Urban Travel and City Structure

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Urban travel as measured by the length of the work trip (in miles and minutes) was found to be highly related to the structure of a city, as reflected by the time distribution of job opportunities within a metropolitan area. This measure of city structure combines effects of the spatial allocation of jobs and the speed of the transportation network. It is clear from research of this relationship that, as the transportation network has been improved through an increase in network speed, greater mobility has been afforded to the increasing population, which has allowed for new kinds of development at lower residential densities, and the work-trip length in miles has increased. As mobility has increased, the average trip length of job opportunities has increased. It would thus appear that the selection of city structure and of broader environmental and living preference objectives are the key decisions that should be made in a metropolitan area. Once city structure and environmental objectives are selected, care must be exercised by the planner to develop a transportation system directed toward these objectives.

•THE INTERRELATIONSHIP between urban travel and city structure has often been discussed. The early works of Mitchell (1) certainly demonstrated that there was a strong tie between city structure and urban travel. It is only recently, however, that this complex interrelationship is beginning to be understood; and it seems appropriate now to examine what this research is indicating so that cities and associated transportation systems can be better planned.

URBAN TRAVEL

In the past, various techniques to quantify urban travel have been developed. This has largely been done by breaking travel into trip purposes, such as work, shop, and recreation. It is also advantageous to look at travel for these purposes in terms of average trip length (in minutes or miles) or trip-length distribution (2).

Research has indicated that the most frequent trip is the work trip and that this trip is also the longest made on the average, in many cases accounting for 40 percent of the vehicle-miles traveled in a metropolitan area. The other trips are important as well, particularly the social-recreation trips, which seem to be growing at a faster rate than all others. Planners will have to consider these trips more when planning transportation and land-use systems.

CITY STRUCTURE

In dealing with the urban structure, there has been no effective way of describing the socioeconomic structure of the city. Considerable work, however, has been done in describing the city in terms of density versus distance from the central business district (CBD), as in the early work of Colin Clark (3). As shown by Figure 1, the population density descends rapidly as distance from the CBD increases. The population density near the core is much higher in the older cities, such as Philadelphia and St. Louis, than it is in a city like Houston, which has developed largely in the auto age.

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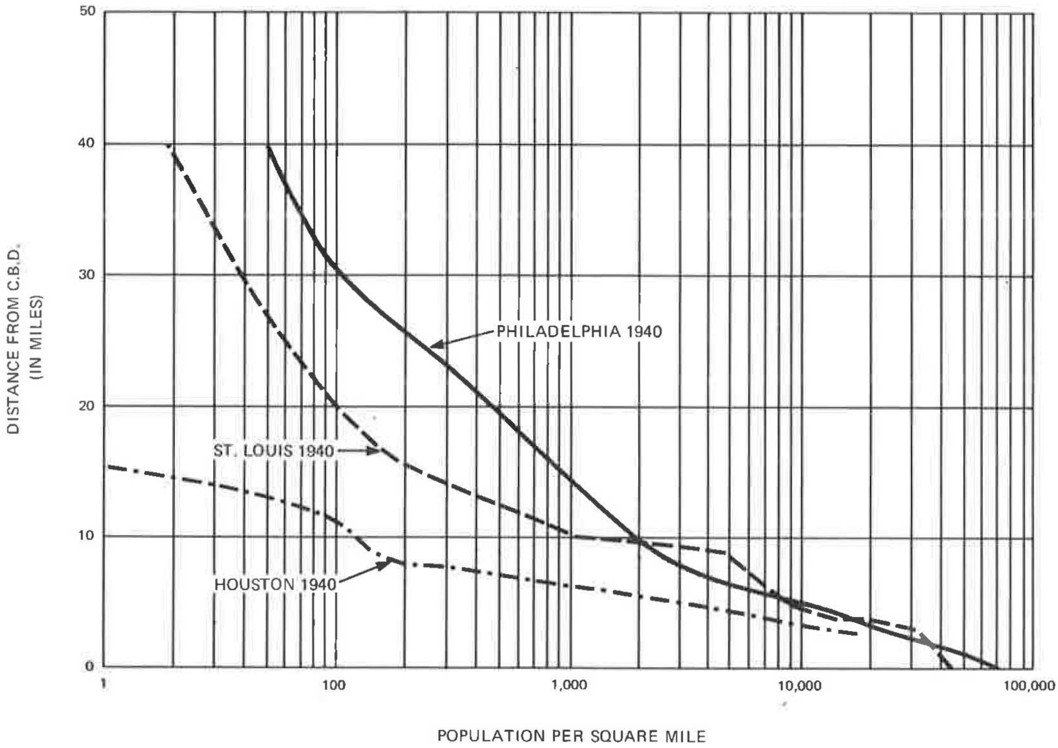

Figure 1. Residential density patterns for different metropolitan areas. (From Arthur Row and Ernest Jurrat. The Economic Forces Shaping Land Use Patterns. Jour. Amer. Inst. Planners, Vol. 25, No. 2, p. 78.)

There is variation within the general framework shown in Figure 1. A more recent way to measure the socioeconomic structure of a city in a more precise manner is to develop a distribution for work-trip opportunities. This appears to be a better way of stating the structure of a city. In effect, by this technique we measure the distance from a residential area to all the jobs in the area. This can be presented as a distribution of trip opportunities (Fig. 2). It can also be stated for various sections of the metropolitan area, or it can be aggregated into a mean value for the metropolitan area.

An advantage of this approach is that changes in the structure of a city can be determined. Figure 2 is a good illustration of this; it shows the distribution change in Washington between 1948 and 1955 which occurred largely with no substantial change in the speed of the transportation network.

VARIATIONS IN TRIP LENGTH

Residential density patterns for the Washington metropolitan area (Fig. 3) show the typical declining residential density profile from the CBD. The work-trip opportunity distribution related to an area close to the CBD has characteristics different from those in an area farther away. These differences can be demonstrated by taking three zones within the Washington area at different distances from the downtown area. These zones are labeled A, B, and C and are 8, 14, and 21 minutes from the downtown area respecitvely.

