Factors in Work Trip Lengths

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This paper analyzes the major factors affecting the length of urban work trips. Evaluation of travel data from a number of cities in the United States and Canada revealed that trip length is primarily related to the size and physical structure of the urban area, characteristics of the transportation network, and various social and economic factors. Some of these concepts were also investigated through the use of simulation studies.

This research has shown that, to improve work trip forecasting procedures and understand travel behavior, the income of the trip maker, the mode of travel, the peak-hour travel characteristics, and the opportunity distribution should be taken into consideration.

•IN recent years the art of planning future transportation systems has become heavily dependent upon the factual analysis of travel behavior. Large digital computers make it possible to consider the effects of detailed alternative land-use and transportation plans on travel demand. One of the most significant characteristics of the demand for travel is the length of the trip, for it is the total of all individual trip lengths which creates the total travel demand and the length of the trip itself which dictates the type of transportation facility. A sound estimate of trip length is essential to transportation planning and the calibration of mathematical models that are used to forecast travel demand.

The National Cooperative Highway Research Program, a joint undertaking of the American Association of State Highway Officials and the Bureau of Public Roads, which is administered through the Highway Research Board, is sponsoring a two-year study of factors and trends in trip lengths. The emphasis during the first phase of the study, upon which this report is based, is on work trip travel (5). The other types of urban travel are covered in the second part of the study.

The data used in the analyses presented in this paper were made available by cooperating transportation planning agencies in the United States and Canada. In addition, a number of the analyses are based on digital computer simulations of urban form and travel behavior. The research was oriented toward identifying the fundamental determinants of urban work trip length. This research found that the three most important factors are the size and physical structure of the urban area, transportation system characteristics, and social and economic patterns.

SIZE AND PHYSICAL STRUCTURE OF THE URBAN AREA

Characteristics of work trip length are closely associated with the size and physical structure of the urban area in which they are made. Figure 1 and Table 1 show the association of urban area population with average automobile work trip duration, length, and average network speed. The deviation of some cities from the general trend of correlation appears to be explained to some degree by their unique structural characteristics.

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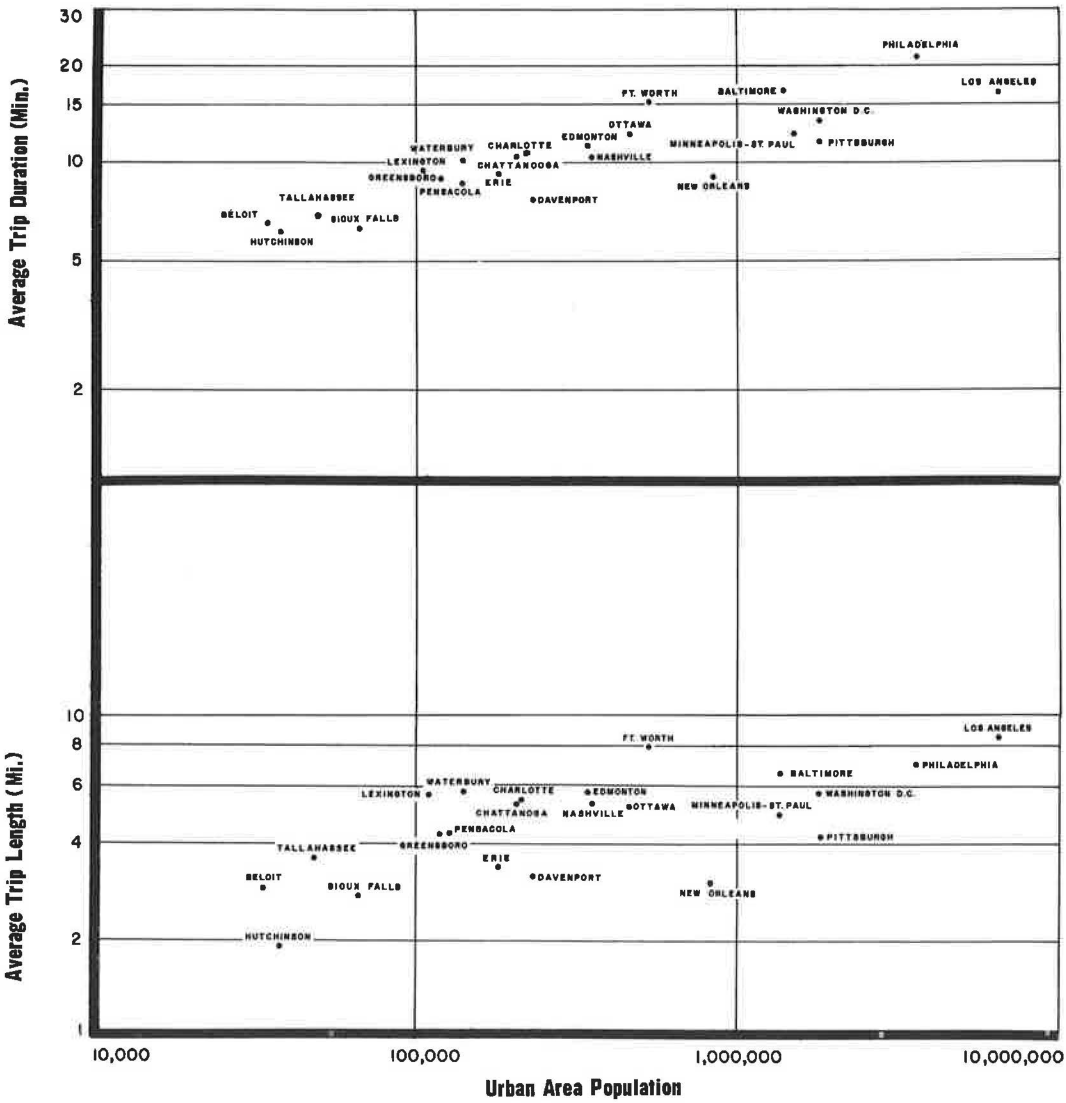

Auto Driver Average Trip Times & Distances exclude terminal time effects.

Figure 1. Average auto driver work trip length, duration, and population—twenty-three cities.

A regression analysis was performed to examine the effect of population upon average work trip duration in data obtained for 23 cities. The developed equation, which used a logarithmic transform, was as follows:

$$\log_e \bar{t} = -0.025 + 0.19 \log_e P$$

where

$\bar{t}$ = average trip duration (minutes); and
P = urban area population.

