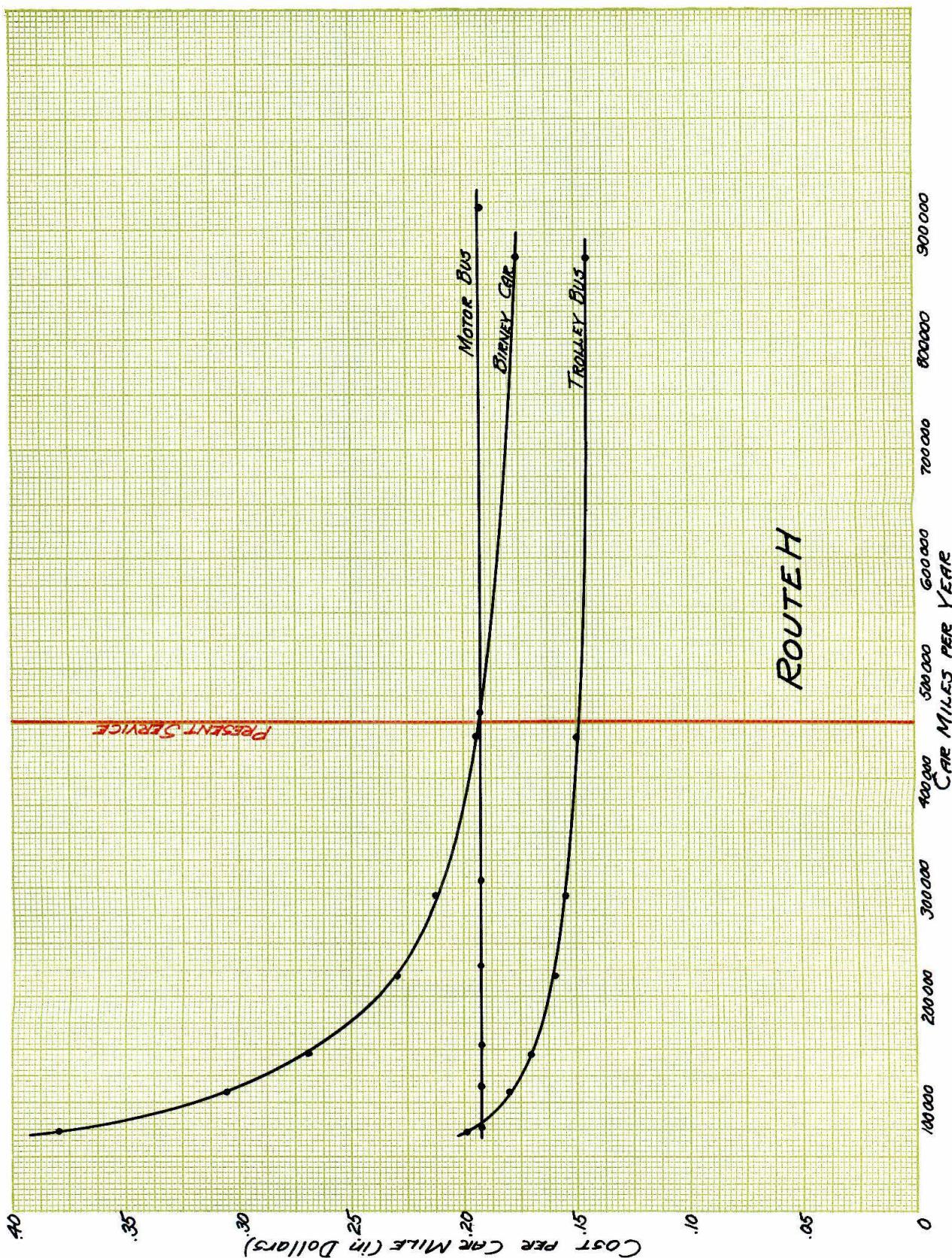


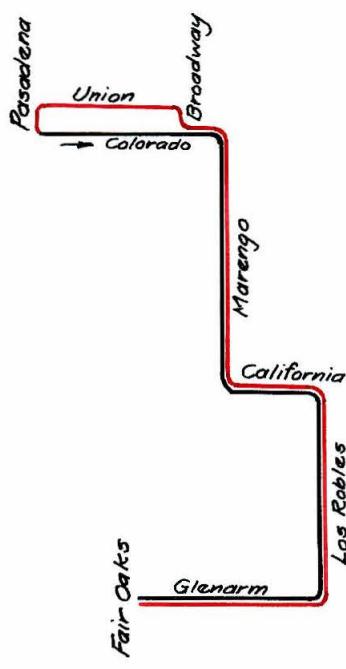
ROUTE H

— OUTBOUND
— INBOUND

ROUTE H

PERIOD OF YEAR in months	LENGTH OF LINE in miles	CAR MILES PER YEAR		VEHICLES REQUIRED		COST PER CAR MILE in dollars				
8 HOURS	20 HOURS	Bus	BIRNEY CAR TROLLEY BUS = b_1	Bus.	BIRNEY CAR TROLLEY BUS = m_1	Bus	Birney Car Trolley Bus = b_1	Bus	BIRNEY CAR TROLLEY BUS = c_1	TROLLEY BUS = c_2
30	60	4.2	4.0	76650	73000	2	2	.1927	.3798	.1989
20	40	"	"	114975	109500	3	3	.1927	.3060	.1799
15	30	"	"	153300	146000	4	4	.1927	.2691	.1705
10	20	"	"	229950	219000	6	5	.1927	.2306	.1593
7.5	15	"	"	306600	292000	8	7	.1927	.2123	.1549
5	10	"	"	459900	438000	12	10	.1927	.1937	.1498
2.5	5	"	"	919800	876000	23	20	.1921	.1753	.1451