The opportunity distribution related to these three zones is shown in Figure 4. As one would expect, zone A has greater job opportunities with 5- to 10-minute trips because it is closer to the job opportunities, particularly those in the downtown area. Zone B has most of its job opportunities with 10- to 15-minute trips, whereas zone C

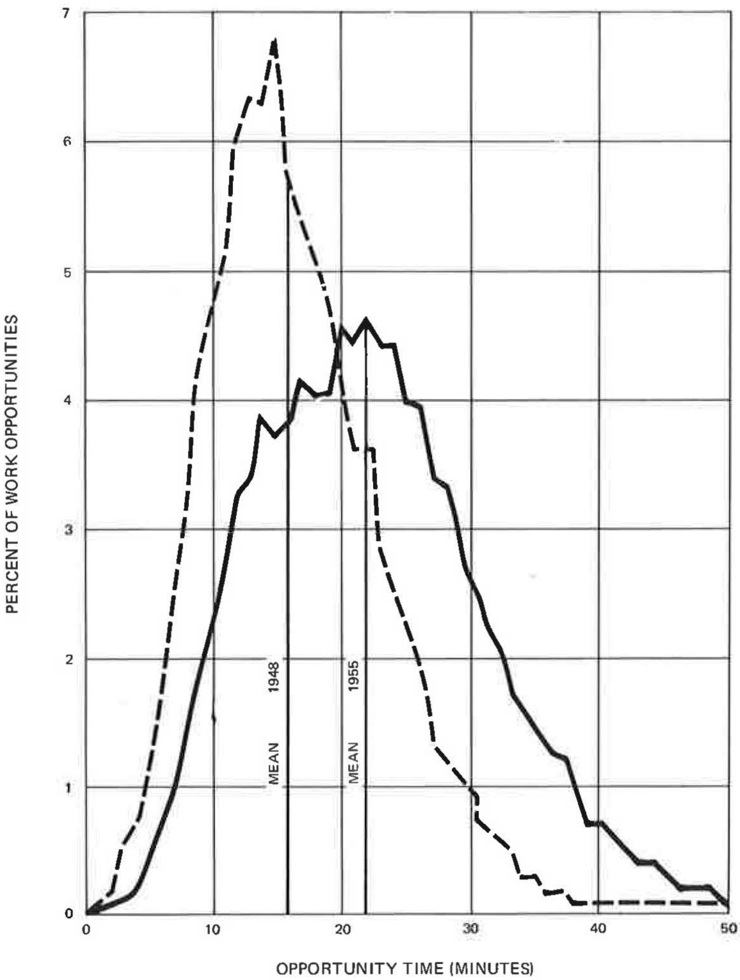

Figure 2. Opportunity distribution for Washington, D. C., 1948/1955. (From Alan M. Voorhees, Salvatore J. Bellomo, Joseph L. Schofer, and Donald E. Cleveland. Factors in Work Trip Length. Highway Research Record 141, 1966, pp. 24-46.)

has the bulk of its job opportunities within the 20- to 25-minute trip range. The work-trip lengths that are found for these zones reflect these differences in the opportunity distribution. As shown in Figure 5, the trip distribution patterns are related to the opportunity distribution. The average trip in zone A is smaller than those in zones B and C, and zone A trips are concentrated in the shorter time ranges. Trips for B and C are longer in length. This relationship can be estimated through the use of the gravity model trip distribution formula. There is a direct relationship between the opportunity trip length and the average trip length. Figure 6 shows this relationship for the three zones analyzed.

CITY STRUCTURE AND TRIP LENGTH

The total trip pattern that is produced in a metropolitan area is the composite of all the opportunity distributions in various sections of the metropolitan area; it is not

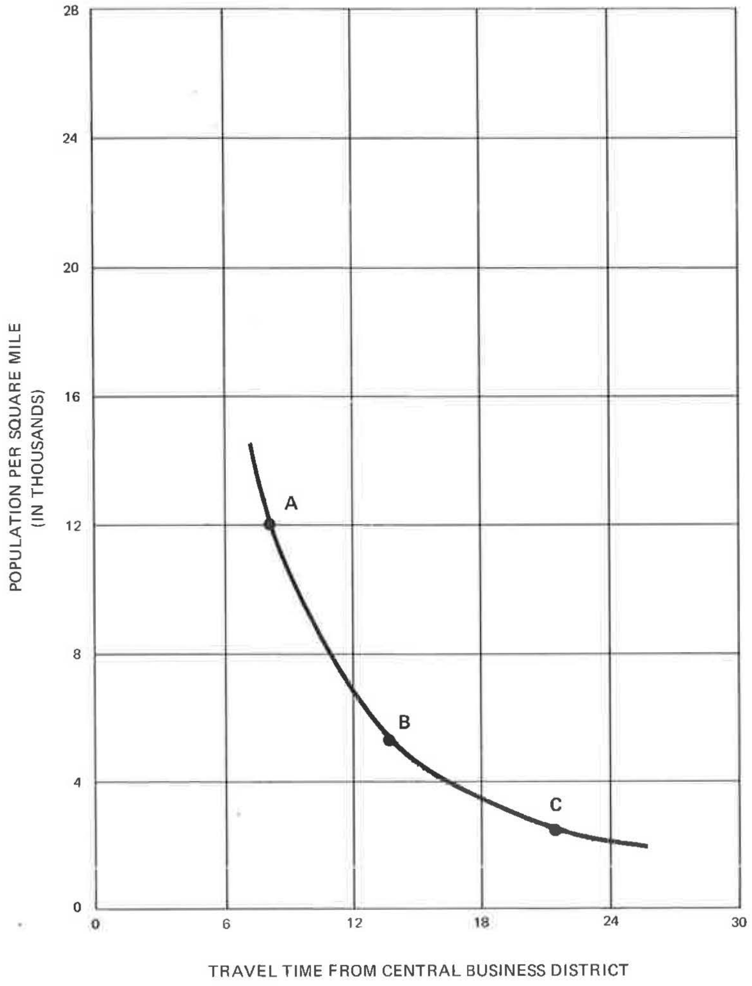

Figure 3. Residential density profile for Washington, D. C. (From Economic Base Study for the General Development Plan—National Capital Region. Council for Economic and Industry Research, Inc., Washington, D. C., June 1956.)