This can be written as

$$\bar{t} = 0.98P^{0.19}$$

TABLE 1

CHARACTERISTICS OF TRIP LENGTH, DURATION, AND POPULATION[a]

Location	Population[b] (thousands)	Work Trip Duration[c] (minutes)	Work Trip Length (miles)	Average Network Speed
1. Los Angeles	6,489	16.8	8.7	31.0
2. Philadelphia	3,635	20.1	7.2	21.5
3. Washington	1,808	14.3	5.9	24.7
4. Pittsburgh	1,804	12.6	4.2	20.0
5. Baltimore	1,419	16.7	7.0	24.6
6. Minneapolis-St. Paul	1,377	12.5	5.1	24.5
7. New Orleans	845	9.1	3.0	20.2
8. Fort Worth	503	15.7	8.1	30.9
9. Ottawa-Hull	406	12.6	5.3	25.2
10. Nashville	347	10.8	5.4	30.0
11. Edmonton	336	11.6	5.8	30.0
12. Davenport	227	7.7	3.2	24.9
13. Charlotte	210	11.0	5.5	30.0
14. Chattanooga	205	10.8	5.4	30.0
15. Erie	177	9.4	3.4	21.7
16. Waterbury	142	10.1	5.9	35.0
17. Pensacola	128	8.7	4.4	30.3
18. Greensboro	123	8.9	4.3	29.0
19. Lexington	112	9.1	5.7	37.6
20. Sioux Falls	67	7.0	2.9	24.8
21. Tallahassee	48	7.3	3.7	30.4
22. Hutchinson	38	6.1	2.0	19.2
23. Beloit	33	6.7	2.9	25.9

[a]These data were obtained from various sources and attempts were made to keep them as compatible as possible by removing terminal time effects.
[b]Auto driver trips.
[c]Auto driving time.

The standard error of the regression coefficient was 0.026, and the coefficient of determination, R^2, was 0.71.

New Orleans, one of the oldest and most compact of the cities listed, has an average trip duration or length typical of that normally found in newer cities only one-tenth its size. The duration or length in the spreadout city of Fort Worth is greater than that of New Orleans, while the latter is somewhat larger in terms of population. The physical structure of an urban area seems to have the same general impact on trip length that it has on trip duration.

Average urban population density did not contribute significantly to the explanation of variations in trip durations. A better measure of the density of urban development would probably have shown that increases in trip duration associated with higher populations would be offset if some of the population growth occurred at higher densities.

This expectation was verified in a computer simulation study of a set of hypothetical cities. Three hypothetical cities were constructed with work trip populations of 500,000, 1,000,000, and 2,000,000. Population and employment densities were assumed to decrease exponentially with increasing distance from the downtown. The gravity model was used to simulate travel patterns.

These studies showed that, under a constant population, average trip length decreased as the slope of the urban density curve became steeper. In addition, average trip duration in minutes and trip length in miles seemed to be associated with the fourth root of population, approximately verifying the results of the regression analysis. The results of applying this relationship to available time series trip durations for Baltimore and Washington are shown in Table 2.

Changes in population alone may not always affect the average trip length. From 1958 to 1964 the work trip duration in Broward County, Florida, increased by only 4 percent over its existing average trip duration of 10.5 minutes, even though the population increased by 40 percent (5). This can be explained by the fact that growth did not extend the urban area; instead, the growing population filled in previously unused land.

Opportunity Distribution

To measure and analyze urban structure effectively, an "opportunity distribution" was determined for certain urban areas. This measure is the frequency distribution of separations (travel times) between homes and jobs. This distribution was determined by assuming that travel time had no effect on the work trip distribution. (In actual practice, this was done by making travel time, F, factors equal to 1.0 in the gravity model trip distribution procedure.) An important aspect of this measure is its ability to measure opportunity separation in terms of time or distance. Thus, the distribution considers city structure and network speed.

Figure 2 shows the opportunity distribution for three urban areas. The first distribution is Erie, Pa., where the opportunity distribution is quite limited. Pittsburgh has a broader distribution but is still not as widely spread as the Seattle-Tacoma area. These patterns affect trip length, since Erie has an average trip duration of 9 minutes, Pittsburgh has one of 13 minutes, and Seattle-Tacoma one of about 20 minutes.

These patterns can also be observed within a city. Figure 3 shows the 1948 opportunity distribution for three zones in Washington, D.C. Zone 48 is near the CBD, zone 255 is several miles from the downtown area, and zone 298 is in the suburban area. This pattern is reflected in the average trip duration developed for each of these zones. Zone 48 had a trip duration of 8.0 minutes, zone 255 had one of 12.8 minutes, and zone 298 one of 17.4 minutes (terminal times were omitted for the selected zone average trip durations shown).

Figure 4 illustrates what happens to the opportunity distribution for a city over time; in this case, Washington, D.C., between 1948 and 1955. The mean and variance of the opportunity distribution increased. However, the average trip duration did not increase as fast as this change, since average trip duration is probably more related to nearby opportunities than to those which are farther away.

There were developed two indices to measure changes in average trip duration over time based on the effect of changes in the work opportunity distribution. The first index was quantified by applying travel time factors, with time raised to the second power,

TABLE 2

TRIP DURATION CHANGES IN BALTIMORE AND WASHINGTON

City	Year	Population	Average Trip Duration (minutes)	
			Actual	Predicted
Baltimore	1945	900,000	14.6	–
	1962	1,400,000	16.7	16.3
Washington	1948	1,100,000	12.6	–
	1955	1,600,000	14.3	13.9