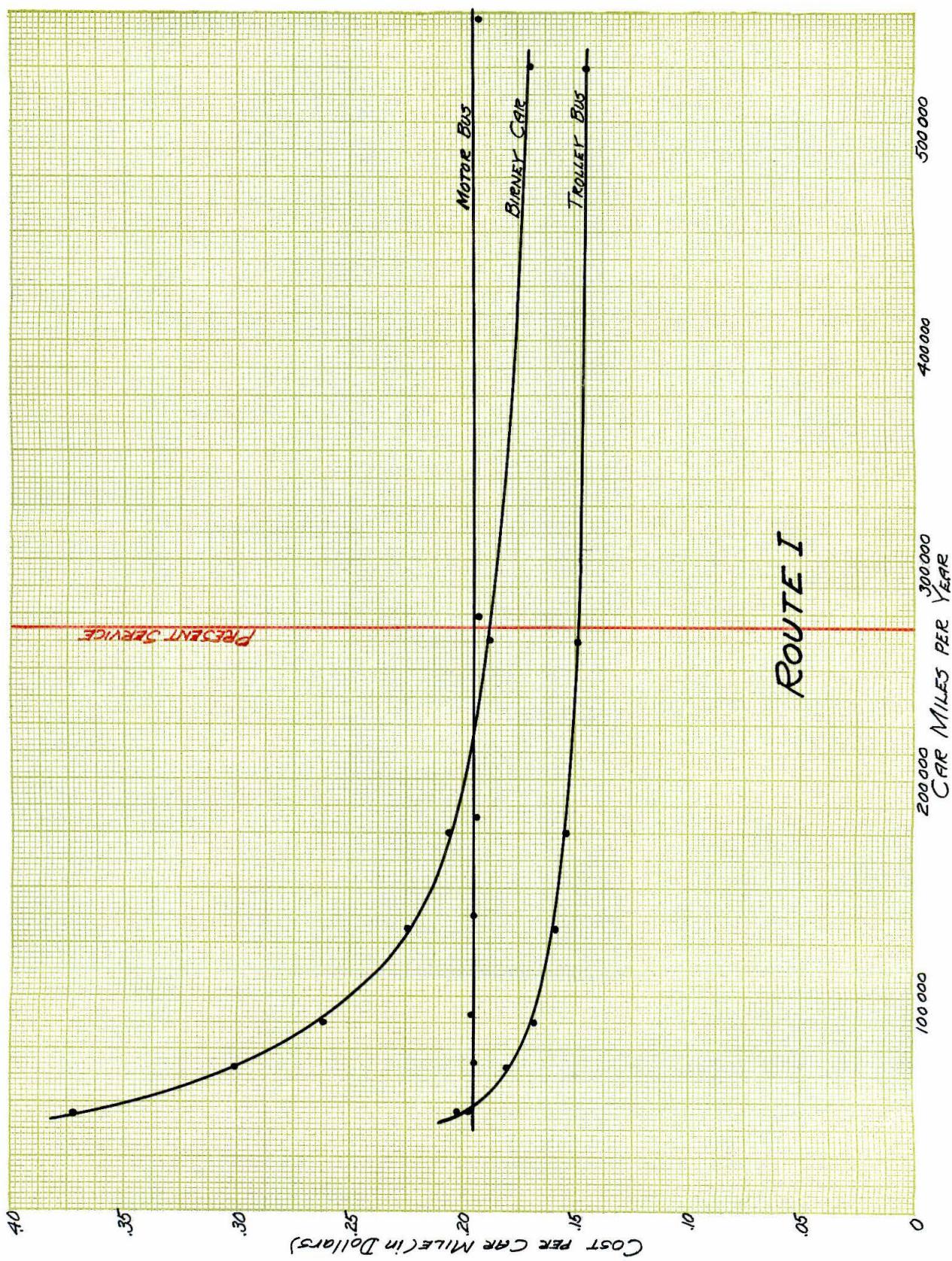


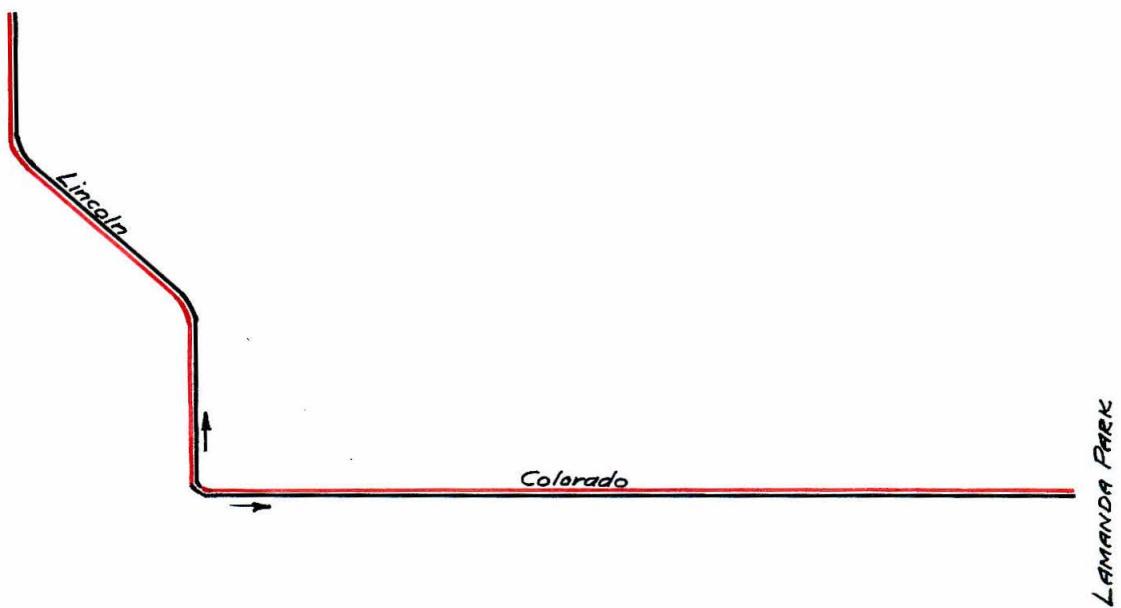
ROUTE I

— OUTBOUND
 — INBOUND

ROUTE I

Population in millions	Length of route in miles	CAR MILES PER YEAR		VEHICLES REQUIRED	COST PER CAR MILE in dollars			
		Bus	Car		Bus	Car	Trolleybus	
30	60	2.5	2.4	45625	43800	2	1	.2026
20	40	"	"	68438	65700	2	2	.1945
15	30	"	"	91250	87600	3	2	.1965
10	20	"	"	136875	131400	4	3	.1945
7.5	15	"	"	182500	175200	5	4	.1934
5	10	"	"	273750	262800	7	6	.1924
2.5	5	"	"	547500	525600	14	12	.1924