surprising, therefore, that the same kind of relationship can be found for the overall opportunity distribution across various cities. Figure 7 shows the work-trip opportunity distributions for three cities that have quite marked differences in their structure. Aside from the size differences, which affect the work-trip opportunity distribution, the cities represent quite different structures. In Erie, most of the trip opportunities are within 20 minutes; in Detroit, these work-trip opportunities are largely less than 40 minutes long; and in Seattle-Tacoma the trip opportunity distribution seems to be almost flat. It is not surprising, therefore, that we find the cities of Seattle and Tacoma with the longest actual work-trip lengths and Erie with the shortest because of this difference in city structure. This relationship between trip length and the opportunity length is shown in Figure 8. It was found that the work-trip length increased as the opportunity length increased in several cities and as a result of the simulation study.

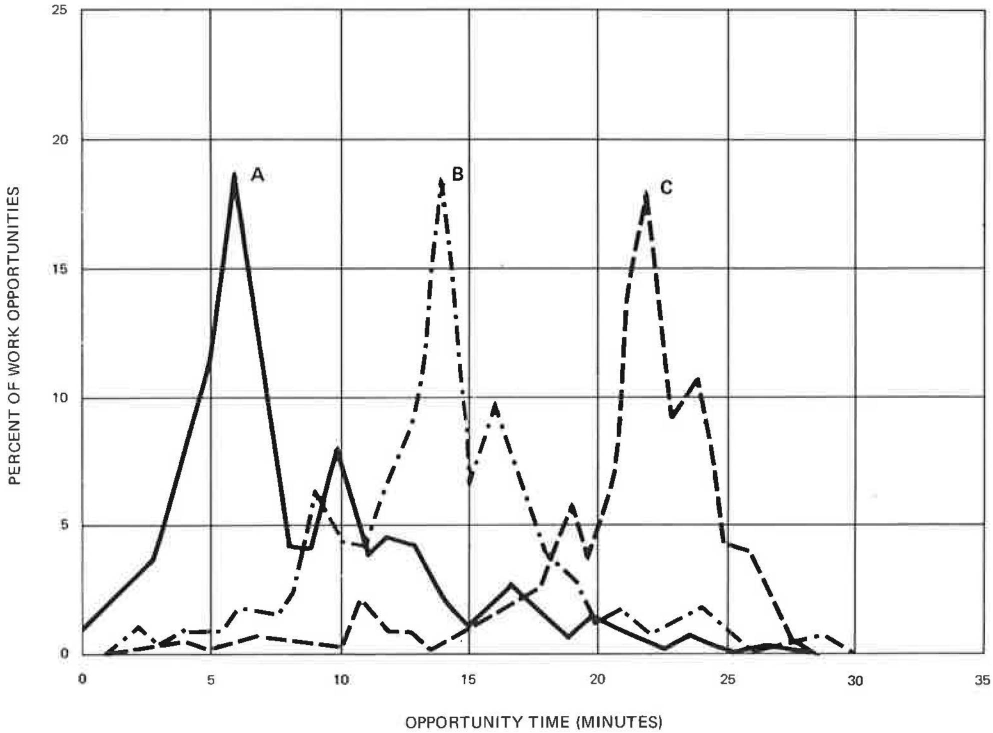

Figure 4. Opportunity distributions for selected zones in Washington, D. C., 1948. (See Fig. 2 for source.)

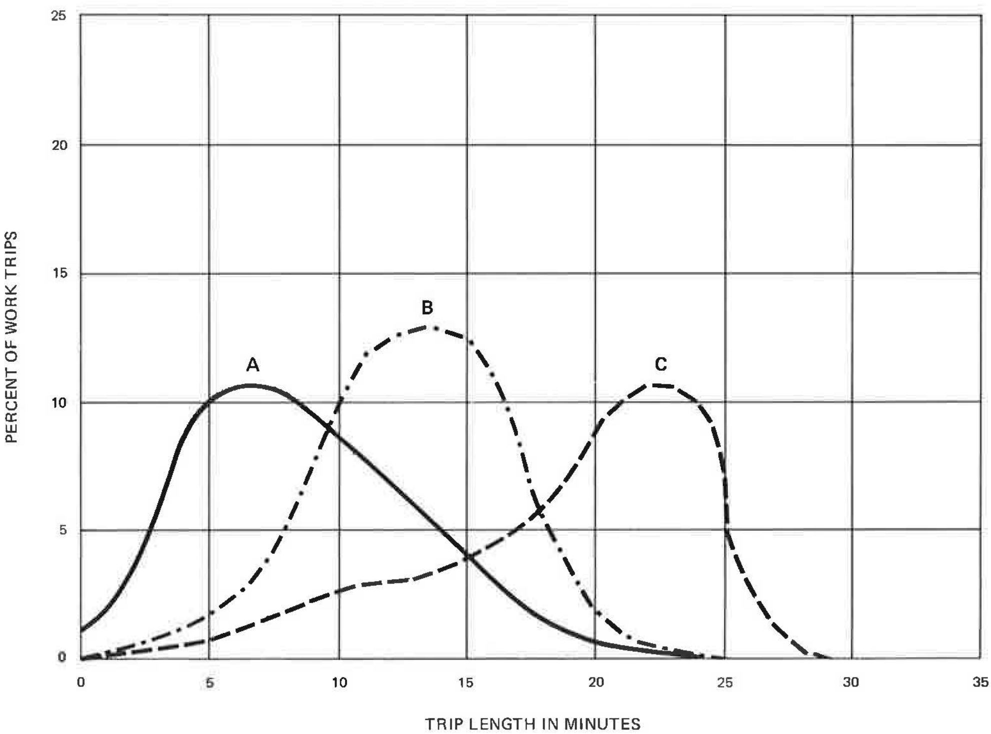

Figure 5. Trip-length distribution in Washington, D. C., 1948. (See Fig. 2 for source.)