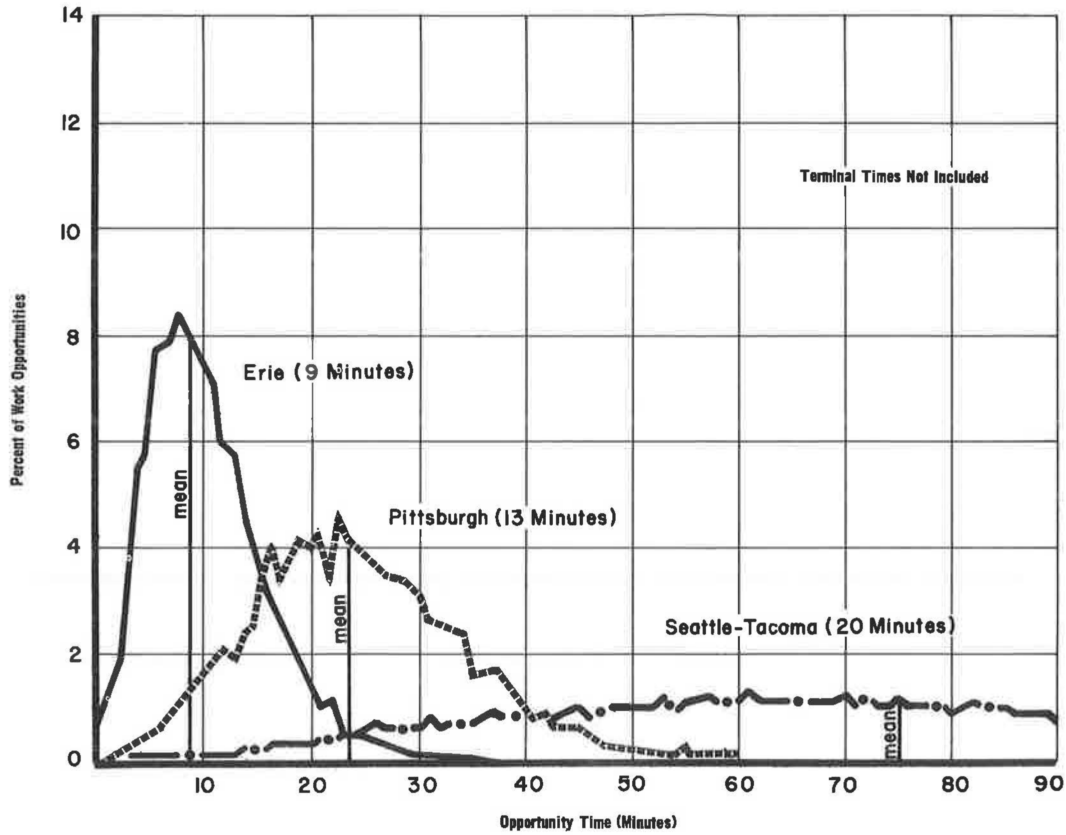

Figure 2. Opportunity distributions across cities, approximate average trip duration (minutes).

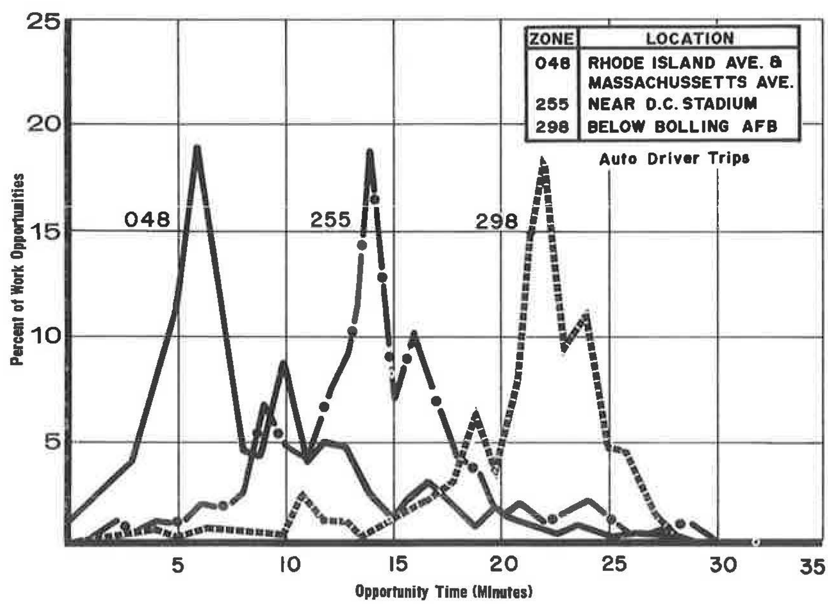

Figure 3. Opportunity distributions for selected zones in Washington, D.C., 1948.

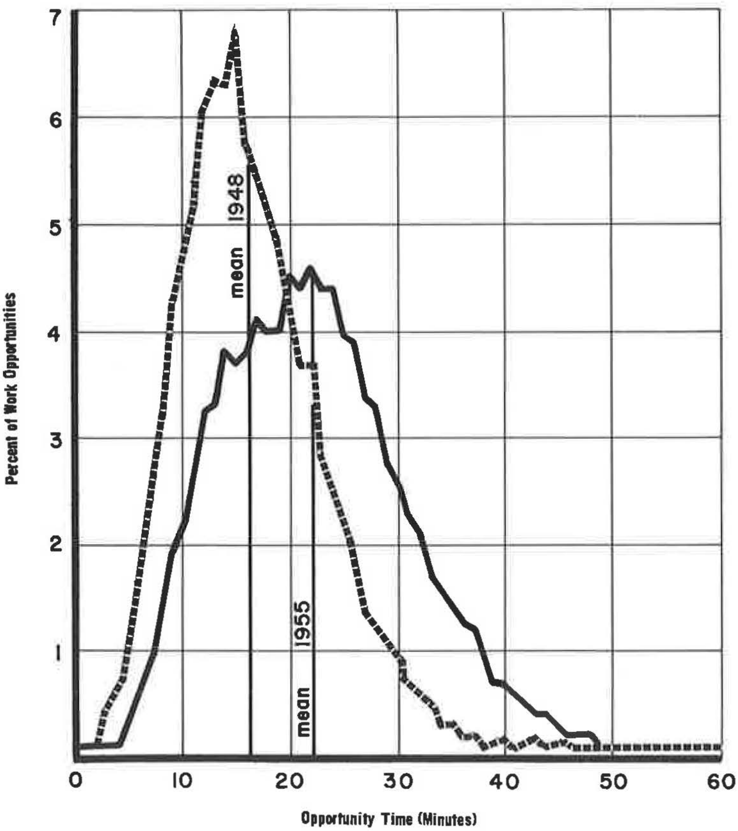

Figure 4. Opportunity distribution for Washington, D.C., 1948/1955.

to the opportunity distribution for the two time periods. The second index was calculated by raising the ratio of the means of the work opportunity trip distributions of the two time periods to the 6/10 power. These rules concerning the opportunity distribution were based on data observed from several cities and the results of the simulation study.

The basis for the first index is shown in Figure 5, which shows a plot of the trip length index (travel time factors of $1/t^2$ applied to the opportunity distribution) vs the average trip duration for five cities with populations of 800,000 or greater. Although the data are far from sufficient, the plot is approximately linear. It should be noted that the 15 percent increase resulting from a change in this index for Washington, D. C., between 1948 and 1955 closely approximates the 14 percent increase that actually occurred (a seven-minute terminal time was assumed).

The second index was obtained from results of the simulation study and work opportunity distributions for seven urban areas. The relationship between average opportunity time ($\bar{o}$) and average trip duration ($\bar{t}$) from the simulation study, using travel time exponents of one and two and actual relations for seven urban areas, is shown in Figure 6. In applying this observation to time series data from Washington between 1948 and 1955, it was found that it did not give quite as good results as did the gravity model using travel time factors equal to $1/t^2$, because any rule related to a change in the mean of the opportunity distribution will not be as accurate as one related to an entire change in the distribution.

