A Road Network Design Method Revisited:
Expressway Spacing and Economic Evaluation

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Problem of Urban Road Network Design

- Urban transportation planning began in America in the 1950s, in part to locate and design urban segments of the Interstate Highway System;
- Major advances in forecasting traffic were achieved in these efforts, both practical and theoretical;
- An ambitious effort to determine the spacing, system configuration and level of investment in expressways was initiated by the Chicago Study;
- This talk explores why this effort failed to accomplish its ambitious objectives and seeks to can learn from this experience.

Context and Objectives of the Chicago Study

- Urban growth and suburbanization of large American cities following WW II;
- Rapid increase in car ownership;
- Concern with the efficient use of cars in a new and untested road technology, urban expressways;
- A desire to devise and apply a scientific approach to road network planning led to:

  - creation of an expressway spacing formula

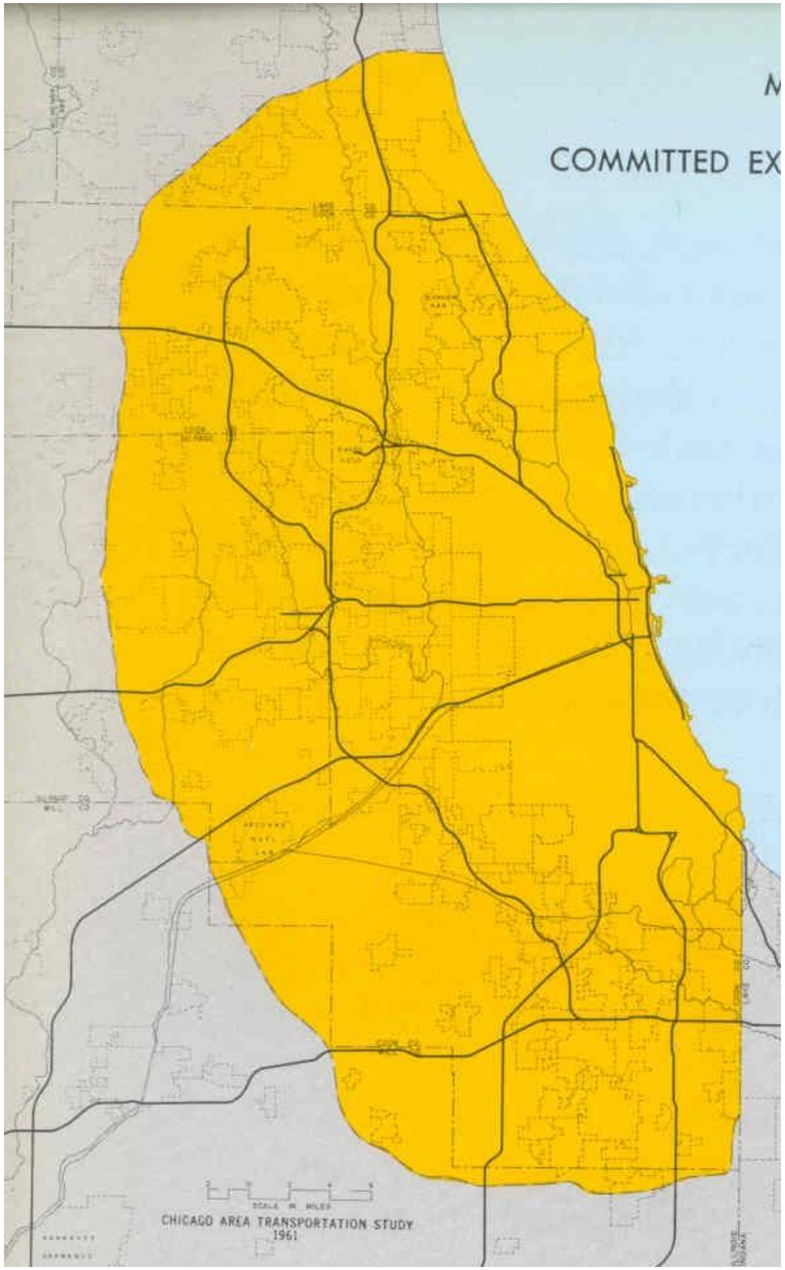
  - its use in devising alternative plans for the area

  - economic analyses to determine the best plan.