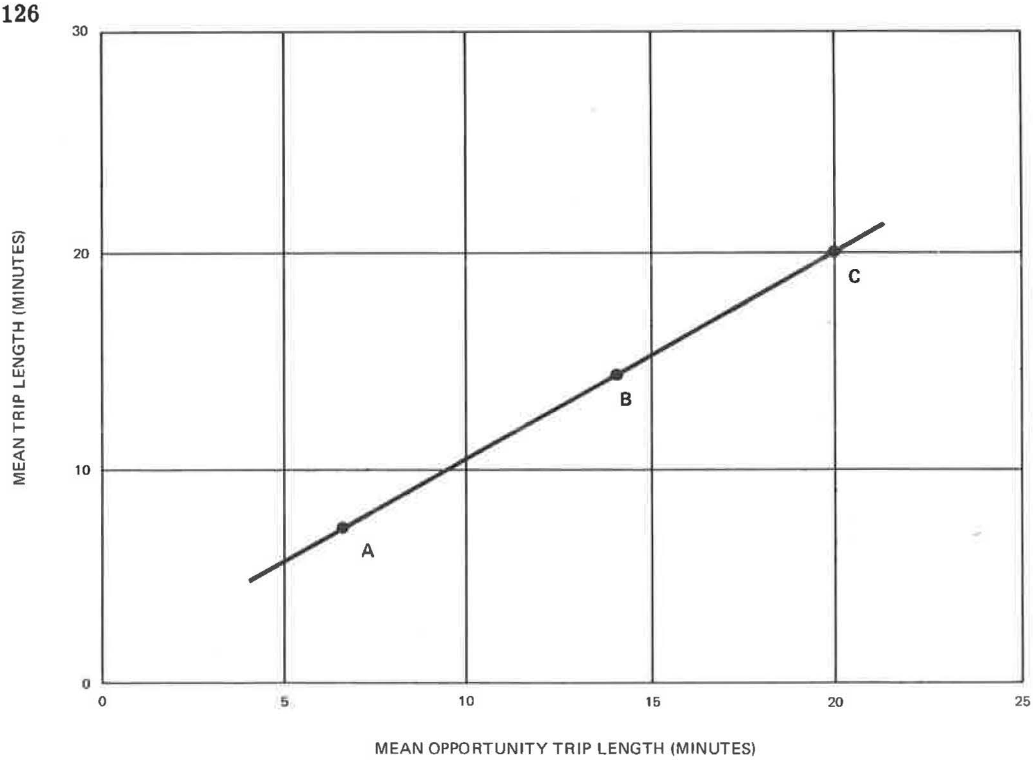

Figure 6. Mean work-trip length versus mean opportunity-trip length. (See Fig. 2 for source.)

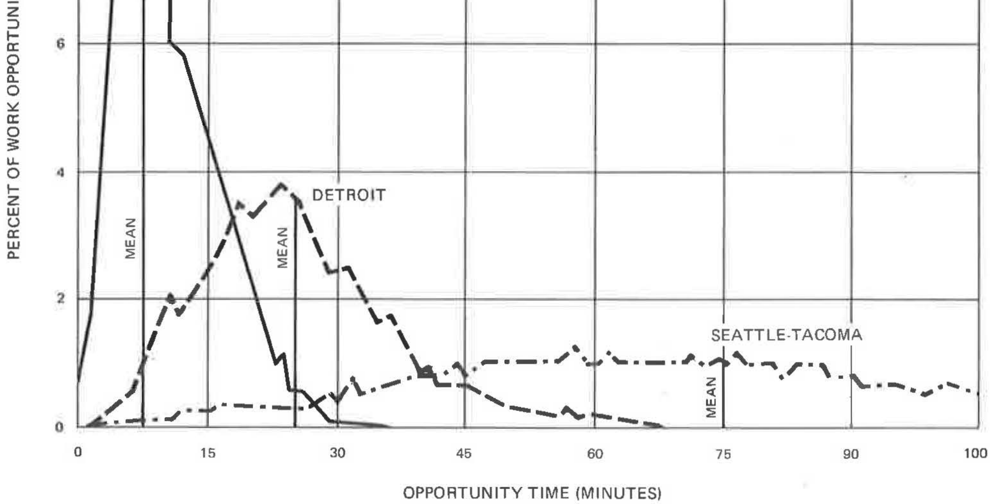

Figure 7. Opportunity distribution across three cities. (See Fig. 2 for source.)