The arrangement of opportunities around a given zone also had an effect on travel characteristics. Figure 7 shows the relationship of travel time to the ratio of actual over probable trip distribution for three selected zones in Washington, D. C. These

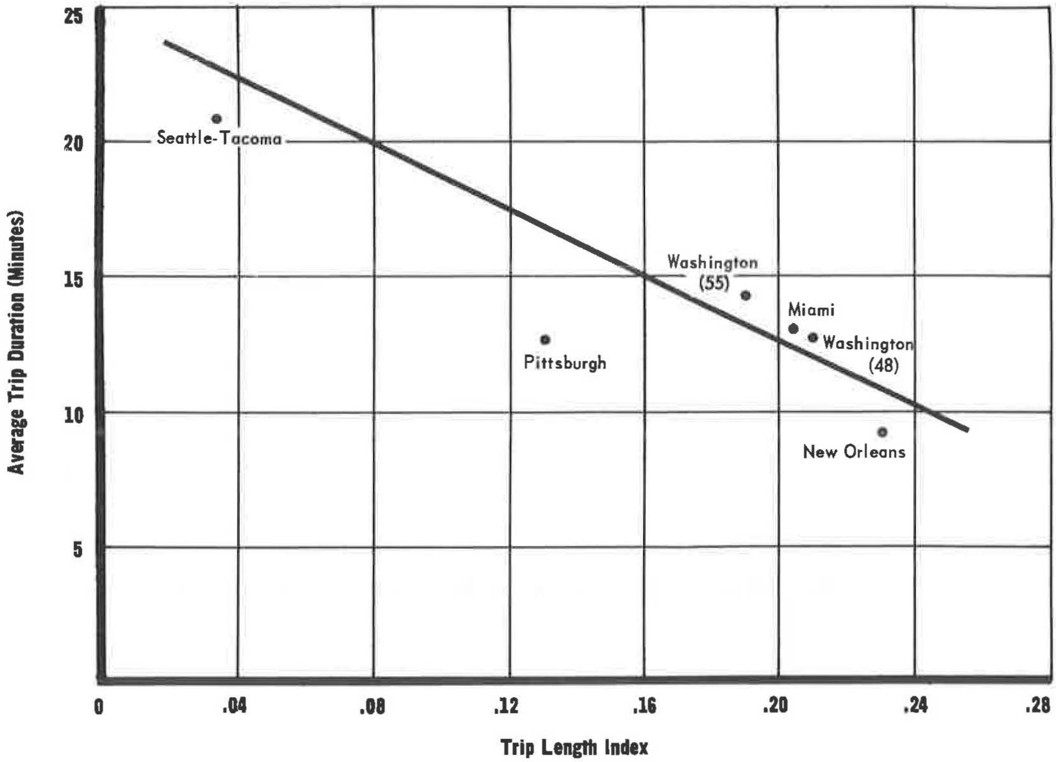

Figure 5. Trip length index vs average trip duration.

three zones give a representation of the mean and extreme ends of the opportunity trip distribution of 8 of 11 selected zones analyzed. Figure 8 shows that the shape parameter of the travel time factor distribution decreased as the mean of the opportunity distribution increased. This relationship implies a greater weighting of nearby activities as spatial opportunities arrange themselves at greater mean opportunity times from a particular zone. This observation seems to indicate that the L factor in the opportunity model or the F factor in the gravity model should be modified for variations in the opportunity distribution. Even though such an improvement may have a limited impact on trip length forecasts, it may improve existing trip distribution models. There might be developed a new model that takes into consideration the opportunity distribution and travel impedance. This hypothesis should be explored and tested for applicability on a system-wide basis using a more exhaustive statistical sample.

TRANSPORTATION SYSTEM CHARACTERISTICS

This research also indicated that the transportation system and its operation had a significant impact on the work trip length (see Fig. 1). Although Los Angeles had the longest trip length in terms of miles, the average travel time to work is only three-fourths that of Philadelphia, because the average speed on the highway network in Los Angeles is higher. The average travel time in Fort Worth is about the same as that in Baltimore, while the actual length of the trip in miles is considerably different. Again this is largely due to the difference in speeds of the highway systems in these areas. This was further demonstrated in a regression analysis based on data from 23 cities, which showed that the average network speed was correlated with trip length measured in miles. The following equation was developed:

In Boston, a need for similar adjustment factors has been observed. It is due in part to intracommunity attitude characteristics. Los Angeles, however, a "one-newspaper town," does not exhibit a tendency toward community separation. The persistence of such travel patterns in spite of improved transport services indicates the slow rate at which local traditions change. Although it is difficult to predict the occurrence and effects of such phenomena, the possibility of their existence should not be overlooked in the process of travel forecasting.

The effects of the spatial distribution of families in various income groups was found to be of considerable importance in determining home-job linkages. Workers from families of specified income levels do not select their work trip destinations from the field of all available job opportunities. Instead, they must be oriented towards jobs at their own income levels. This implies that a meaningful income stratification of trip opportunities might be helpful in reproduction of urban travel patterns, especially where there are strong patterns of economic segregation.

In Washington, D.C., failure to recognize these linkages resulted in an incorrect simulation of corridor volumes (2). There was a significant difference in the average work trip lengths for people in different income groups in the Northwest Corridor. An