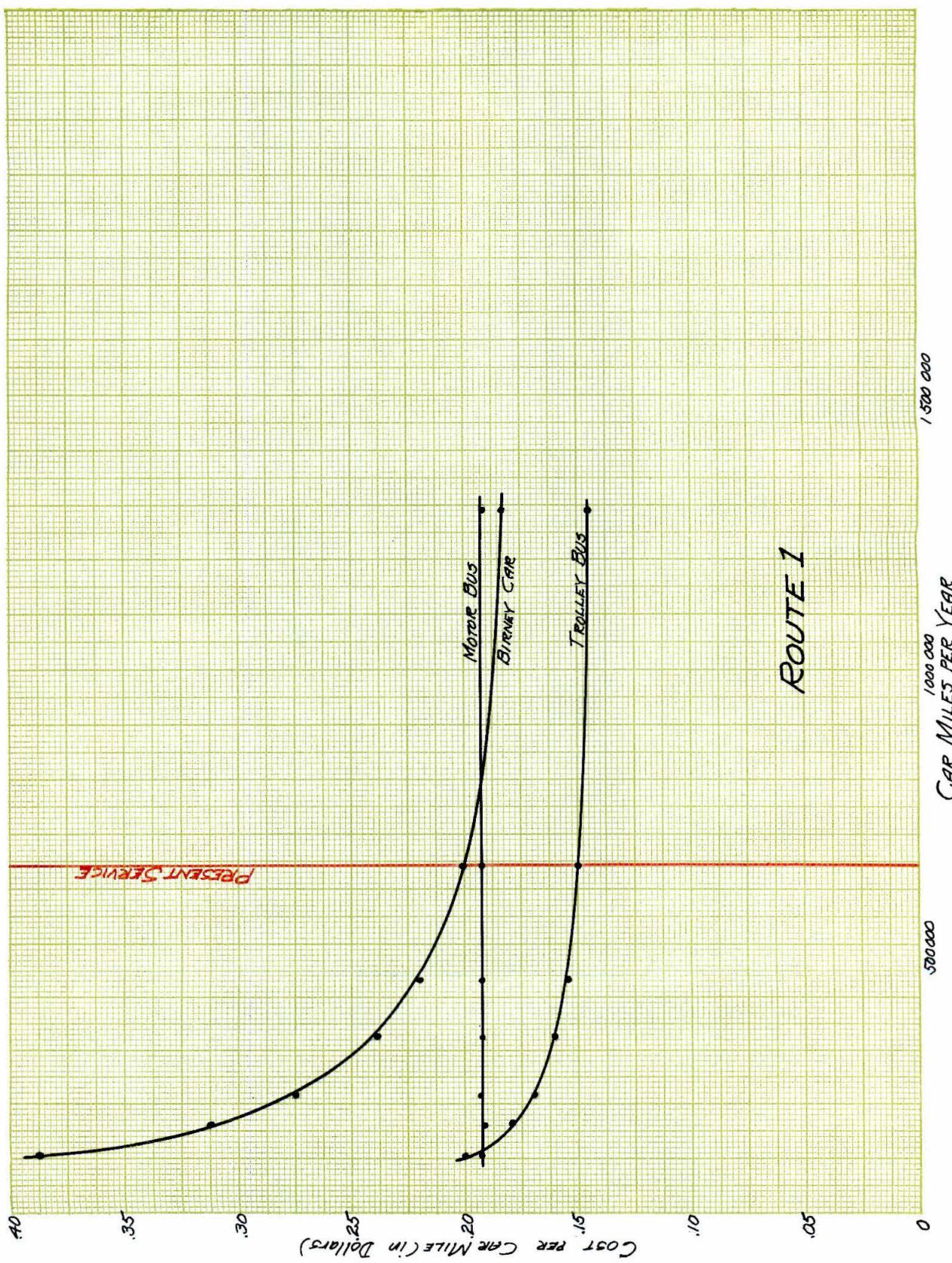
ROUTE 1

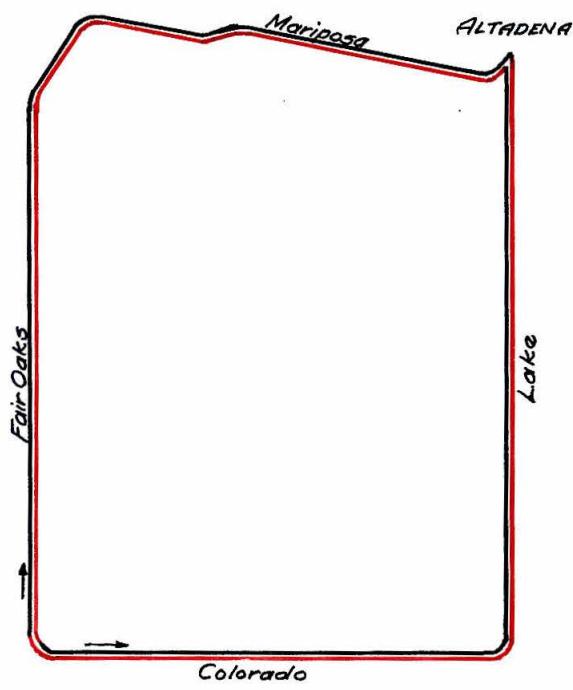
— OUTBOUND
— INBOUND

ROUTE 1

- 39 -

HEADWAY in minutes		LENGTH OF LINE in miles		CAR MILES PER YEAR		VEHICLES REQUIRED		COST PER CAR MILE in dollars		
5 Hours	20 Hours	Bus	BIRNEY CAR TROLLEY BUS	Bus	BIRNEY CAR TROLLEY BUS	Bus	BIRNEY CAR TROLLEY BUS	Bus	BIRNEY CAR TROLLEY BUS	Bus
30	60	5.9	5.9	107675	107675	3	3	.1937	.3873	.1991
20	40	"	"	161513	161513	4	4	.1920	.3123	.1790
15	30	"	"	215350	215350	6	5	.1937	.2748	.1689
10	20	"	"	323025	323025	8	8	.1920	.2385	.1600
7.5	15	"	"	430700	430700	11	10	.1924	.2195	.1547
5	10	"	"	646050	646050	16	15	.1920	.2010	.1500
2.5	5	"	"	1292100	1292100	32	29	.1920	.1823	.1499