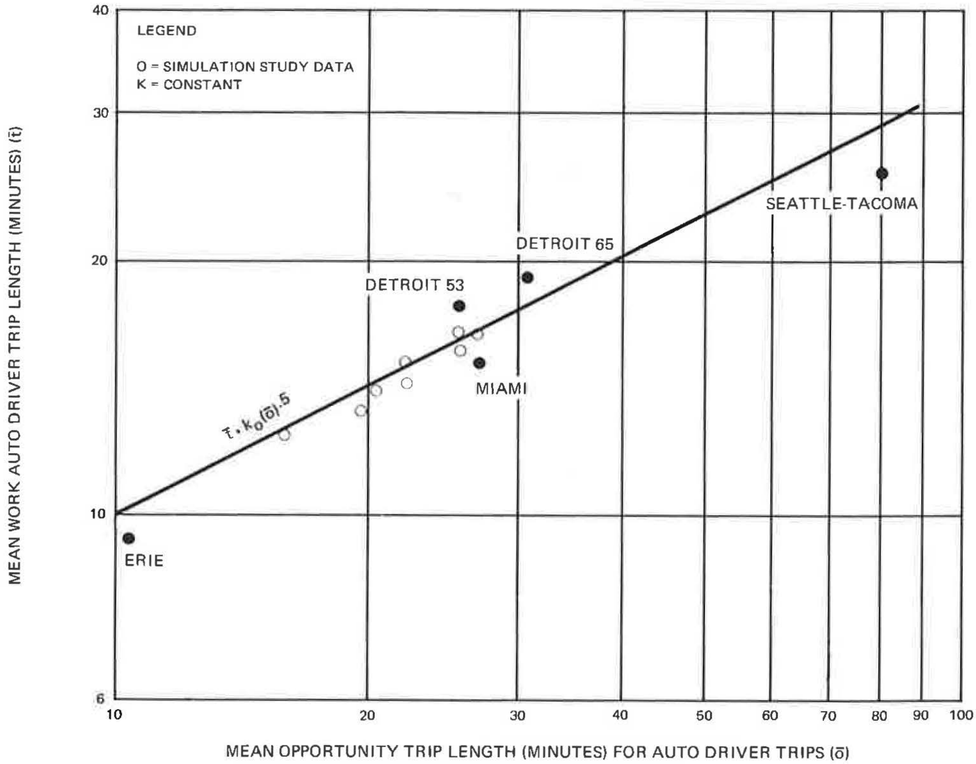

Figure 8. Mean work-trip length versus mean opportunity-trip length. (From Alan M. Voorhees and Salvatore J. Bellomo. Factors and Trends in Trip Lengths. National Cooperative Highway Research Project 7-4, 1969.)

NETWORK SPEED AND TRIP LENGTH

Now that we have established the relationship between city structure, as measured by the opportunity trip-length distribution with its associated mean value, and urban travel, as reflected by the work-trip distribution, we can analyze what happens when the speed of a transportation network is increased. If we take a simple case, for example, where the travel time to all the other zones is reduced by increasing the speed by 50 percent, the opportunity distribution shown in Figure 9 actually changes. If we apply an average set of travel time factors for the work trip, the trip length will change. In fact, the trip length in terms of minutes actually reduces slightly, whereas the trip length in miles increases. Various simulation studies of the work trip have demonstrated that trip length in miles for a constant urban form is proportional to about the 0.75 power of the change in network speed, whereas change in trip length in minutes is inversely proportional to about the 0.25 power of change in network speed.

The relationship between the opportunity trip length and average network speed can also be derived mathematically. We know from Figure 8 that a relationship exists between the mean work-trip length (in minutes) and the mean opportunity work-trip length. This relationship, which was verified using cross-sectional, historical, and simulation study data, can be stated as

$$t = k_1 O^{0.5}$$

where

t = mean work-trip length, minutes;
O = mean opportunity trip length, minutes; and
k_1 = a constant.

For two points in time (t_2 and t_1) this relationship would expand to

$$\frac{t_2}{t_1} = \frac{O_2^{0.5}}{O_1} \qquad (1)$$

We also know from the historical and cross-sectional research analyses in Detroit, Reading, Washington, and so forth that

$$L = k_2 P^{0.2} S^{1.5}$$

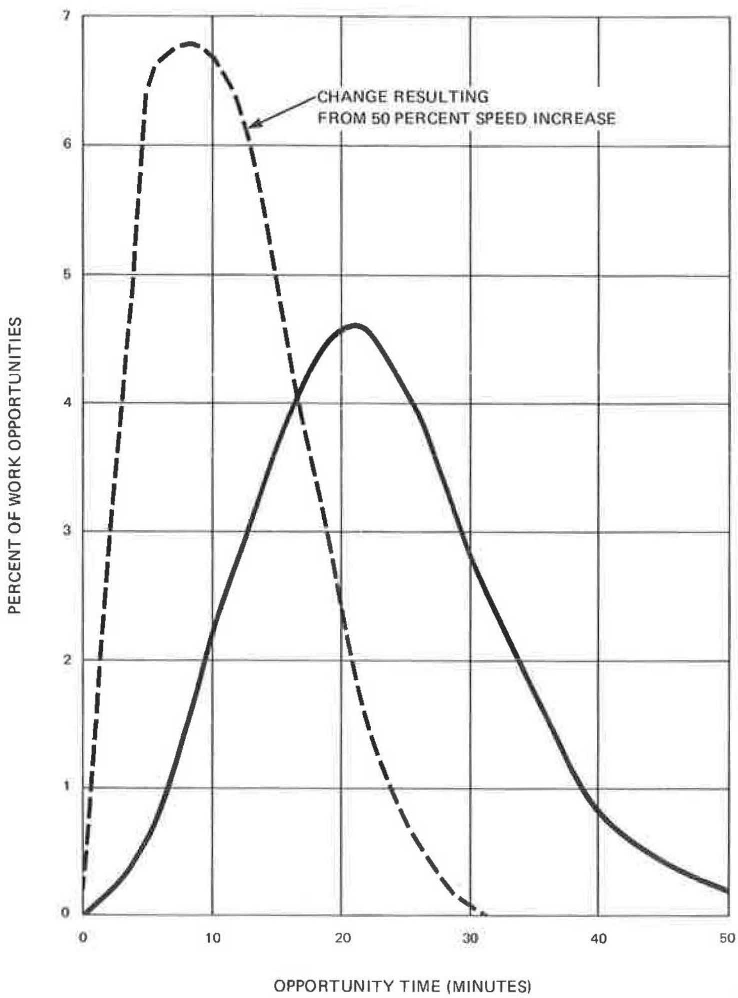

Figure 9. Opportunity distribution change developed by change in network speed.

where

L = mean work-trip length, minutes;
P = population;
S = average network speed, miles per hour; and
k_2 = a constant.

For two points in time (L_2 and L_1) and a constant population, the above expression can be stated as

$$\frac{L_2}{L_1} = \frac{S_2}{S_1}^{1.5} \tag{2}$$

The simulation study of the work trip indicates, however, that

$$\frac{L_2}{L_1} = \frac{S_2}{S_1}^{0.75} \tag{3}$$

Therefore, to derive a relationship between opportunity trip length and average network speed, three cases will be considered: Case A is for the 1.50 power, case B is for the 0.75 power, and case C is for the 1.00 power.