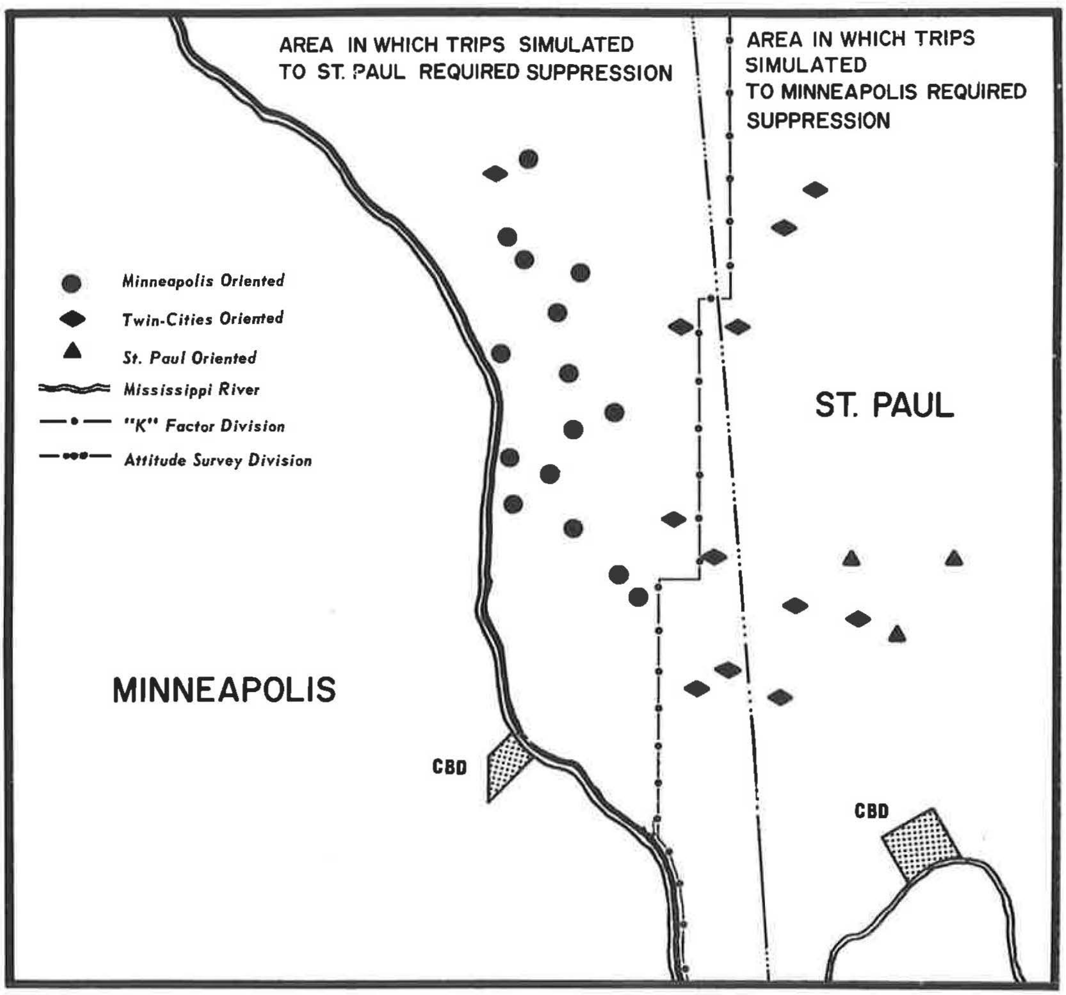

Figure 10. Twin Cities attitude orientation.

income-based stratification of the work trip matrix resulted in a better simulation of travel patterns and effectively estimated the average trip lengths for each income group, although the same travel time factors were used for each of the strata (Table 4).

PREDICTING TRIP LENGTH

In attempting to predict trip length in the future, every effort should be made to evaluate the three factors that have been discussed: size and physical structure, network speed, and socio-economic factors. Estimates should be made of the changes that will occur in these basic factors. Probably the best way to do this is to develop the opportunity distribution for today and estimate it for the future on the basis of population and employment distribution and assumed network speeds. Two of the variables, size and physical structure and network speeds, are thus considered together. If these changes look reasonable in light of historical trends and anticipated growth of the area, then the change in trip length is approximately proportional to the ratio of the future and present means of the opportunity distribution raised to the 6/10 power.

An examination of expected spatial changes in the socio-economic characteristics should also be made. While such changes are slow to occur, major shifts can bring about changes in trip lengths and should, therefore, be given adequate consideration in the forecasting process. The influence of these factors may be accounted for through the use of empirical correction factors or stratification of the work trip matrix.

The following guidelines can be used to approximate the changes that will occur in the mean of the work trip distribution as a function of these three basic factors.

1. Size and physical structure: (a) if an urban area grows by extending its present population and employment density patterns, the change in average work trip duration will probably be proportional to the fourth root of population change (Case 1, Fig. 11); (b) if an urban area grows largely by the filling in of unused land areas, while maintaining its same basic shape, there will probably be no material change in trip lengths (Case 2, Fig. 11); and (c) if an urban area develops by concentrating additional population and employment in the downtown area and/or in other sections of the metropolitan area; the average work trip will probably decline (Case 3, Fig. 11)—simulation studies have shown that this decrease might be as much as 10 percent.
2. Network speed: (a) change in the average trip length (miles) for uniform density cities will probably be directly proportional to the square root of changes in network speed; and (b) change in the average trip length (minutes) will probably be inversely proportional to the square root of changes in network speed—experience, however, has shown that peak hour speeds have not greatly changed in larger metropolitan areas.
3. Socio-economic: (a) wider distribution of income in an urban area could change trip length as much as 10 percent; and (b) elimination of historical and social influences could change length by 5 percent.

TABLE 4

AVERAGE WORK TRIP TIMES
WASHINGTON, D.C., 1955
(Northwest Corridor)

Median Family Income ($)	Average Work Trip Length (minutes)	
	O-D Survey	Stratified Model
0-4,999	15.2	16.4
5,000-6,999	24.6	25.1
7,000-9,999	20.0	19.4
10,000	21.3	21.2

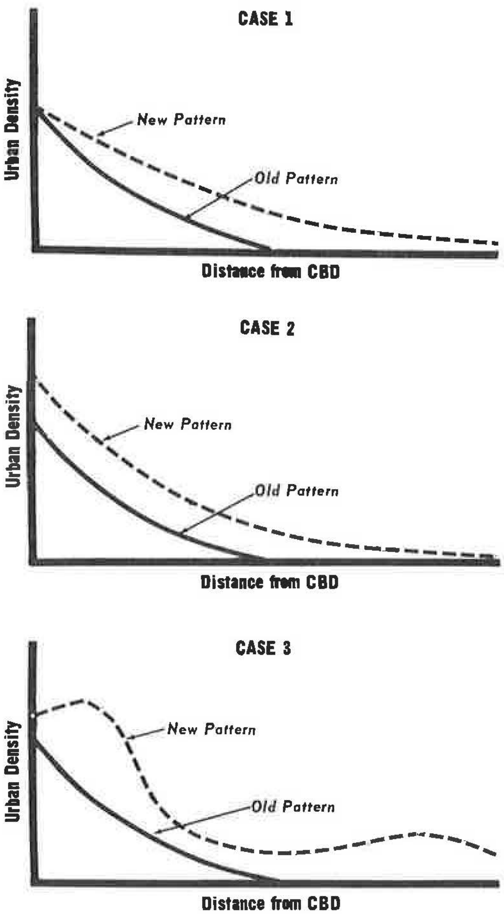

Figure 11. Urban density vs distance from CBD.

In applying these guidelines to any particular urban area, care must be exercised in insuring that proper values for the variables are used and that the distinctive characteristics of the city are considered.