Chicago Area Expressway and Tollway System in 2010

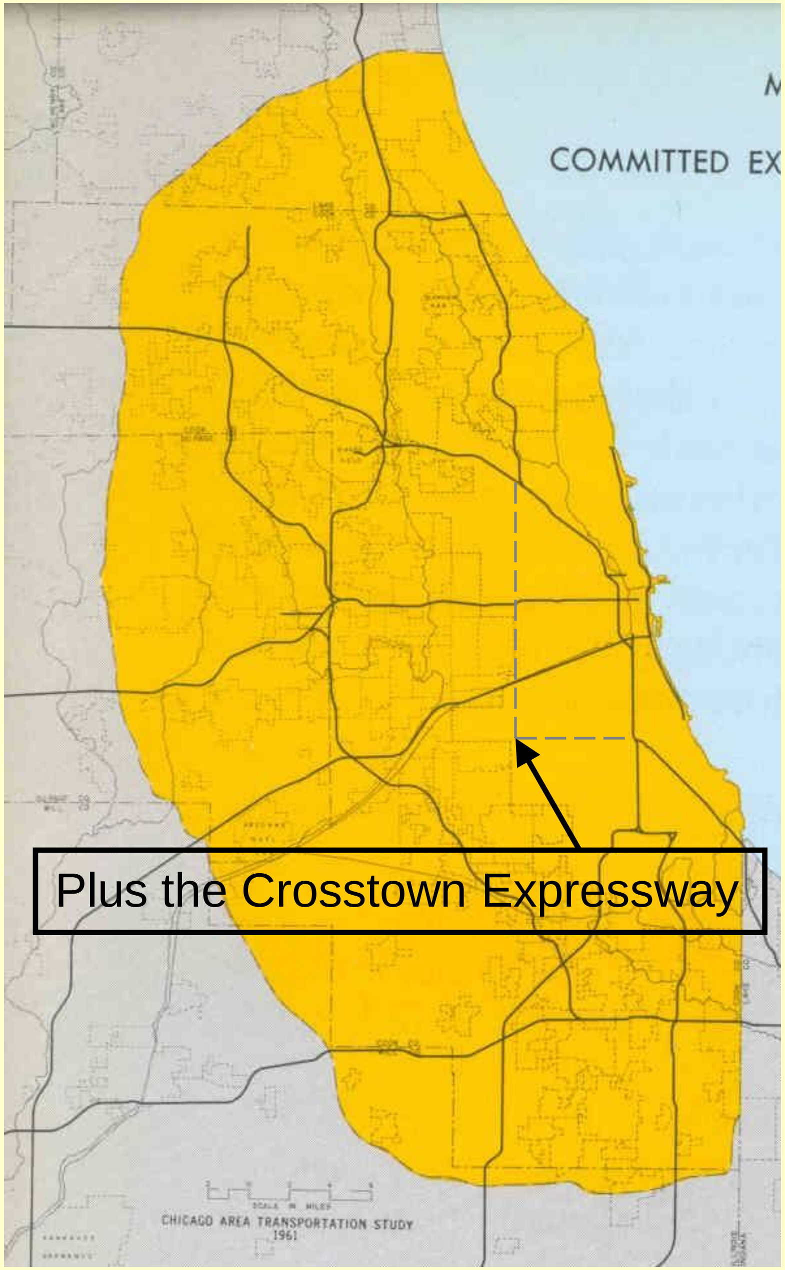
2010 Actual Expressway System

1956 Committed Expressway Plan

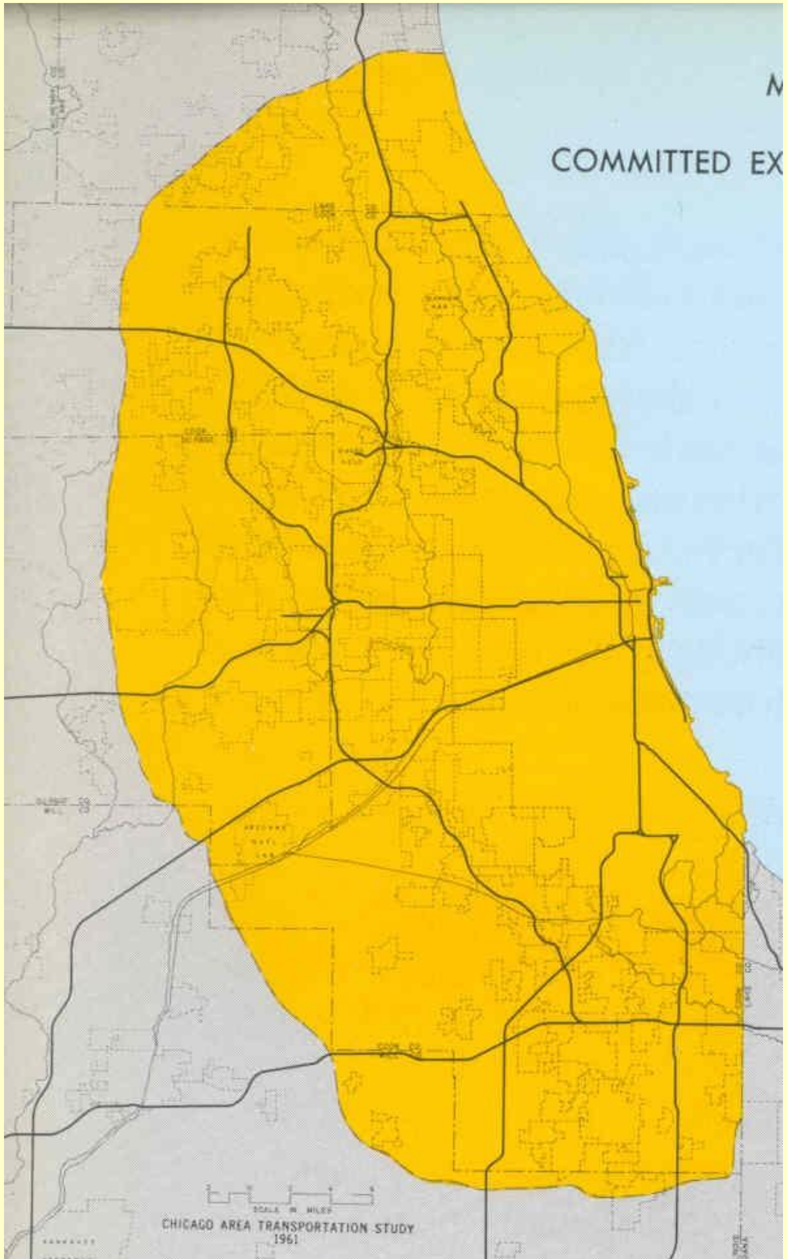


2010 Actual Expressway System

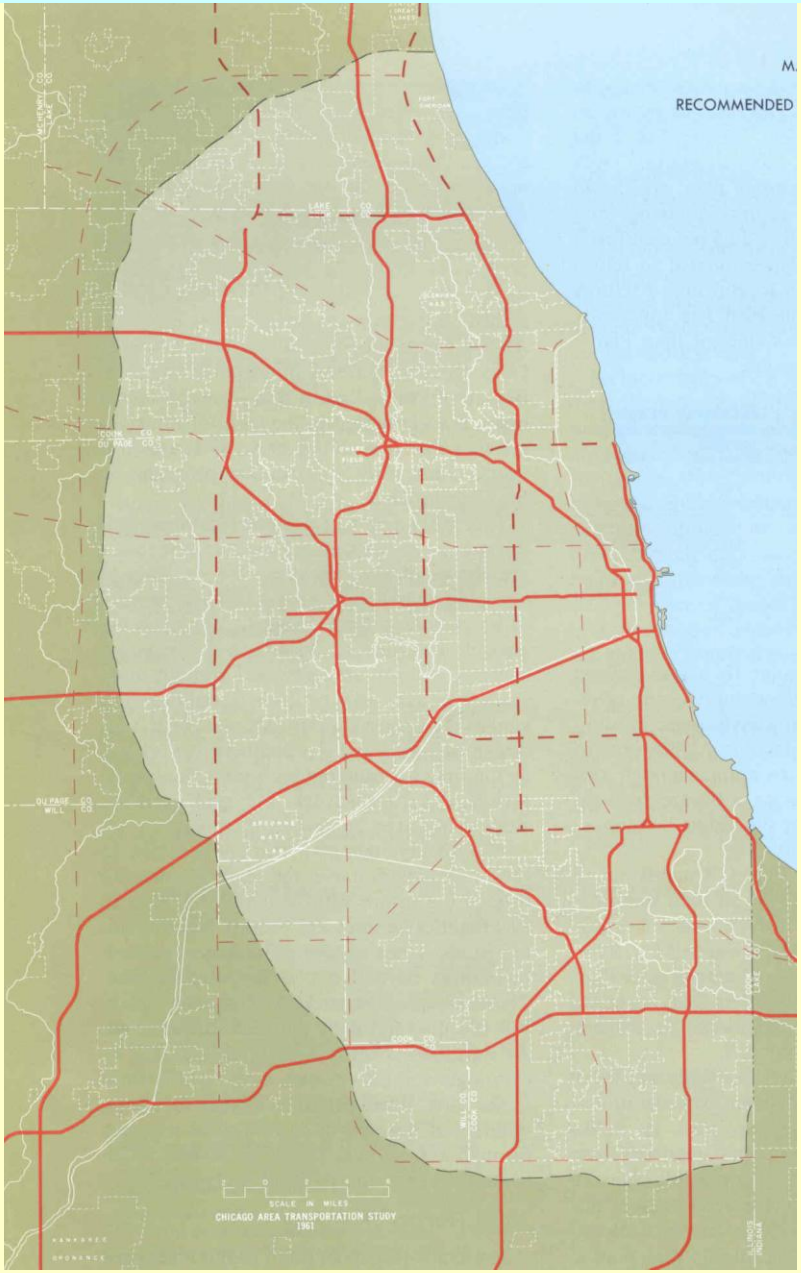
1956 Committed Expressway Plan