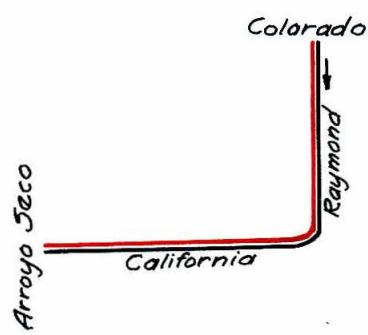
ROUTE 2

— OUTBOUND
— INBOUND

ROUTE 2

HEADWAY in minutes		LENGTH OF LINE in miles		CAR MILES PER YEAR		VEHICLES REQUIRED		COST PER CAR MILE in dollars		
5 Hours	20 Hours	BUS	BIRNEY CAR TROLLEY BUS = I_1	BUS	BIRNEY CAR TROLLEY BUS = m_1	BUS	BIRNEY CAR TROLLEY BUS = b_1	BUS	BIRNEY CAR TROLLEY BUS = c_1	TROLLEY BUS = c_2
30	60	7.0	7.0	127750	127750	4	3	.1956	.3898	.1975
20	40	"	"	191625	191625	5	5	.1927	.3170	.1795
15	30	"	"	255500	255500	7	6	.1934	.2791	.1690
10	20	"	"	383250	383250	10	9	.1927	.2422	.1595
7.5	15	"	"	511000	511000	13	12	.1923	.2238	.1548
5	10	"	"	766500	766500	19	17	.1920	.2049	.1496
2.5	5	"	"	1533000	1533000	38	34	.1920	.1864	.1448