For case A, we know that average network speed can be defined as

$$S = \frac{L}{t} \tag{4}$$

Substituting equations (1) and (2) into equation (4) for two points in time will result in

$$\frac{S_2}{S_1} = \frac{S_2}{S_1}^{1.5} \frac{O_2}{O_1}^{-0.5}$$

Rearranging and solving for O_2/O_1 we obtain equation (5):

$$\frac{O_2}{O_1} = \frac{S_2}{S_1} \tag{5}$$

This indicates that the change in the mean opportunity trip length is directly proportional to the average network-speed change.

For case B, we substitute equations (1) and (3) into equation (4) for two points in time. This results in

$$\frac{S_2}{S_1} = \frac{S_2}{S_1}^{0.75} \frac{O_2}{O_1}^{-0.5}$$

Rearranging and solving for O_2/O_1, we obtain equation (6):

$$\frac{O_2}{O_1} = \frac{S_2}{S_1}^{-0.5} \tag{6}$$

This indicates under simulation study conditions that the change in the mean opportunity trip length would be inversely proportional to the square root of the speed change.

For case C, the relationship between opportunity trip-length change and the speed change is

$$\frac{S_2}{S_1} = \frac{S_2^{1.00}}{S_1} \frac{O_2^{-0.5}}{O_1} \tag{7}$$

$$\frac{O_2}{O_1} = 1.00$$

This indicates that there would be no change in the mean opportunity trip length with changes in network speed.

Change in trip length is caused not only by network speed, but also by changes in city structure as shown in Figure 2 for the city of Washington. The trip length in minutes increased over 14 percent during this period (Fig. 10). There was little concurrent change in the speed of the transportation network, and therefore the trip-length change was caused primarily by change in the city structure. Trip length is sensitive, therefore, to changes in speed of the transportation network and changes in the structure of the city.

NETWORK SPEED AND CITY STRUCTURE

As previously indicated, changes in the work-trip length in miles is proportional to the 0.75 power of the change in network speed. But the historical data available on trip length in five cities—Detroit, Baltimore, Washington, Sioux City, and Reading—indicated that the trip length in miles increased according to the 1.5 power of the change in network speed. The difference between the 0.75 power and the 1.5 power must reflect the amount of change that was a result of the change in the urban structure, where the cities tended to spread out. Whether this pattern will continue into the future is difficult to say. There seems to be evidence at the present time, however, that cities are increasing their residential densities and are not spreading out as much as they did just after World War II. The recent apartment house expansion is an illustration of this pattern.

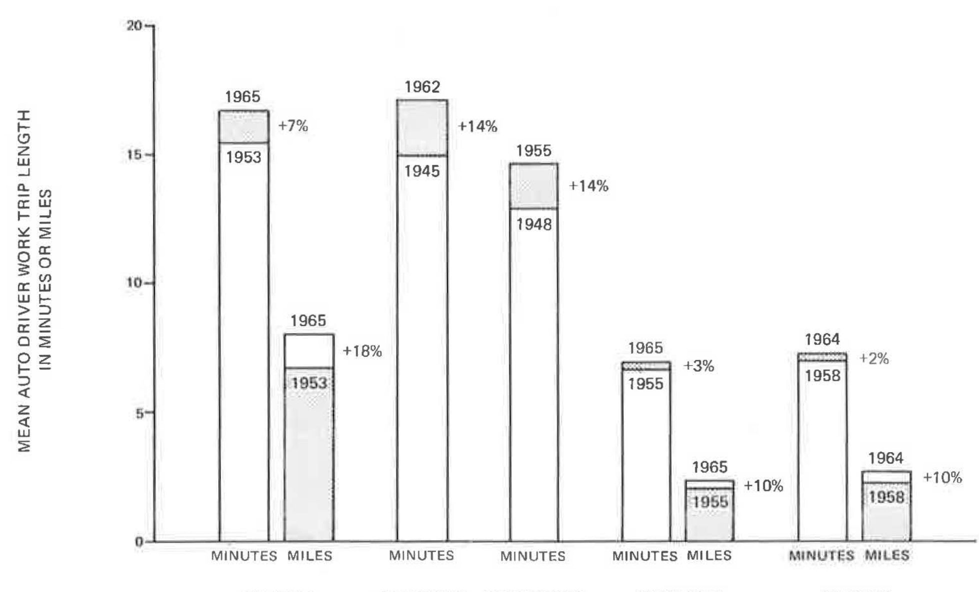

Figure 10. Historical increases in the work-trip length. (See Fig. 8 for source.)

The socioeconomic structure of the metropolitan area also has an effect on the work-trip length. In Detroit in 1965 it was found that the average work-trip length for certain geographic areas varied by as much as 70 percent from the metropolitan-wide average (Table 1). This large difference was caused by spatial separation of work-trip opportunities for different socioeconomic classes (Table 2). The data indicate that the actual trip length and the opportunity work-trip length increase as the income of the trip-maker increases. This explains the differences in trip length in relation to income that have been found in other metropolitan areas. The fact that the rich or poor have work-trip lengths that are not consistent from one metropolitan area to another is really a result of the differences in the spatial distribution of work-trip opportunities. Low-income workers in the CBD of Detroit find themselves surrounded by many job opportunities. The job opportunities relevant to their skill levels, however, are often found at some outlying manufacturing plant. The related average opportunity-trip as well as the actual work-trip length is therefore longer than the average for the metropolitan area.

TABLE 1

THE WORK-TRIP LENGTH BY GEOGRAPHIC AREA: DETROIT (1965)

Geographic Area	Percent of Total Auto Trips	Mean Trip Length[a] (min)	Percent Difference From Total/Average
CBD	2	29.5	+70
Central	33	20.1	+16
Other	65	15.9	-8
Total/average	100	17.3	

[a]Mean trip lengths do not include terminal times (6 minutes in the CBD and about 2 to 4 minutes in other areas).

Another way to explore whether this change in trip length is likely to continue in the future is to attempt to use the proposed relationships between urban travel and city structure to see what probably has occurred in the past as transportation systems have been improved and as cities have changed.