1956 Committed Expressway Plan



1980 Recommended Expressway Plan



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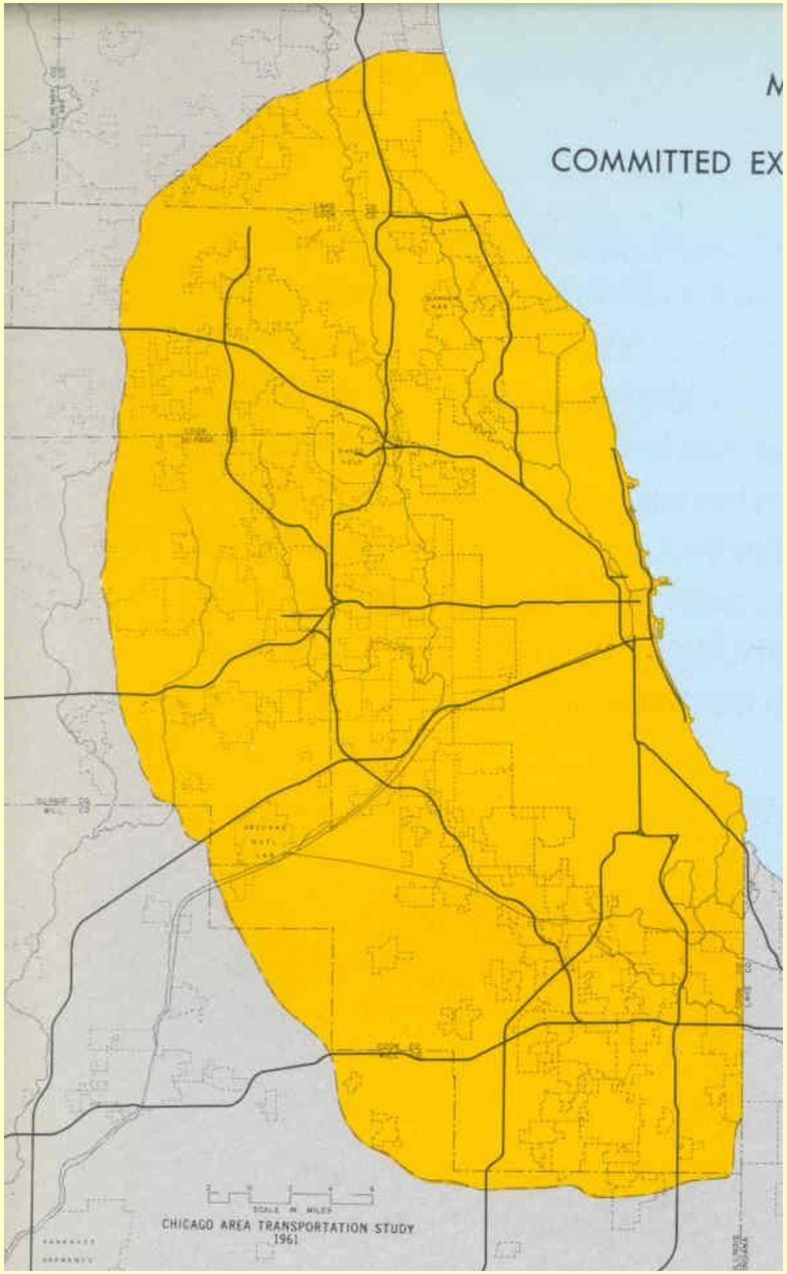
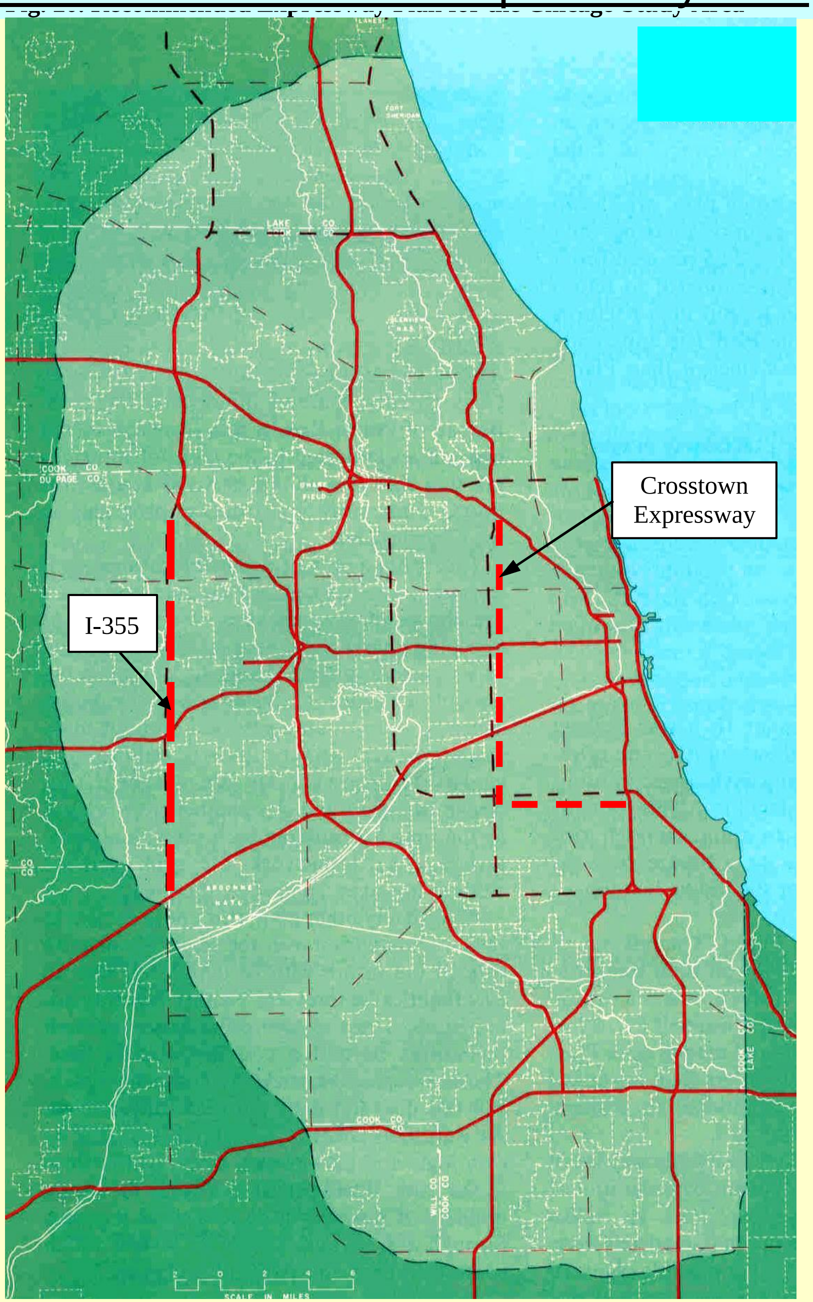
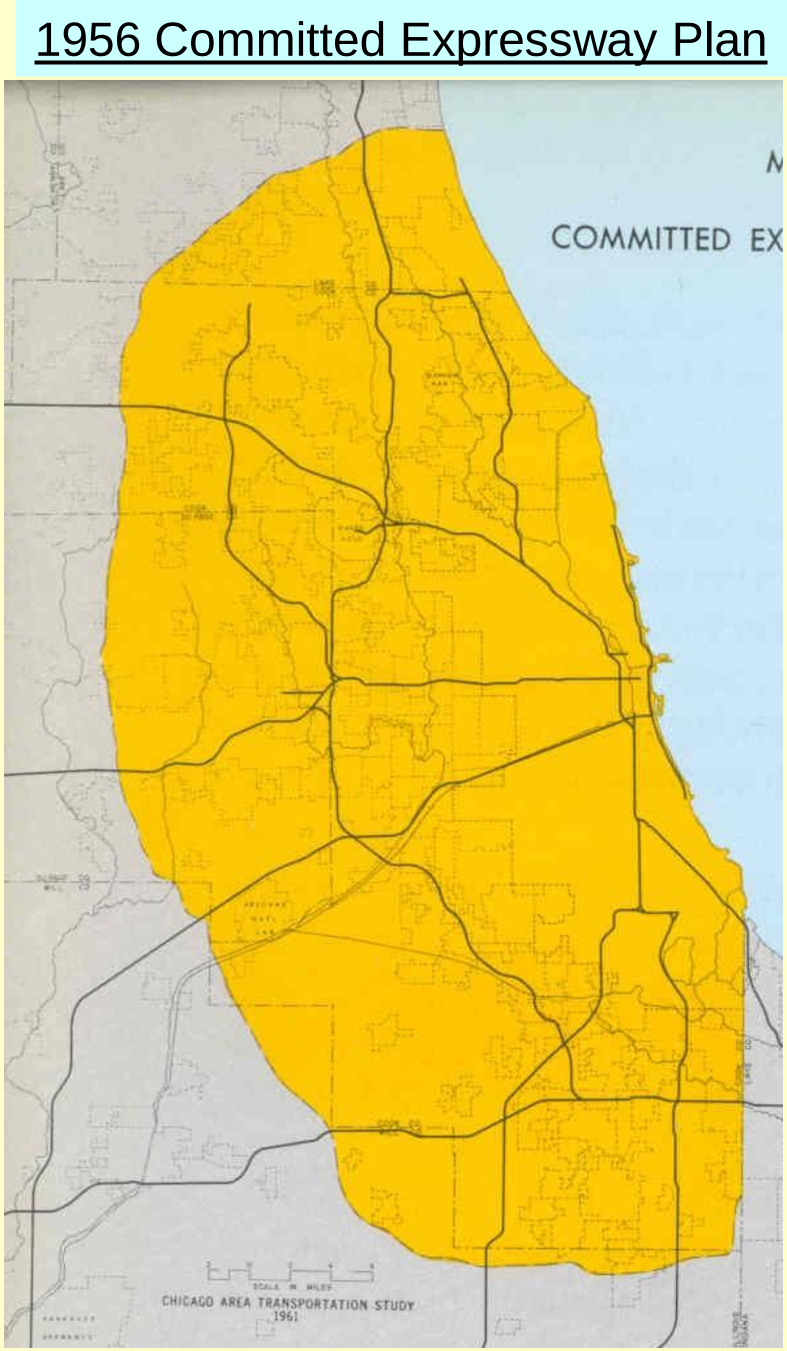
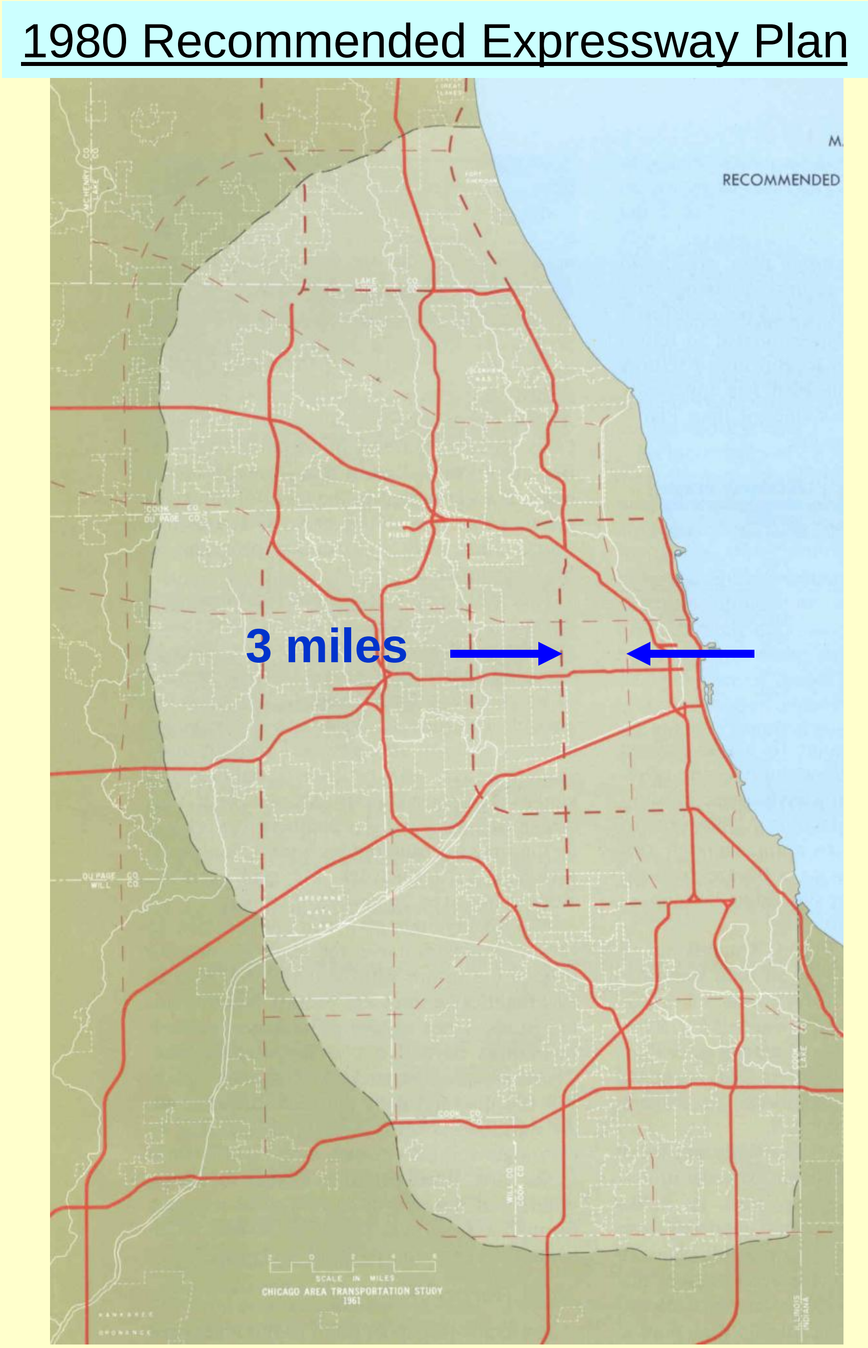