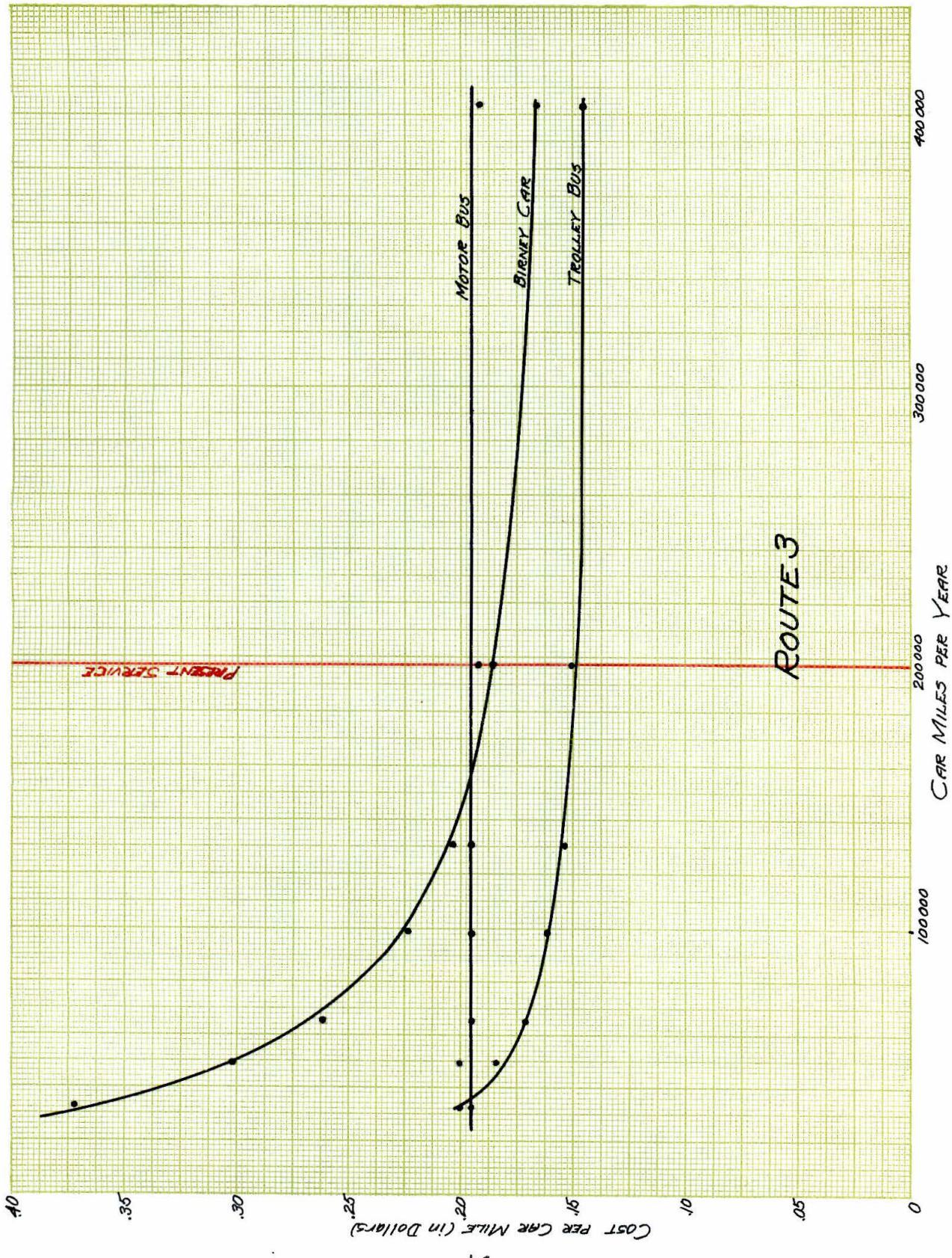


ROUTE 3

— OUTBOUND
— INBOUND

ROUTE 3

HEADWAY in minutes		LENGTH OF LINE in miles		CAR MILES PER YEAR		VEHICLES REQUIRED		COST PER CAR MILE in dollars			
5 Hours	20 Hours	Bus	Birney Car Trolley Bus = b_1	Bus	Birney Car Trolley Bus = m_1	Bus	Birney Car Trolley Bus = b_1	Bus	Birney Car Trolley Bus = c_1	Bus	Birney Car Trolley Bus = c_2
30	60	1.8	1.8	32850	32850	1	1	.1951	.3727	.2000	
20	40	"	"	49275	49275	2	2	.2008	.3024	.1847	
15	30	"	"	65700	65700	2	2	.1951	.2616	.1715	
10	20	"	"	98550	98550	3	3	.1951	.2244	.1620	
7.5	15	"	"	131400	131400	4	3	.1951	.2038	.1546	
5	10	"	"	197100	197100	5	5	.1923	.1862	.1507	
2.5	5	"	"	394200	394200	10	9	.1923	.1669	.1451	



V - STUDY OF CURVES

On examination of the curves shows that the cost of bus operation is practically constant regardless of the number of bus miles operated. The slight variation in the cost is due to the fact that when a fraction of a bus is required by formula, an entire bus must be used in practice. The same explanation applies to the irregularities in the Birney Car and trolley bus curves. In practice, the equivalent of using a fraction of a car or bus would be secured by regulating the headway to eliminate hold-overs at the end of the line.

The curves for the Birney Car and trolley bus are similar because of similarity in operation. With the operation of but a few car miles per year the cost is prohibitive because of the cost of track and trolley installation and their appurtenances. As service increases, however, these large costs are more widely distributed, and because actual operation of both the Birney car and trolley bus are cheaper than the motor bus, their curves eventually cross below that of the motor bus.

A study of the curves for each route will show which system of transportation is best for the service demanded. On the curves vertical lines are drawn showing the present service on each route. The curve which is lowest at this point designates the service which is at present the most economical.