TRIP LENGTH AND CITY DEVELOPMENT

The kind of trip length that might be expected in a city can be calculated if certain assumptions about the average network speed are made and if it is assumed that the impact of the change in network speed is related to the 0.75 power, the 1.0 power, or the 1.5 power of the change in network speed. Figure 11 shows the work-trip length in terms of minutes for different network speed—3, 10, 20, and 30 mph—using the exponents of 0.75, 1.0, and 1.5. It was also assumed that the average work-trip length would be about 20 minutes, with network speed of 30 mph. (This average length is generally found in cities of approximately 2 to 3 million people.)

These results indicate that in a pedestrian society (3 mph) with a corresponding high-density city structure, the average work-trip time with today's automobiles would be down to about 3 to 5 minutes. Although historical data on the pedestrian society are not available, one does have indications from literature such as Dickens' work dealing with London that people did walk more like 20 minutes to work rather than 3 minutes. Such

TABLE 2

RELATIONSHIP BETWEEN THE MEAN WORK-TRIP LENGTH AND THE MEAN OPPORTUNITY-TRIP LENGTH: DETROIT (1965)

Income Class (dollars)	Actual Trip Length	Ratio of Actual to Average	Opportunity-Trip Length	Ratio of Opportunity-Trip Length to Average Trip Length
0-3,000	14.4	0.83	28.3	0.92
3,000-5,000	15.7	0.91	28.2	0.92
5,000-7,000	15.7	0.91	29.2	0.95
7,000-10,000	17.8	1.03	30.9	1.01
10,000 and over	19.6	1.14	31.1	1.02
Average	17.3		30.6	

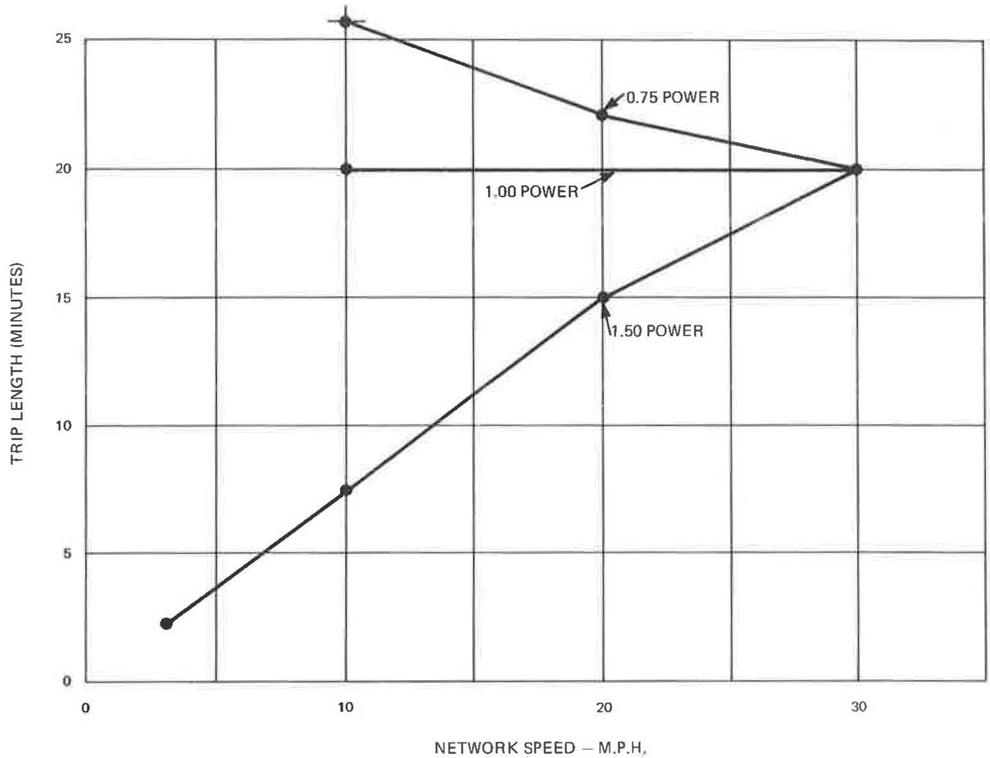

Figure 11. Relationship between network speed and trip length (minutes).

literary references seem to indicate that people are traveling about the same time to work as they did 50 to 100 years ago for comparable size cities. Thus, perhaps the impact that network-speed change has on trip-length change is more nearly related to the 1.0 power than to the 1.5 power.

CHANGES IN ACCESSIBILITY

A recent report of Bieber and Jorry (4) shows that the network speed for typical European cities is about one-half that for comparable U. S. cities and that the average distance from the CBD to the center of population in Europe was about one-half the average distance in the United States. This would indicate that the average opportunity distance in the United States and Europe for comparable size cities is nearly the same.

Figure 12 shows how the mean opportunity length changes with various exponents (0.75, 1.0, and 1.5) for changes in network speed. The results indicate that if the work-trip length goes up in proportion to the 1.5 power there is a substantial reduction in the average length of trip opportunities. This reduction would imply that cities are becoming less convenient in terms of time. On the other hand, if trip length goes up at the 1.0 power related to network speed, there would be no change in opportunity; this is probably what has been happening, as indicated in the comparison between European and United States cities. This relationship raises a very basic question. Are we providing a better transportation system if we neither decrease the average opportunity trip length nor hold it constant?