1980 Recommended Expressway Plan





1956 Committed Expressway Plan
COMMITTED EX
CHICAGO AREA TRANSPORTATION STUDY
1961



1980 Recommended Expressway Plan
RECOMMENDED
3 miles
CHICAGO AREA TRANSPORTATION STUDY
1961

Expressway Spacing Formula Derivation

- Derive a formula for an idealized street grid, rather like the built infrastructure of Chicago;
- Minimize the sum of road construction and travel costs (travel time, fuel and accidents) for future patterns of population and employment density;
- Apply the formula to the existing and predicted development patterns, both urban and suburban;
- Apply design criteria regarding the system layout to assure a smoothly functioning system.

The <u>Construction Cost</u> per grid cell of length S is:

$$C_1 = 2S^2\left(\frac{C_X}{x} + \frac{C_Y}{y} + \frac{C_Z}{z}\right)$$

where C_X, C_Y, C_Z = the annualized construction cost per unit distance of local and arterial streets and expressways, respectively;

x, y, z = the respective intervals between each type of roadway.

The <u>Total Cost of Travel Time</u> per grid cell of length S is:

$$C_2 = NK\left[\sum_{i=1}^{r-1}\left(\frac{L_i}{v_X}\right)\cdot F_i + \sum_{i=r}^{s-1}\left(\frac{2A}{v_X} + \frac{L_i - 2A}{v_Y}\right)\cdot F_i + \sum_{i=s}^{t}\left(\frac{2A}{v_X} + \frac{2B}{v_Y} + \frac{L_i - 2A - 2B}{v_Z}\right)\cdot F_i\right]$$

where N = number of trips/day originating or terminating per unit area;

K = (value of time/hr)(number of days/yr)/Present Worth Factor (30 yrs, 5%)

= (\$1.43/hr)(340 days/yr)/0.065 = \$7,500 (1960 dollars)

$L_i =$ average trip length for interval i of the trip length distribution, $i = 1,\ldots t$

$F_i =$ proportion of trips occurring in interval i

$v_X, v_Y, v_Z =$ average travel speeds on facility types x, y and z

A = average distance traveled in moving from facility type x to type y

B = average distance traveled in moving from facility type y to type z

$$\min_{(y,z)} C(y,z) = C_1(y,z) + C_2(y,z) \text{ yields}$$

$$y = \left(\frac{5 \cdot C_Y}{K \cdot D \cdot (P_R \cdot V_{XY} + P_S \cdot V_{XYZ})} \right)^{1/2} \text{ and } z = \left(\frac{5 \cdot C_Z}{K \cdot D \cdot (P_S \cdot V_{YZ})} \right)^{1/2}$$

where $P_R = \sum_{i=1}^{s-1} F_i =$ total trip frequency of trips using both local-arterial streets

$P_S = \sum_{i=s}^{t} F_i =$ total trip frequency of trips using all types of facilities

$D = N / S^2 =$ density of trip originations or terminations, the number of trips divided by the area of a square with a side of length S

$$V_{XY} = \frac{v_Y - v_X}{v_X \cdot v_Y} \; ; \; V_{YZ} = \frac{v_Z - v_Y}{v_Y \cdot v_Z} \; ; \; V_{XYZ} = \frac{v_Y \cdot v_Z + v_X \cdot v_Z - 2 \cdot v_X \cdot v_Y}{v_X \cdot v_Y \cdot v_Z}$$

Fig. 1. Use of Local and Arterial Streets and Expressways by Trips of Different Length