PREDICTING THE WORK TRIP LENGTH DISTRIBUTION

The previous analyses were concerned primarily with the average trip duration and length. A more complete picture of trip length is obtained when the dispersion around the mean (the standard deviation) is considered. An investigation was undertaken to identify a mathematical function which considers both the mean and standard deviation in synthesizing the actual work trip length distribution. Figure 12 shows the form of the work trip distribution observed in most urban areas. The gamma distribution was found to fit such data very well. The parameters of this distribution are the values of the mean, $\bar{t}$, and the standard deviation, σ_t, of the work trip distribution

$$f(t) = K\left(t^{(\bar{t}^2 - \sigma_t^2)/\sigma_t^2}\right)\left(e^{-(\bar{t}/\sigma_t^2)t}\right)$$

where

$f(t)$ = the relative frequency of trips of duration, t;
K = a constant;
e = the base of natural logarithms;
$\bar{t}$ = average trip duration; and
σ_t = standard deviation.

To use the gamma distribution as a tool in estimating future trip distribution, it is necessary to establish the mean and variance (σ_t^2) of the work trip length distribution. It has been shown that the mean of the future work trip length distribution can be estimated by using one of the established guidelines. The change in variance can be approximated by using the relationship between the mean and the variance developed in Figure 13. Thus, with estimates of the mean and the variance it is possible to construct the work trip distribution approximately, using the gamma distribution as a tool in the forecasting procedure.

IMPLICATIONS FOR FORECASTING

The results of this research indicate that additional refinements in forecasting procedures and data collection may be desirable in order to predict accurately the complex movements of people in urban areas.

Stratification of the work trip by various categories of trips should help advance the understanding of travel behavior and the growth and decay of cities, as well as improve land-use models. In large cities, an income stratification would appear almost essential.

Separation of trips by mode of travel, as well as by time of day, may be warranted in large metropolitan areas. This means that peak-hour networks for both the highway

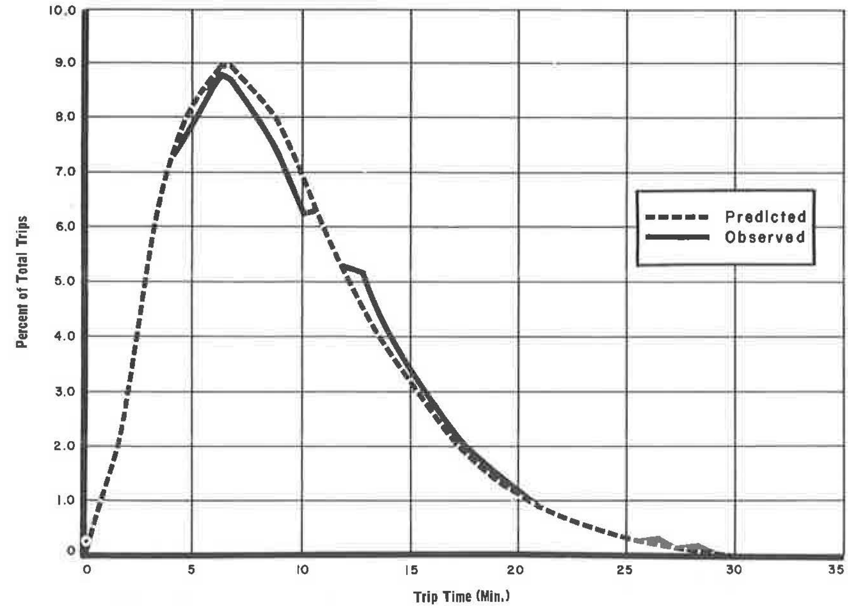

Figure 12. Auto-driver work trip distribution, Erie, Pa.

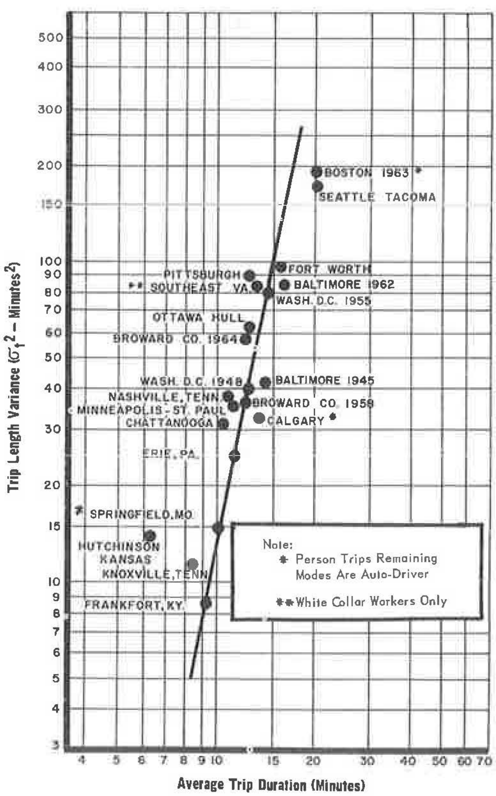

Figure 13. Work trip length variance vs average trip duration.

and transit systems could be used to predict work trip travel patterns.

To maintain a realistic relationship between peak-hour speeds and volume forecasts, consideration of capacity constraints and incremental traffic assignments by time-of-day may be needed. Attempts should also be made to use travel costs rather than travel time to measure the effect of zonal separation in the trip distribution procedure.

Extreme changes in the future spatial arrangement of opportunities around zones within the system might be analyzed with respect to their impact on developed trip distribution procedures. This analysis is especially important where the affected zones constitute a large proportion of total trip generation.

These conclusions also imply that there may be need for a higher level of sophistication in future data collection. More information on the socioeconomic characteristics of travelers, especially their incomes, will be useful and could be gathered in conjunction with the origin-destination surveys. In addition, transportation system inventories should include data on peak-hour characteristics of the highway and transit networks.

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Discussion

LOUIS E. KEEFER, Transportation Planning Consultant. —There will always remain some curious questions concerning the distance from work that people will live. Putting it this way deliberately suggests that we are not simply talking about the length of urban work trips, as if they have some life of their own, but about people and where they choose to live with respect to where they work.

This introduces socioeconomic ramifications which are only indirectly measured in terms of distance or travel time frequencies. For this reason, perhaps, the work trip is among the most popular "traffic" phenomena to attract the attention of nontraffic technicians. Many studies have been made. Still, I suggest that the following questions remain unanswered.

When only the head of the household was the breadwinner, it was easy enough to talk about average work trip lengths. Now that at least half of the nation's wage-earning families cash at least two paychecks, can we meaningfully talk about averages, without distinguishing primary from secondary wage earners?

In deciding where the family will live, to the extent that the decision is affected by place of employment, one would presume that the primary wage earner would most heavily weight the decision. Would this leave the secondary wage earners to find employment wherever convenient? This line of thought would suggest that, other things being equal, the overall average work trip length would have decreased over the last two decades.