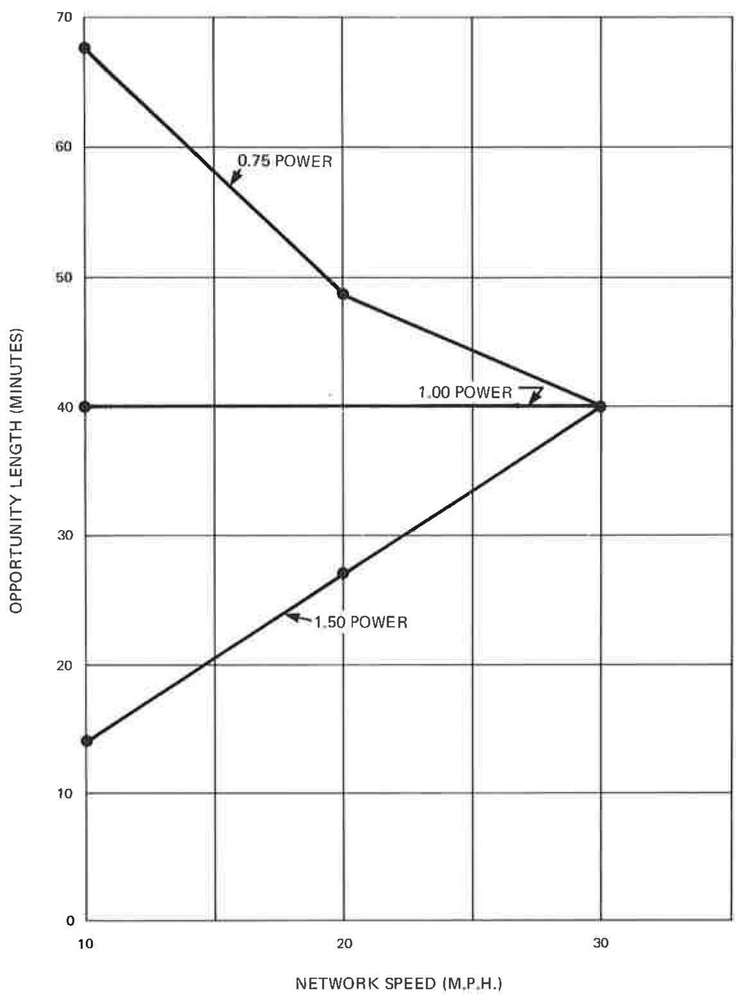

Figure 12. Relationship between network speed and opportunity length.

URBAN DEVELOPMENT AND TRANSPORTATION OBJECTIVES

Urban and transportation planners have allowed for lower density of development, both residential and commercial. Certainly there are strong indications that people prefer lower residential densities, but our residential areas could be developed to improve accessibility to jobs and other activities, particularly in the first 10 to 15 minutes of travel. Low-density commercial areas have allowed us to take advantage of new methods of manufacturing and handling of goods, but again these areas could have been structured and related to residential areas to improve accessibility.

What has become of transportation costs with the improvement of the transportation system? As shown in Figure 13, regardless of the assumption that we make on the value of the exponent, it is quite clear that the work-trip length in miles increases substantially with increases in network speed. For example, if we increase the average speed of a transportation network from 20 to 30 mph we could be increasing the work-trip length from 40 to 100 percent.

As has been demonstrated by the various needs studies performed by the Automotive Safety Foundation, Washington, D. C., the increases in transportation costs are related to the work-trip length and the amount of travel involved. Thus the average cost of

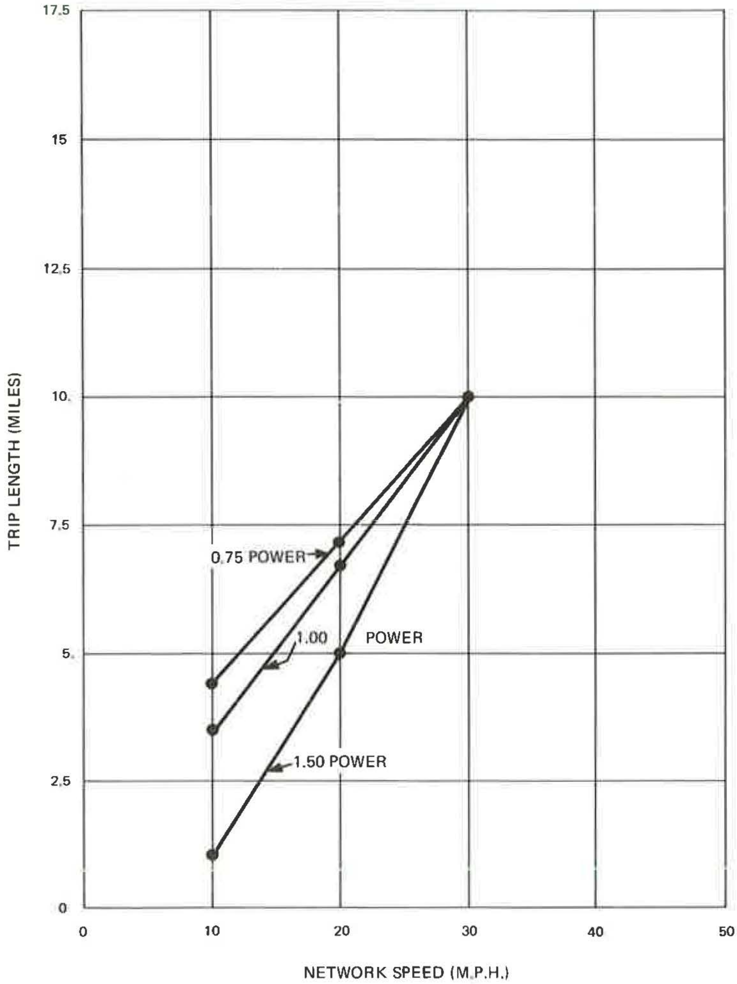

Figure 13. Relationship between network speed and trip length (miles).

providing transportation service has been going up with the improvements in transportation systems, resulting in lower residential density patterns.

SUMMARY

Urban travel as measured by the work-trip length (in miles and minutes) is highly related to city structure, which is reflected by the distribution of job opportunities within a metropolitan area.

Increases in the speed of transportation systems (a) cause the average work-trip length to increase, (b) increase the average length of job opportunities, and (c) allow for lower residential densities within the metropolitan area. Conversely, slower speeds result in lower work-trip lengths, reduced average lengths of job opportunities, and higher densities (urban living).

The selection of city structure and broader considerations relating to the environment and living preferences are the key decisions that must be made. Once city structure and environmental objectives are selected, care must be exercised by the planner to develop a transportation system that is directed towards that particular city structure and to assure that the broader environmental considerations are met.

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