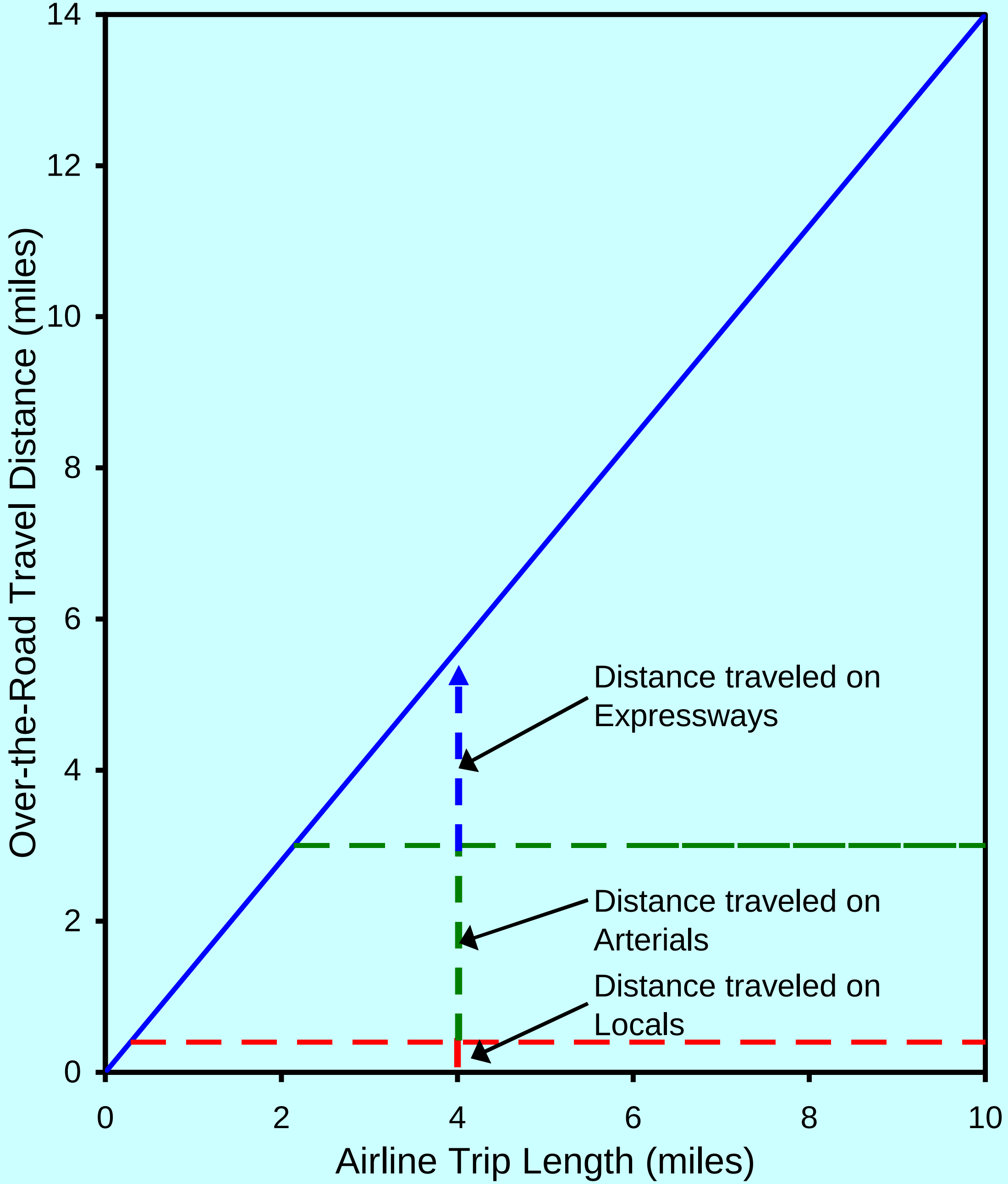
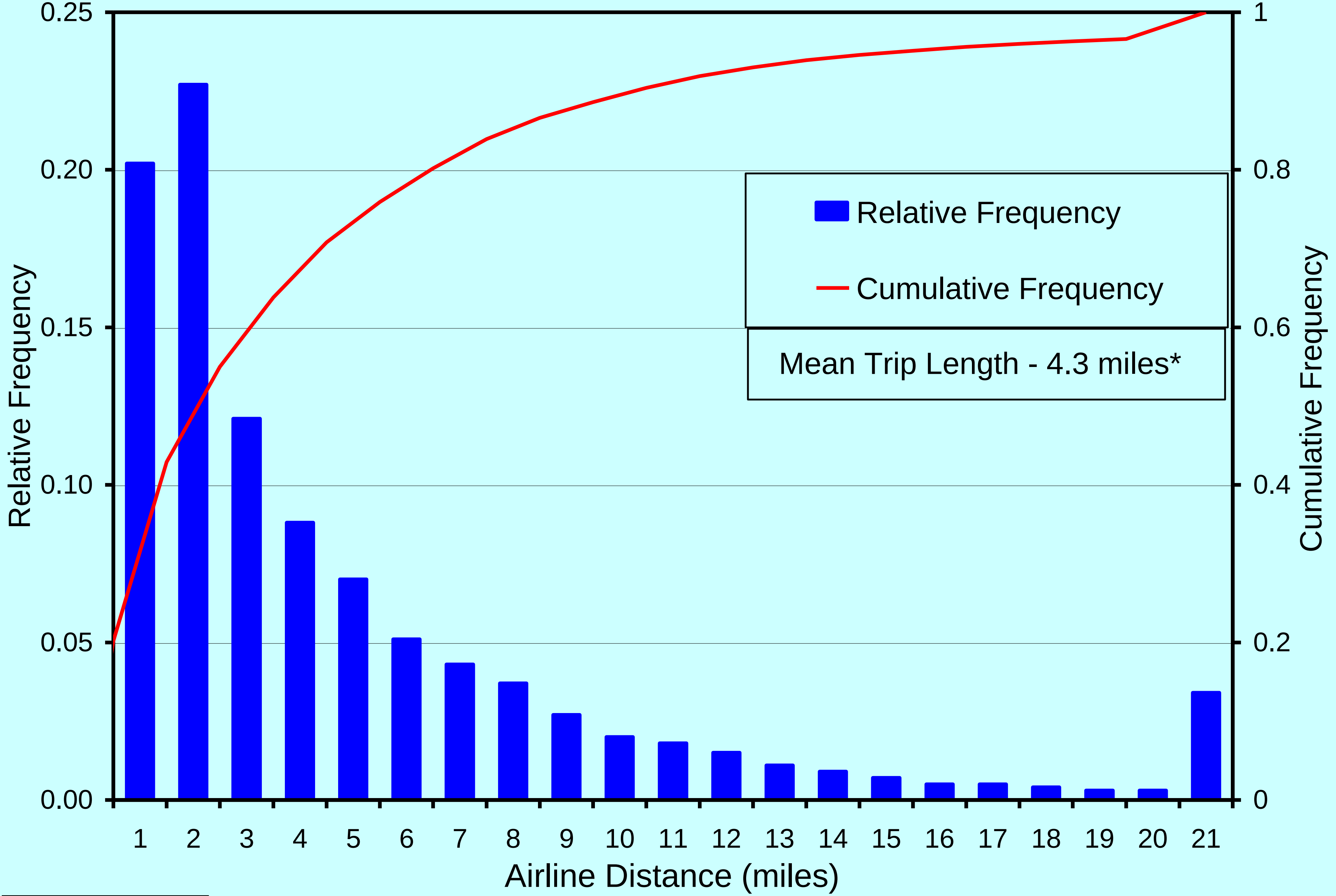


Fig. 2. Frequency Distributions of Person Trip Length



*Reported for person trips to all land uses in Table 32, p. 117, CATS Final Report, Vol. 1 (1959).

Values assumed in estimating Minimum-Cost Spacing

Given values	Example 1	Example 2
Expressway cost/mile	$8,000,000	$4,000,000
Trip density (destinations/sq. mile)	20,000	6,200
Expressway speed	50 mph	50 mph
Non-expressway speed	12 mph	20 mph

The trip length frequency distribution assumed in the examples is for the entire Chicago Study Area.
Source: Creighton et al (1960, Table 4, p. 19)

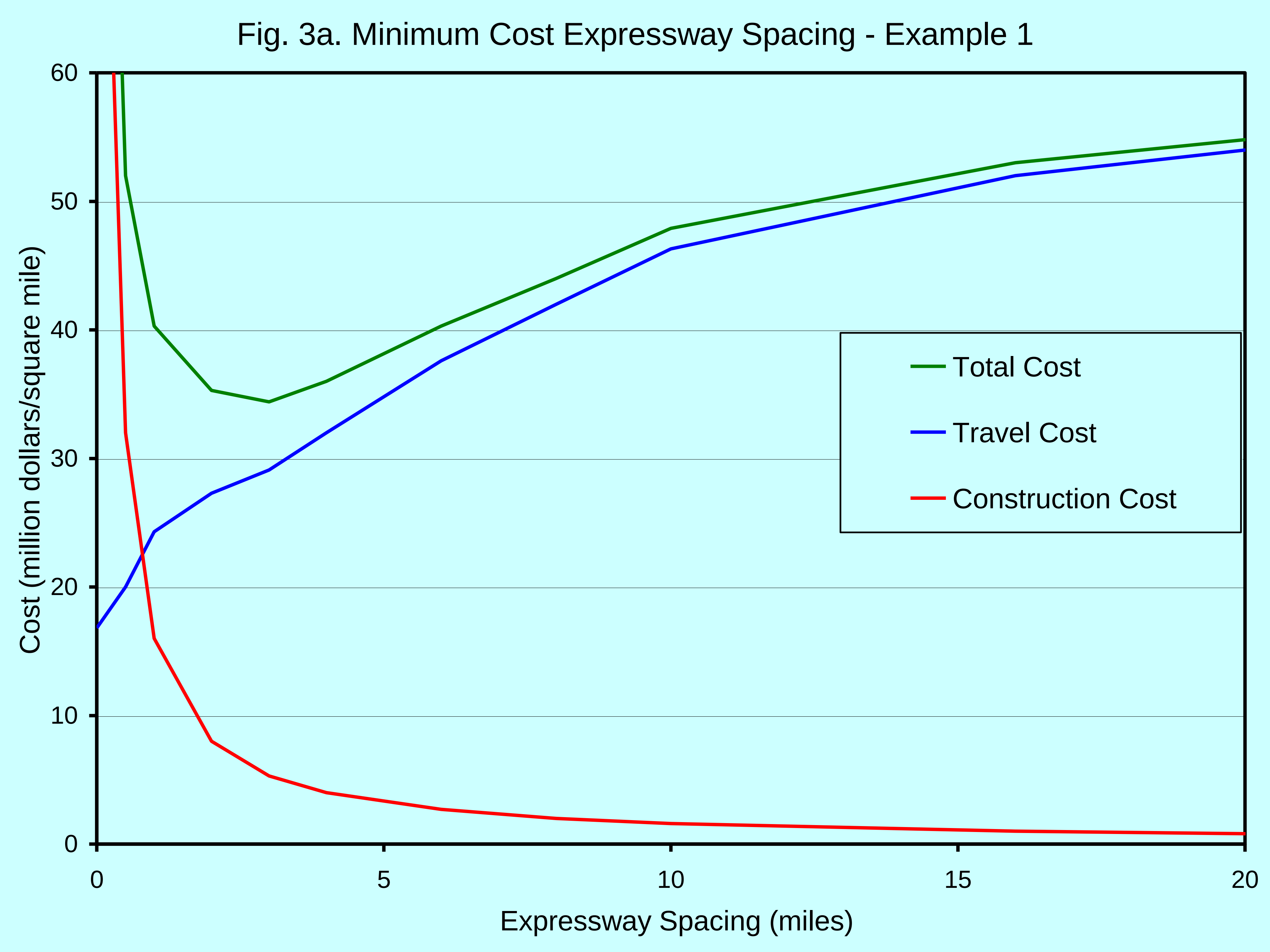
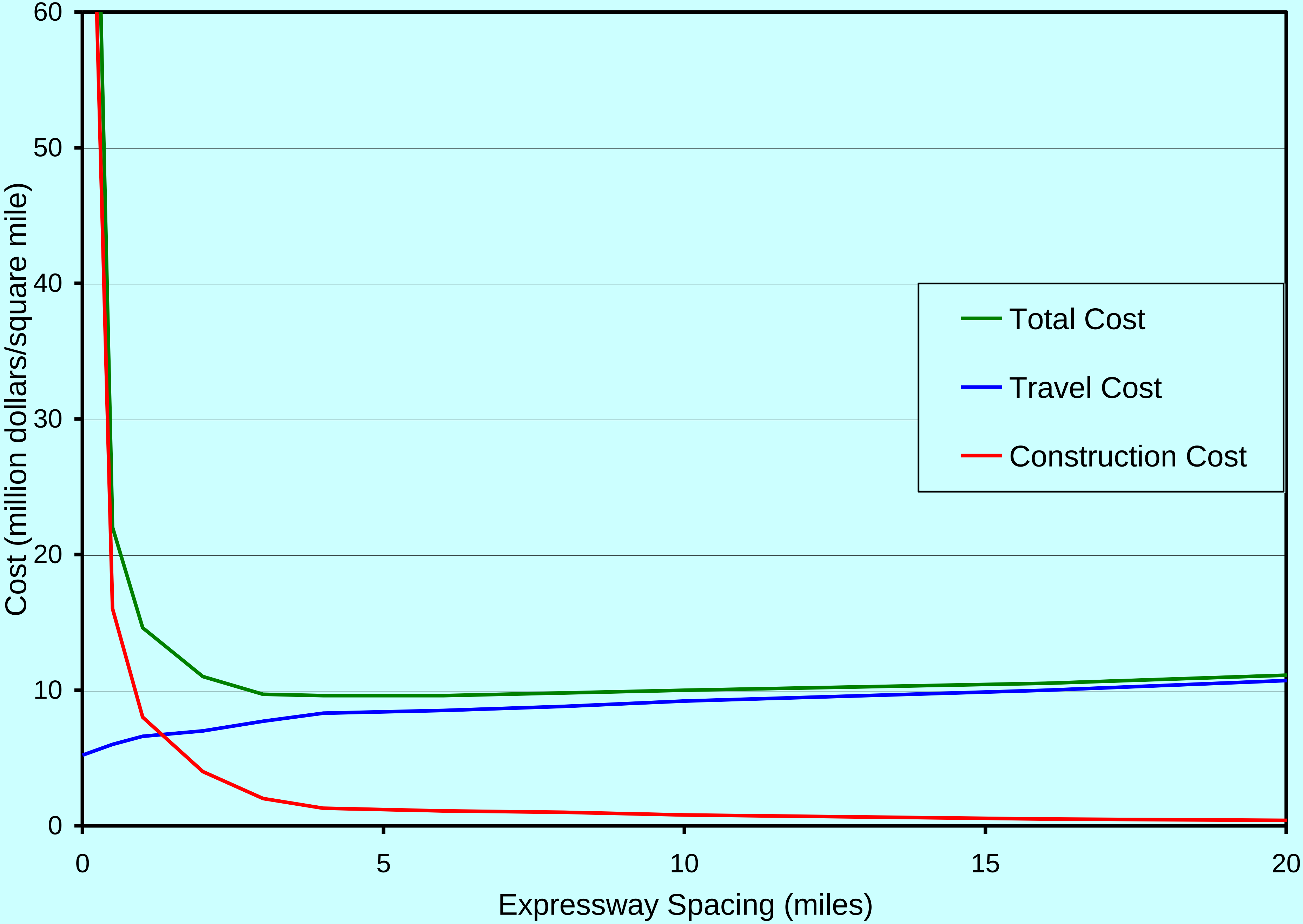