VI - CONCLUSIONS

Although it is seen that the trolley bus is eventually cheaper than the motor bus, and that the point is finally reached where the Birney Car is the most economical, it must be remembered that on a given route the demands of service may never be such that a large investment for track or trolley operation is justified. Until such a point is reached, the motor bus system is the logical one to use. One of the main advantages of a bus is that it can be used for experimenting on a proposed route. If experience shows that such a route will not pay it can be abandoned without a financial loss, since the buses can be transferred to another line. If, on the other hand, the line pays, tracks can be laid later.

One cost which has not been considered in the motor bus and trolley bus, and which may in view of possible legislation be a big item, is that of taxes for the use of pavement. However, should such taxes be imposed, the only effect on the curves here presented would be to raise them without changing their shape.

These curves do not take into consideration any variations in revenue from the three systems. The actual carrying capacity of the Birney Car is about twenty or twenty-five percent greater than either bus, and consequently its earning capacity is greater under the same headway.

The study here presented shows that buses have a very important place in city transportation problems. They are

valuable in experimenting on new routes because the initial outlay is not so great as for the other systems, and can also be used for districts which need transportation service, but where such service is not great enough to warrant the heavy investment required for track or trolley operation. They are especially useful in California where suburban expansion has been unable to take care of the service required, both because of the large investment required for an initial small revenue, and because of the time required for track construction.