Of course, it should be established, first, whether or not the home location is at all affected by the distance to work. Perhaps it is not. If not, then in a sense the average journey length becomes a random variable, and attempts to describe it by mechanical measures must fail. All we would know are the probabilities, under given circumstances, of people finding suitable homes at given distances from work. Presumably these would vary among metropolitan areas according to personal taste, history of housing development, topography, and many other variables not readily subject to measurement.

The increasing segregation of races is creating a trend toward longer work trips. A very excellent discussion of this in Lapin's "Structuring the Journey to Work" suggests that whites working in the central city are forced to live farther and farther out in the suburbs, while nonwhites must reverse-commute to the suburbs and mixed fringe areas in order to find the lower-skilled jobs not usually available in sufficient quantity to them in the central city. Since an end to segregation is not yet in sight, how can this be accounted for by transportation planners?

What about increasing car ownership? In a National Cooperative Highway Research Program project we are conducting, work trips to over 50 major plants in a dozen different cities have been considered through transportation study O-D data. These data show that car owners make considerably longer trips than noncar owners. When the latter get a car, will they not be tempted to move farther from the plant areas in which they work? If existing car owners' residences remain the same, then the average trip length to any given plant would tend, we assume, to increase.

What is the effect of increasing worker skills? We know that professional and technical people now tend to make the longest work trips; if a greater proportion of the work force assumes higher occupational categories, will not the average journey length increase? This is perhaps the same as asking about the effect of the continuing rise in real family income. The net result may be a move from city to suburbs, and hence a longer trip length.

Contrast this experience with the "returnees"—the families who tire of suburban living and return to the city. Realtors consider this an important market for city housing, and the trend is encouraged by provision of more expensive housing in or near CBD's. How much would this inwards movement, and its probable shortening of work trips, offset the longer trips of the less affluent moving outwards?

The effect of improved travel facilities has been much bruited about. Some maintain that as long as speeds increase, the same worker can live farther away and still take no longer in time to get to place of employment. And—that since he can, he will. Assuming this, doubt has been cast on the planning effectiveness of transportation studies which did not postulate that the total vehicle-miles of travel would increase far more quickly than the total trips in an urban area. Do the critics know or are they guessing?

Looking at just one aspect of the problem, one might argue that new travel facilities would actually shorten many trips. For example, in lieu of round-about arterial connections, a more direct trip by freeway, even allowing for distance diverted to use it, might be no longer overall. Moreover, a freeway may more easily cross major travel barriers, such as mountains and river valleys, than would an older arterial highway. This may be stretching a point, but it seems too easy to assume that freeways will always increase average journey lengths to work.

As the density of development increases in the growing suburban areas, longer trips become less necessary. Does not the changing proportion of suburban versus central city employment reduce the relative frequency of the long commute? Everyone can recognize that circumferential work trips to suburban plants and offices need not be long. If people can live and work in the suburbs, in effect, why should we immediately assume that they should want to work farther from home even if there are new freeways to carry them?

Then there is the puzzling evidence (a) that total trip production rates per family are increasing, while (b) the average annual mileage per car owned has remained constant. This certainly suggests that the auto trips (for all purposes) are actually getting shorter.

We know that the number of transit trips is decreasing; we suspect that car loading factors are decreasing (in effect, auto passenger trips are decreasing relatively). If this is correct, then the number of auto trips must be increasing. And, if we do not question the annual mileage estimates of the Bureau of Public Roads, it seems to follow that auto trips must be getting shorter.

Assuming that work trips are holding constant, or getting longer, then the various kinds of other trips must be getting shorter. This is not difficult to believe: the general aversion to walking is pronounced. Driving trips are now readily substituted for many walking trips of only one or two blocks. Somehow it seems we have the knowledge to untangle all this.

What is the psychology of the work trip? Some say that it is a necessary time-space transition from place of employment—a chance to change gears. How long should this take? Perhaps no less than 15 minutes; no longer than 30 minutes? What are the long range mental health effects of long commutes?

If these questions could be resolved, perhaps we would learn that we may always be talking in terms of some fixed time range. If so, and if travel times really do not change much (because of the sooner-than-expected congestion on the new freeways), then we may be wasting time worrying about changes in trip lengths. Within practical limits they may not change enough to affect transportation planning one way or another.

Finally, we might double check some of our methods of measurement and what they mean. Most of our work deals with airline trip distance. Should not we really be talk-about over-the-road distance? And is it not true that this is not collected in most surveys, and never accurately established? Clearly, any comparison of trip lengths should seem to account for differences in the airline to over-the-road factor from city to city. But how important are such mechanics?

ANTHONY R. TOMAZINIS, Institute for Urban Studies, Philadelphia. —Although I am going to repeat statements already made previously, I feel that the importance of more accurate knowledge on trip length variations in metropolitan regions is such that it requires stressing in every possible occasion until the people involved take it seriously into account. Trip lengths are certainly the result of the influences of a number of forces and factors. Trends might also be distinguishable if significant variations do persist over the years. In terms of ramifications, we should be prepared to take into account all the significant and verifiable associations between trip length on one hand and land-use pattern and/or transportation system characteristics on the other. It is, indeed, encouraging that this significance of trip length variations began to be increasingly recognized and our scientific knowledge and concern began to include more than merely the measurement of the average size of trip length and the simple simulation and projection of it, within a framework of complete uncertainty.

The present attempt to relate auto driver work trip length with measures of population size, average highway network speed and socioeconomic factors is in concept meaningful and reasonable. Since this is the first real attempt in relating these variables, one might normally expect an initial definition and expression of the pertinent variables and a utilization of the generally known statistical tools to be part of the undertaking. The rather good results of the correlations with population size and average system speed indicate the meaningfulness of the selected variables and of the statistical tools in use. However, strong evidence of needed additional work is obvious in improving the grossness of the present results, in reducing the number of irrelevant statements and in the predictive part of the present work where rapidly drawn suggestions prevail and where simple models are put to use. The simplistic tool of the fourth route of population is, for instance, too easily misleading in spite of any incidental coincidence of limited results. The application of the gamma distribution is indeed an ingenious application of more advanced statistical theory in the field of urban traffic. However, the results as they stand right now are more speculative than concrete. The gamma density function depends extensively on the values of (a) and (b) parameters and for certain extreme occasions the function takes the form of a completely inappropriate frequency distribution function. This discussant had the benefit of reading also the report of the research project (5) and therefore could see that the researchers were fully cognizant of the nature and the difficulties of the gamma distribution. However, the results at present leave much to be desired with regard to the standard deviation and the mean of the trip length. An additional observation should perhaps be made in reference to the manner in which the socioeconomic factor and the "opportunities" variable were treated. Admittedly these variables are some of the most elusive and difficult to be incorporated in any quantitative analysis. However, the indirect treatment of the socioeconomic variable with the help of a discussion on the K-factors of the gravity model and the brief exploration of the opportunities variable is reasonable and perhaps indicative of tendencies, but completely insufficient for the needs of the occasion.