Fig. 3a. Minimum Cost Expressway Spacing - Example 1
Cost (million dollars/square mile)
60
50
40
30
20
10
0
0
5
10
15
20
Expressway Spacing (miles)
Total Cost
Travel Cost
Construction Cost

Fig. 3b. Minimum Cost Expressway Spacing - Example 2



Expressway Spacing Requirements for 1956 and 1980

Ring	Distance to CBD (miles)	Area (square miles)	Trip Destinations (per sq. mile)		Optimum Spacing (miles)	
			1956	1980	1956	1980
0	0.0	1.2	134.0	152.0	1.2	1.3
1	1.5	12.4	40.7	47.2	2.1	2.2
2	3.5	26.1	24.8	28.7	2.8	2.7
3	5.5	41.2	22.0	25.3	3.0	2.8
4	8.5	85.0	17.0	19.6	3.7	2.9
5	12.5	129.2	8.6	13.4	6.5	4.0
6	16.0	293.7	3.5	9.0	8.3	6.3
7	24.0	647.7	1.1	6.2	12.1	6.9

Sources: Creighton et al (1960, Tables 9, 11, 13, 14, pp. 29-33);
Joseph (1959, Table 1, p.13)

1956 Optimal Expressway System

1956 Optimal Expressway System

1980 Optimal Expressway System

Fig. 6. Travel Volumes on Minimum Existing & Committed Expressway Plan

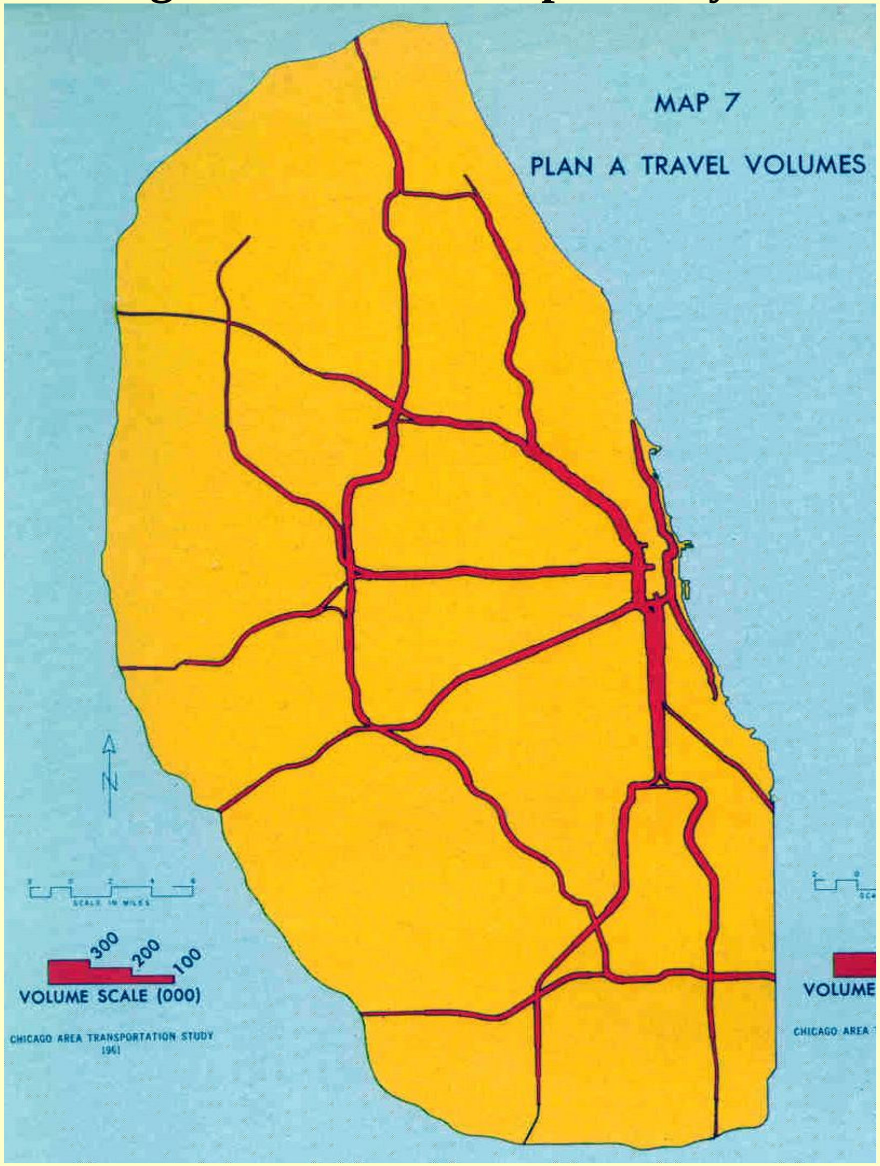


Fig. 7. Travel Volumes on Plan A plus the Addition of Two North-South Routes

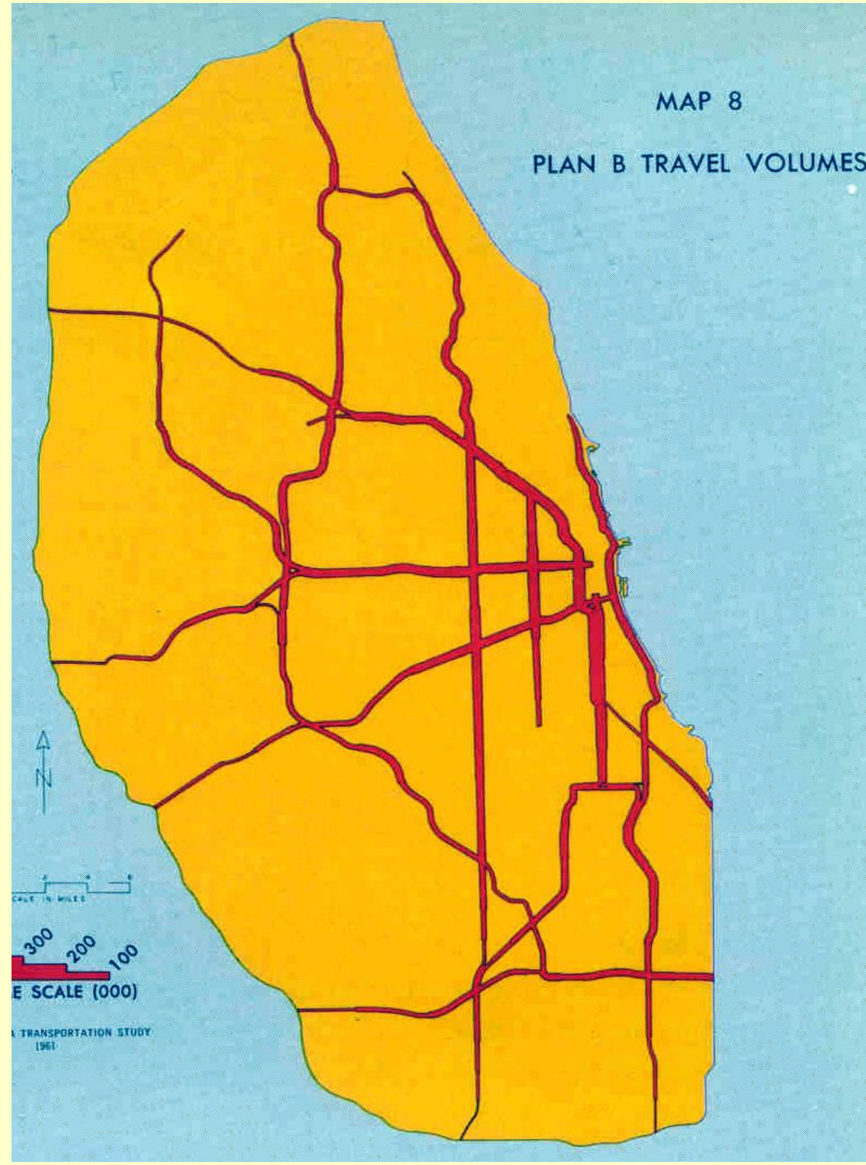


Fig. 8. New Facilities Recommended by Optimal Spacing Requirements

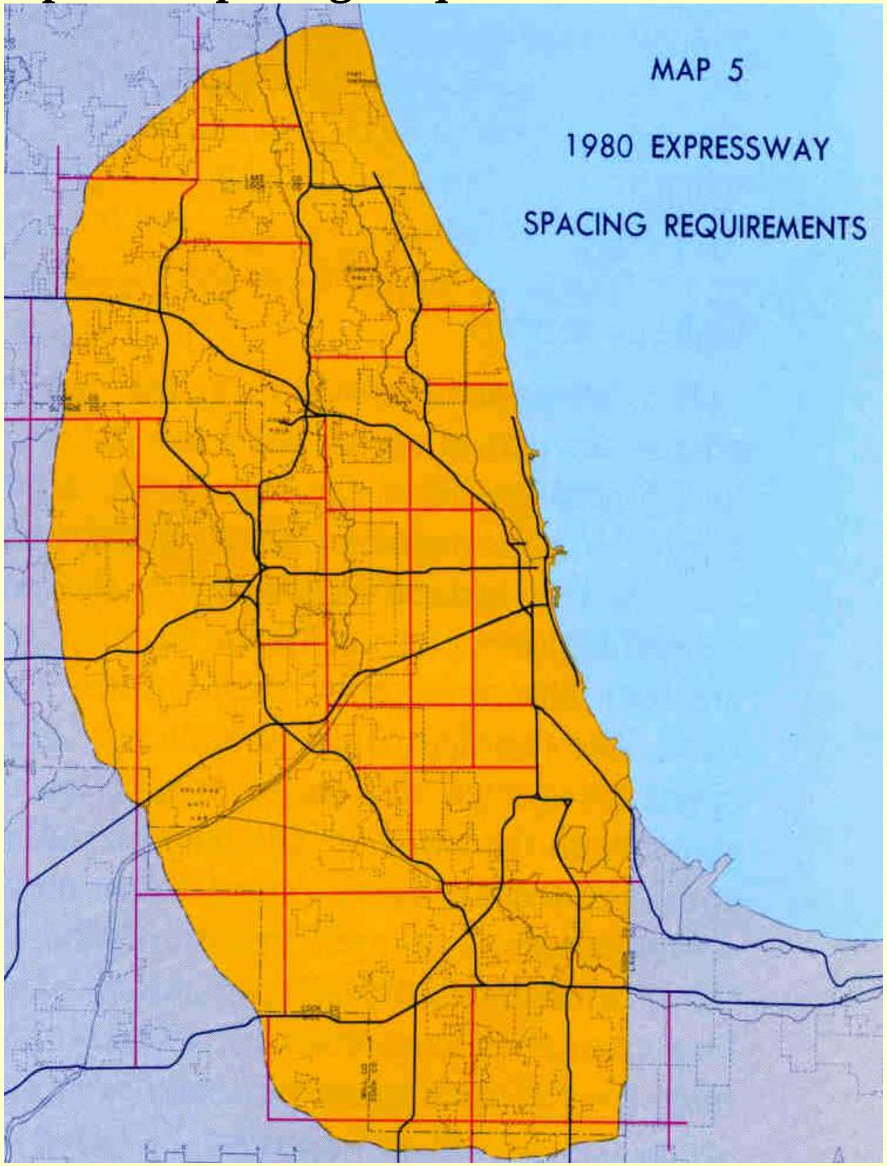


Fig. 9. Travel Volumes for Plan Based on Optimal Spacing Requirements

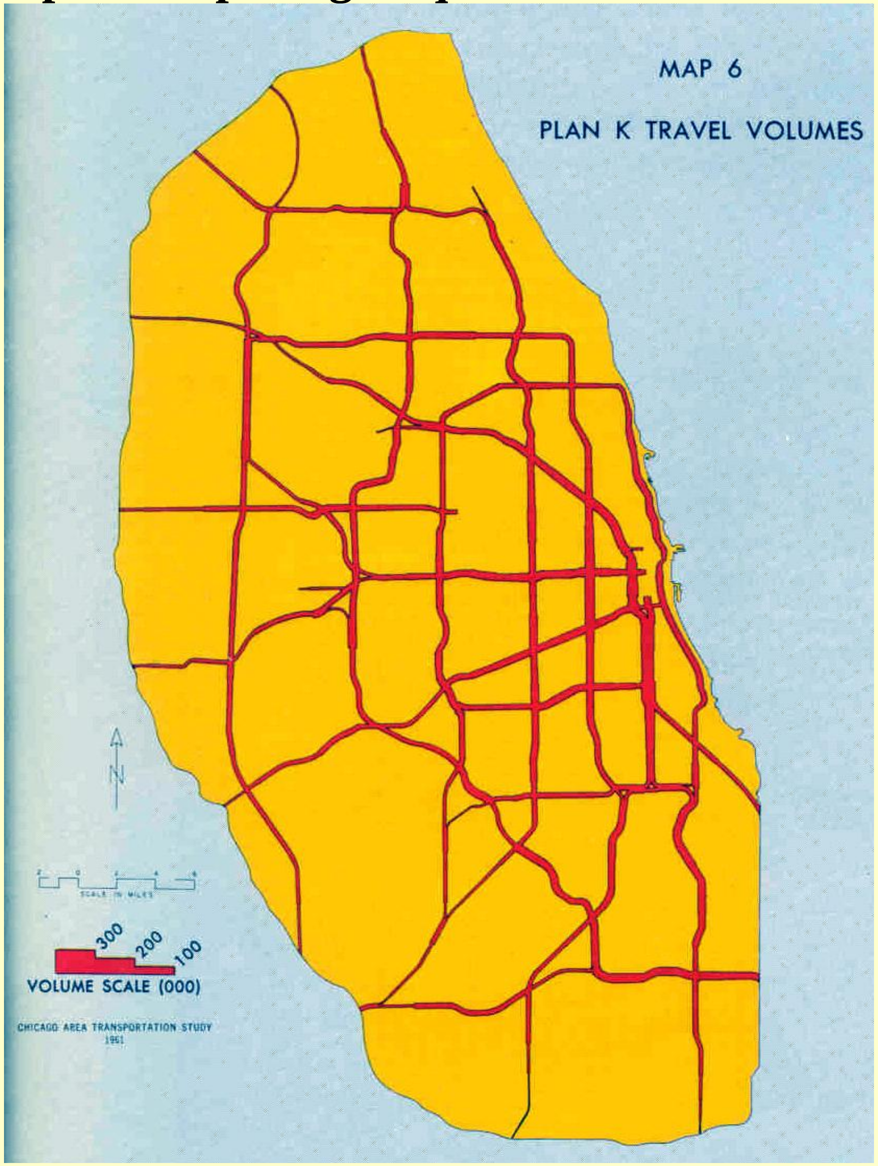


Fig. 10. Travel Volumes on Intermediate Plan with More Facilities than Plan K

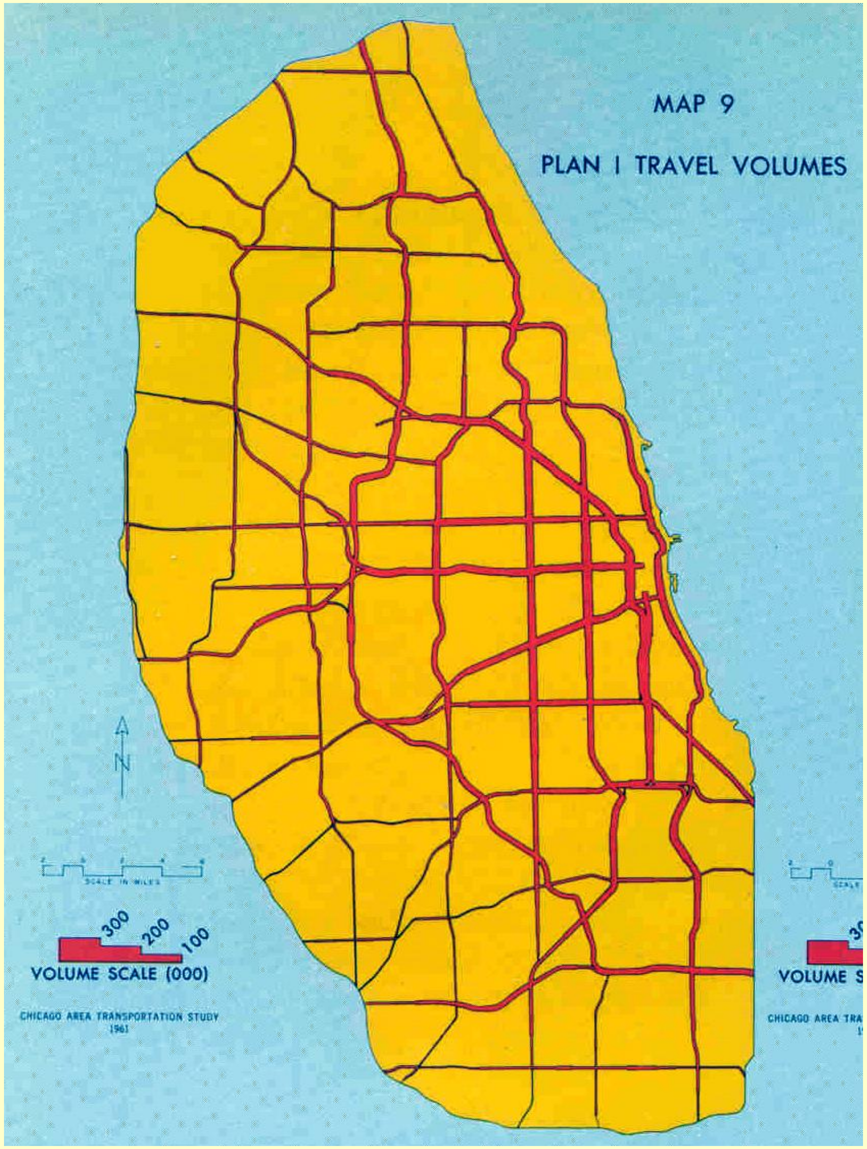


Fig. 11. Travel Volumes on Plan with Maximum Length of Expressways

Fig. 12. Travel Volumes on the Recommended Expressway Plan

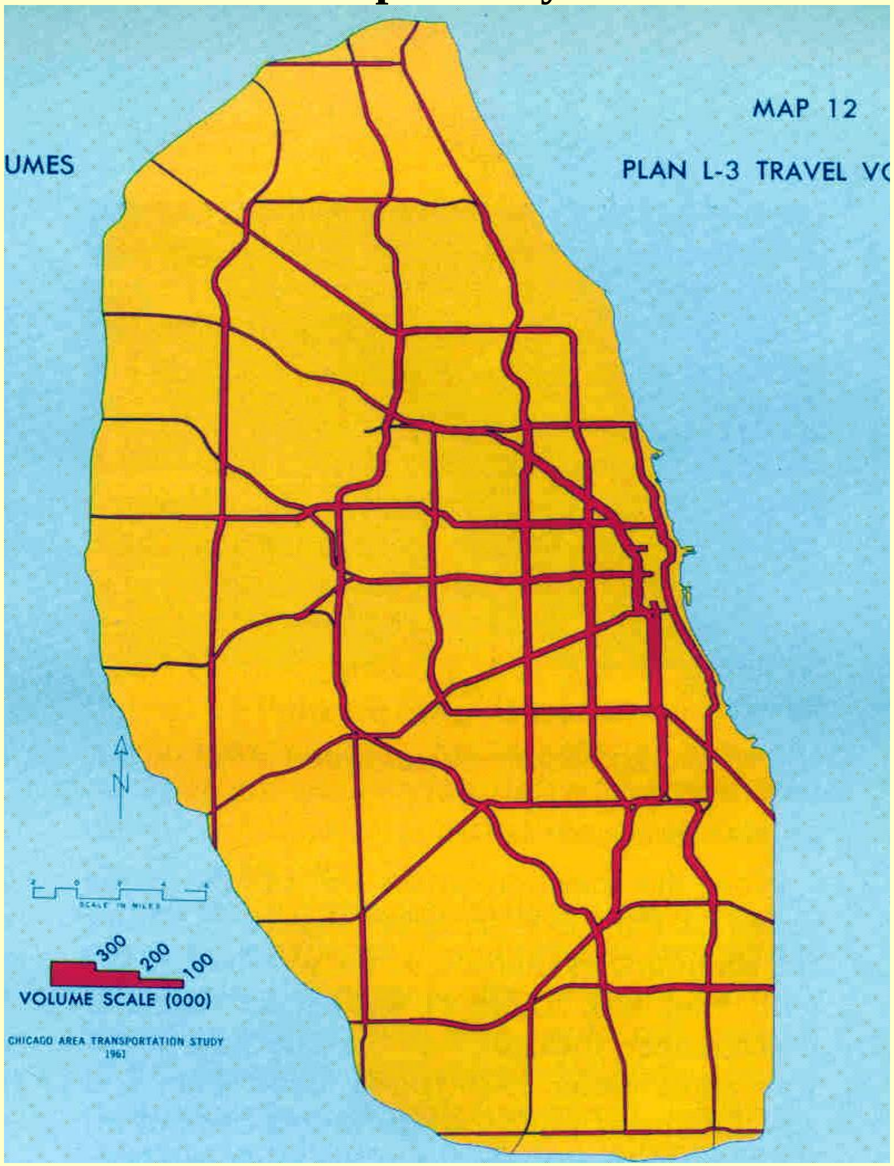
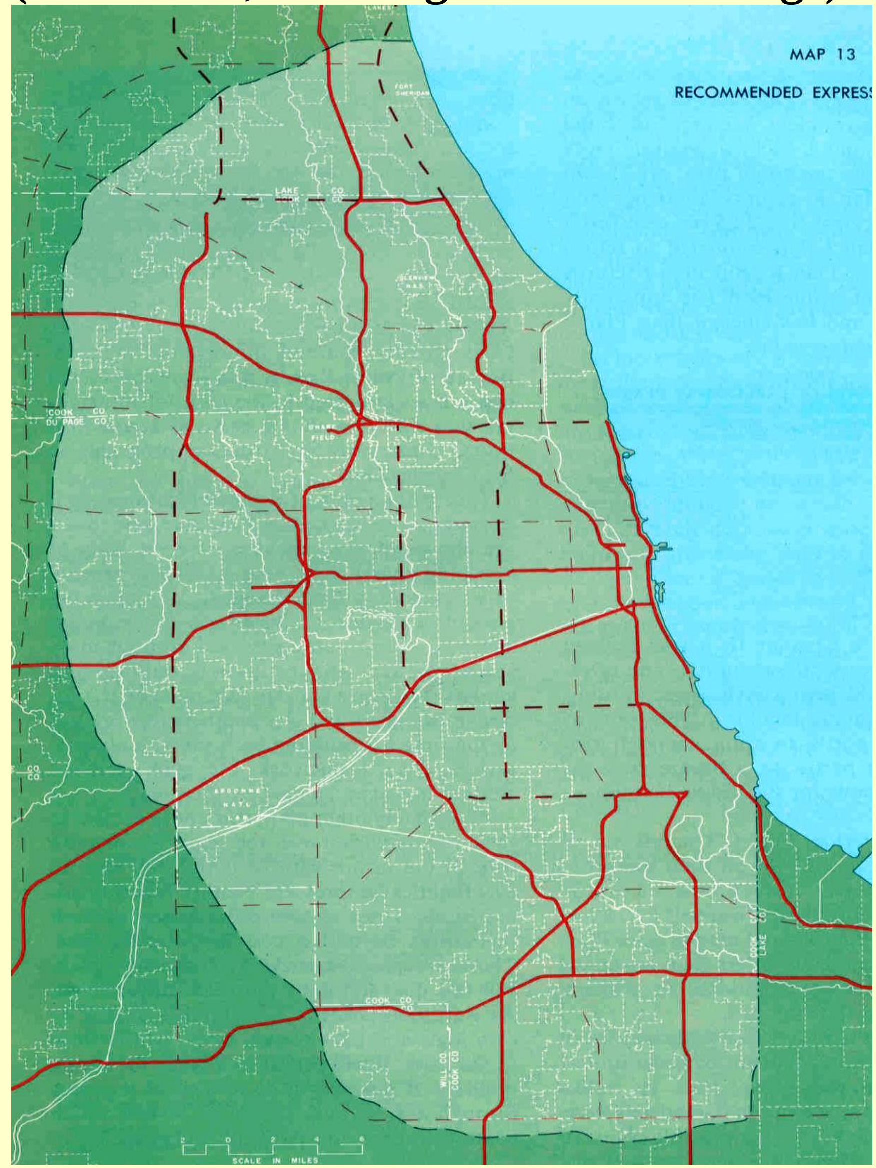


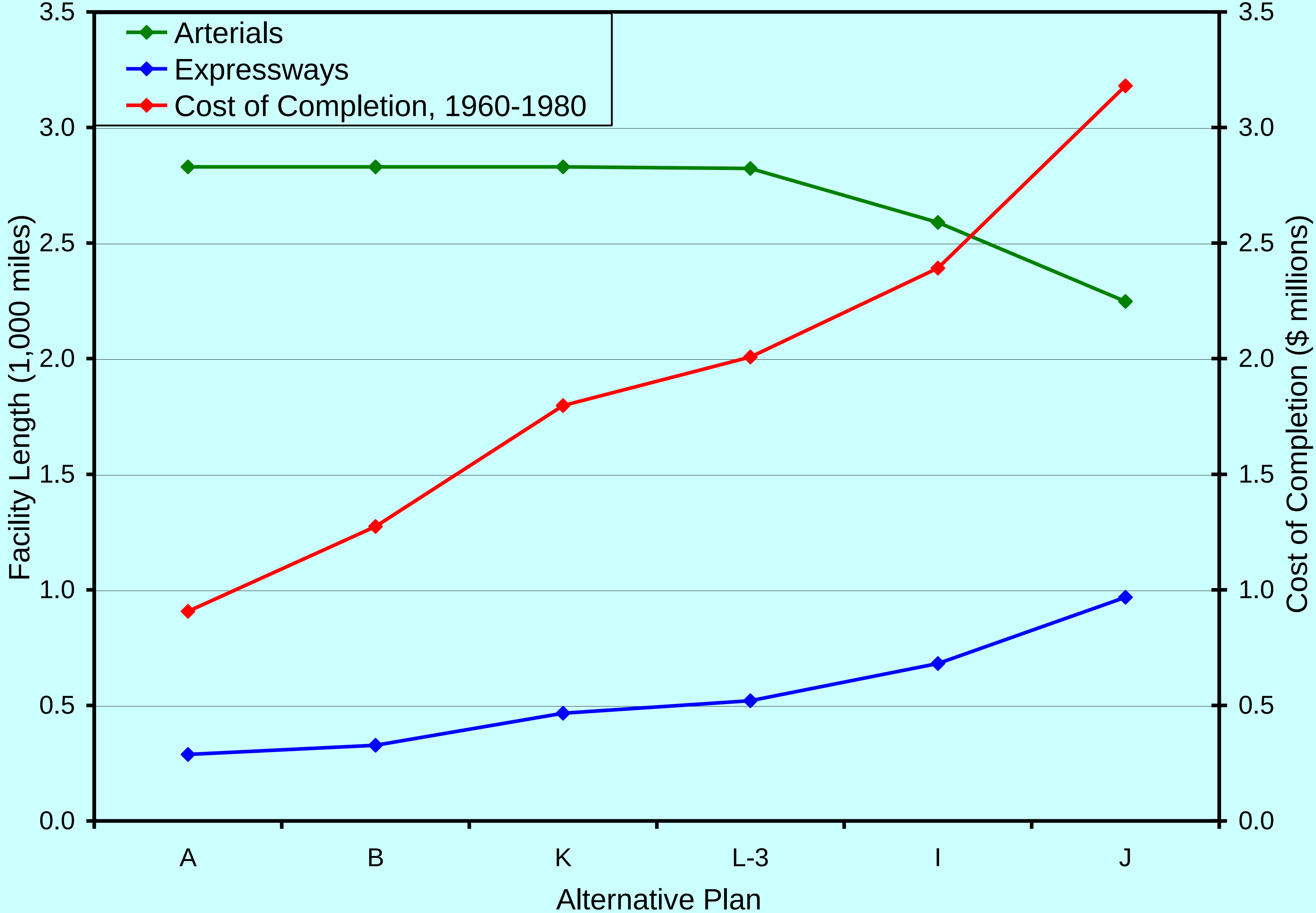
Fig. 13. Recommended Expressway Plan (committed, first stage and second stage)



Characteristics of 1980 Alternative Plans for the Chicago Region

Plan Characteristics - 1980	Alternative Plan					
	A	B	K	L-3	I	J
Miles of Proposed Facilities						
Expressways	288	327	466	520	681	968
Arterials	2,830	2,830	2,830	2,823	2,589	2,247
Cost of Completion, 1960-80, M $	907	1,274	1,797	2,007	2,392	3,180
Weekday Vehicle-Miles Travel, M						
Expressways	22.9	25.2	33.3	34.4	35.1	41.6
Arterials	45.0	42.0	34.4	33.1	31.5	24.2
Total	67.9	67.1	67.7	67.6	66.6	65.8
Weekday Vehicle-Hours Travel, M	2.24	2.28	2.05	1.99	1.94	1.99
Weekday Travel Costs, M $						
Travel Time Cost	3.63	3.38	3.07	2.99	3.03	2.98
Operating Cost	1.87	1.85	1.91	1.91	1.82	1.75
Accident Cost	0.68	0.61	0.51	0.48	0.49	0.47
Total Costs	6.18	5.84	5.49	5.38	5.34	5.20

Fig. 16. Extent and Cost of the Alternative Plans



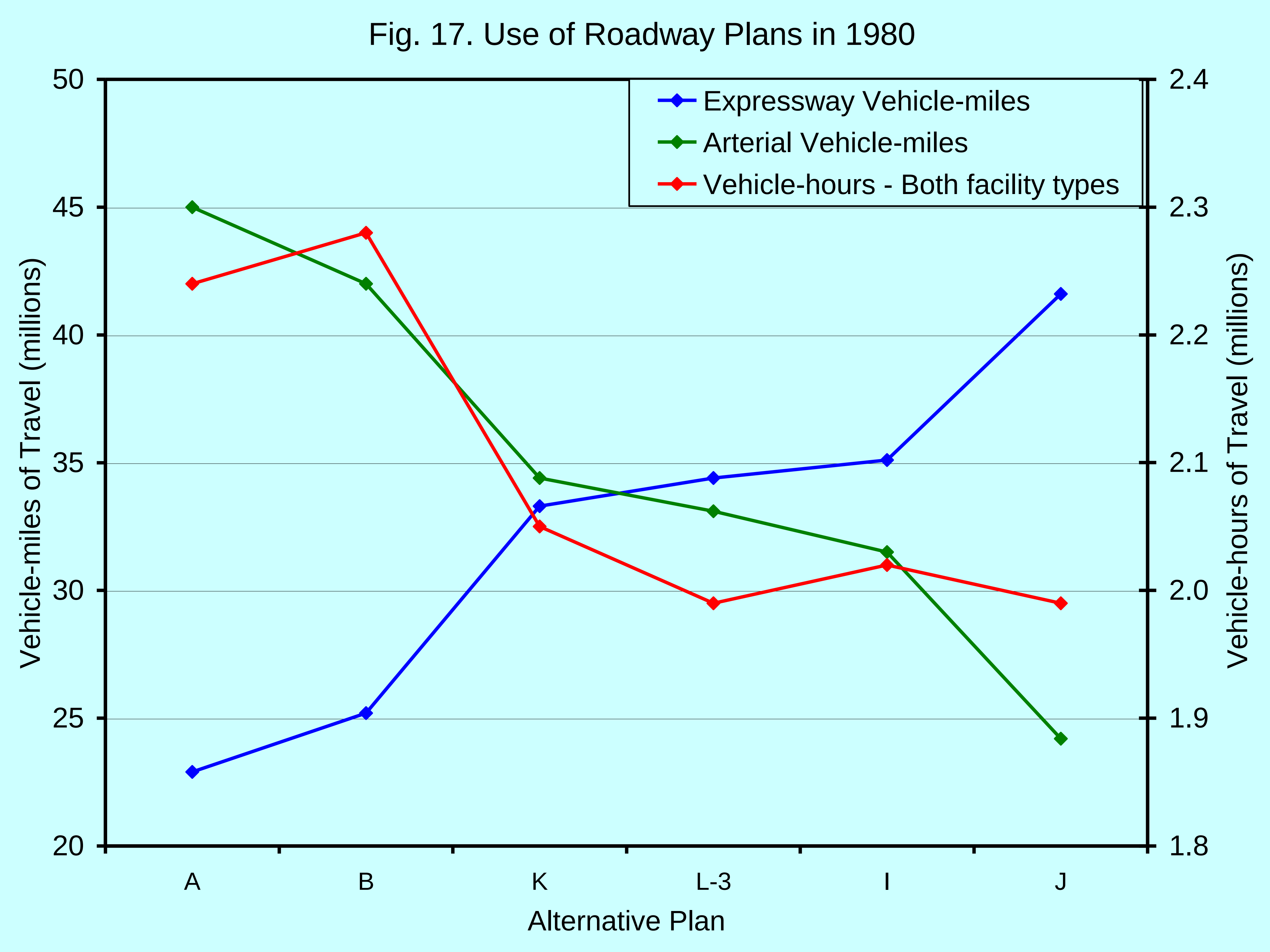
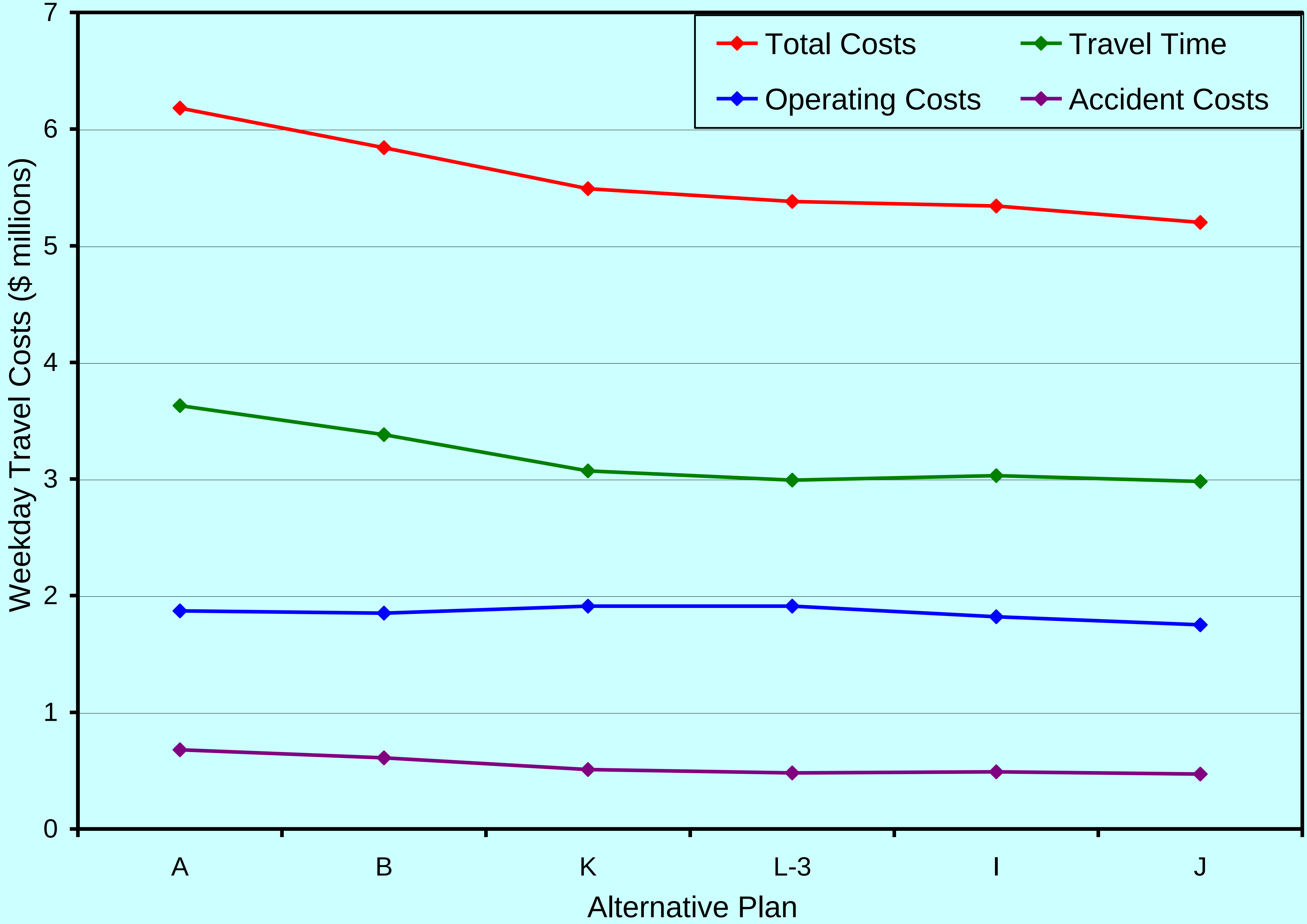


Fig. 17. Use of Roadway Plans in 1980
Expressway Vehicle-miles
Arterial Vehicle-miles
Vehicle-hours - Both facility types
Vehicle-miles of Travel (millions)
Vehicle-hours of Travel (millions)
50
45
40
35
30
25
20
2.4
2.3
2.2
2.1
2.0
1.9
1.8
A
B
K
L-3
I
J
Alternative Plan

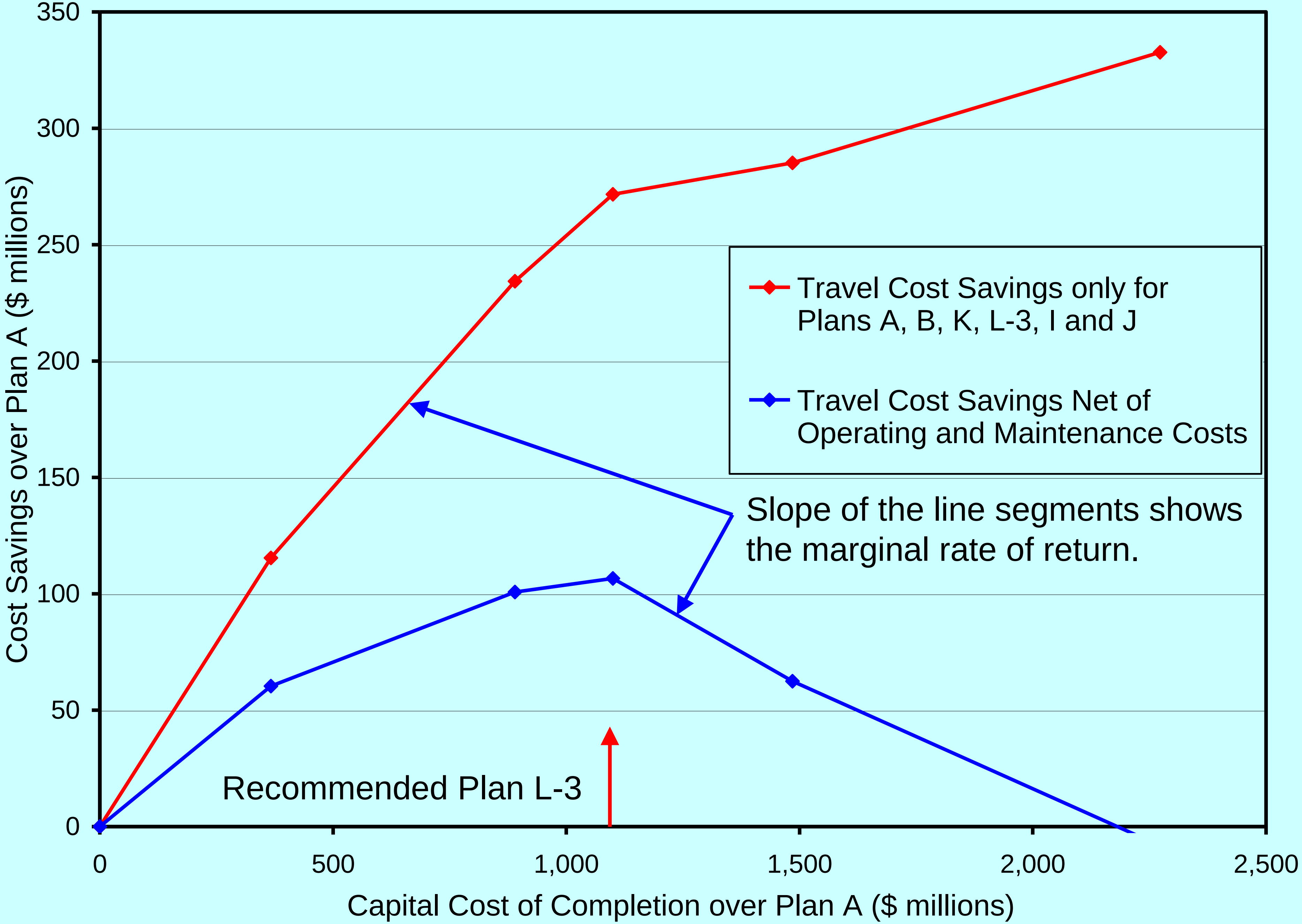
Fig. 18. Weekday Travel Costs of Roadway Plans in 1980



System Costs, Costs of Travel, Operation and Maintenance and Rates of Return

System Cost and Annual Savings in 1980 (millions of dollars)	Alternative Plan					
	A	B	K	L-3	I	J
Total cost of completion, 1960 - 1980	907	1,274	1,797	2,007	2,392	3,180
Marginal cost of completion	0	367	523	210	385	788
Annual users travel cost:	2,098	1,983	1,864	1,827	1,813	1,765
Marginal annual cost savings	0	115	119	37	14	48
Marginal rate of return - % (4/2)	--	31.5	22.7	17.8	3.5	6.0
Annual operation-maintenance. costs - 15%	136	191	270	301	359	477
Marginal annual operation-maint. costs	0	55	79	31	58	118
Marginal annual NET savings (4 - 7)	0	60	40	6	-44	-71
Marginal NET rate of return - % (8/2)	0	16.5	7.7	2.8	-11.5	-9.0

Fig. 19. Marginal Rate of Return of Alternative Plans



Discussion

- The expressway spacing formula resulted in spacings with no clear lowest cost;
- An intuitive desire for a grid system seems to have dominated the analysis;
- Economic evaluation included only three user costs, omitted important public costs, and was not tested for robustness with regard to parameter values;
- Could more attention to design of the “committed” system have led to the implementation of key facilities for which funding was already available, such as the Crosstown Expressway?

Some thoughts about design methods

- Efforts over the past 40 years to apply formal optimization methods to these large-scale network problems have not been successful.
- During the same period, great progress has been made with travel forecasting methods, especially for forecasting mode and route choices. We should build on these successes.
- Carefully designed studies to assess the pros and cons of road and transit configurations (radial-circumferential vs. grid) for a range of land use densities could provide useful guidelines for design.

Future Prospects and Opportunities

- Large Asian cities are constructing expressway systems in response to increased use of cars, and are beginning to invest in rail transit and BRT;
- Are there sound alternatives to large-scale road construction and widespread use of cars from a transportation as well as general economic and societal development viewpoint?
- Are such developments sustainable with regard to their implications for energy consumption and atmospheric emissions?
- What alternative success stories can we examine?

  Singapore? Hong Kong? London? Stockholm?