With regard to future research which appears more appropriate in following up the work reported in this paper, it appears to me that emphasis should be placed in three aspects of the problem. First is the matter of variables to be related. Additional work is required in defining the variables in a more meaningful manner and in measuring them according to more than one method. It appears, for instance, strange that density of development and size of developed area are not part of the predictive equation. Alternative configuration and testing of such variables might easily prove that these variables are indeed closely related (perhaps in a causative manner) with the average trip length in a region. Average regional income and the degree of dispersion of population and jobs should also be considered as variables to be taken into account in the basic correlation.

Second is the matter of statistical tools to be used or developed. It seems to me that this project has demonstrated once more that we are approaching the moment when statistical tools explaining directly transportation and traffic phenomena will be developed. The gamma distribution has primarily been proven useful in analyzing problems of weekly sales, in connection with certain inventory models and with the Poisson probability law. It might or might not prove to be of any relevance to traffic and transportation problems. The same concern might be expressed with regard to the other available probability laws such as the normal curve, the exponential distribution, the rectangular distribution, the beta distribution, the geometric probability law or the Bernouli, binomial or negative binomial frequency distribution which from time to time are proposed. What I am trying to say is that it is time to finance and organize an effort which will develop the probability laws which are directly expressive of traffic and transportation phenomena. Data are plentiful by now and previous research in this field plus previous developments in the statistical theory have already prepared the ground work for the job.

The third item which seems to be relevant to such second and third generation research on traffic and transportation problems is the need of adherence to a vigorous and well thought out research design and reporting in order that aimless motion and incompleteness of tests will be brought to the minimum and that reporting will be accurate, well documented, and limited to what has been researched.

Concluding my remarks, it seems appropriate to stress that we should continue research on methods of trip length projection and that we should be prepared to accept as a rule that future travel demand projections should soon include checks which will be based on independent projections of the average trip length and of its standard deviation for the major types of trips in the region. The present paper makes a significant contribution indeed toward this objective and opens several avenues for the needed additional research work.

GARY R. COWAN and JOHN K. MLADINOV, Puget Sound Regional Transportation Study. —The paper examines lengths of work trips in (and within) different urban areas and attempts to draw some conclusions as to how work trip lengths are related to some characteristics of the urban area.

There are a number of different ways to approach the problem of discussing a paper such as this. One way is to examine and dissect the paper in fine detail, probing to determine the adequacy of the specific techniques and data sources used in the research process and in testing and developing the conclusions set forth in the paper. At another level one may evaluate the paper and its conclusions in such abstract terms as consistency, applicability, relevance, and importance. Is the paper trivial or does it represent a substantive contribution? Does it have some universal or general application or is it really irrelevant to the urban transportation planning field? At yet a higher level of evaluation one may appraise a paper in terms of further and wider implications which may be drawn from its conclusions. All three levels of evaulation are important and have a valid role to play in the appraisal of any scientific work. Any one level is probably no more important than any other.

In a short discussion, it is obvious that it is not possible to do full justice to this paper at all of these levels. This is of some regret since, in a sense, this paper may well be one of the most important papers to be presented at HRB meetings in recent times. This stems not so much from what it says but more from the standpoint of what its longer range implications are.

At the second general level of appraisal, the most important single conclusion cited by the paper is that the average trip length and also the frequency distribution of trips around this average, are not constant between urban areas, given variations in their physical, spatial, and socioeconomic structures. Subsidiary conclusions are that this variation in average trip length is related in regular and quantifiable ways with such factors as the population of the urban area and the transportation network speeds.

At the first level of criticism, and given no more data for appraisal and evaluation than has been directly presented in the paper, it cannot be said that all of the subsidiary conclusions have been substantiated. For example, does the paper in any acceptable scientific sense establish that the average trip length in an urban area is related, either directly or indirectly, to the fourth root of the urban population? The substantiating data and analysis are not present for critical examination. However, our own experience and explorations into this topic do support the main conclusion that, given changes in the urban structure, the trip length frequency distribution will alter. The extent to which the trips will alter, however, is a matter which has not, in our estimation, yet been established.

The differences in average trip length are ascribed to differences in the urban areas, with the regression analysis showing that trip duration is approximately related to the fifth root of the population. It is indicated, however, that the so-called simulation study was the basis for the conclusion that the average trip length in an urban area is related to the fourth root of the population. Our own work has been cast and formulated in such a manner that it has been concluded that differences in average trip length are brought about as a mechanical property of the gravity model, itself, given differences in urban structure. To put the matter differently, the research in this paper has led to the conclusion that variations in the urban structure cause variations in the trip length and trip length frequency distribution, and that these variations are both real and directly associated with the variations in the urban structure. On the other hand, results from the direction our efforts have taken seem to support the hypothesis that variations in the trip length frequency distributions which develop through application of the gravity model, while associated in some manner with differences in the urban structure, are not solely due to these differences per se, but rather can be explained by the mechanical properties of the gravity model itself when applied under varying conditions. Thus, a spurious result is obtained, with the effect of the model properties not being separable from the effect of the change in the urban structure. Our two different approaches have led to different conclusions since we have, in each case, limited our investigations to a particular aspect of a many sided and complex problem. The truth of the matter will probably turn out to be that, in the real world, some of both approaches are operative. That is, to some degree we are both right.

In the larger view, it is really irrelevant as to which of us is correct, or more nearly correct. This is because one fundamental fact stands out in the light of reality. This is that we cannot escape from the unalterable conclusion that a gravity model calibrated to today's conditions cannot be used for tomorrow's conditions, unless tomorrow's conditions are identical with today's. This latter condition is, of course, most unlikely.

This leads us to the third level of criticism, that is, the wider implications to be drawn from the conclusions in the paper. This paper constitutes nothing less than a wholesale assault upon current practice in the application of the gravity model, with all of the widespread ramifications that this implies. It has long been a fundamental tenet in the application of the gravity model that a properly calibrated model will be valid for the future. For instance, it is pointed out in the Bureau of Public Roads' manual on the gravity model that Voorhees' earlier work in Baltimore and the Bureau's more recent work in Washington, D.C., indicate some basis for making this assumption. This paper now asserts that this tenet is flatly wrong. The Puget Sound Regional Transportation Study modified this tenet in the application of the gravity model for the very reason expressed in this paper; that is, that a gravity model calibrated to today's conditions cannot be applied directly to tomorrow's conditions. To our knowledge, the

Puget Sound Study is the only group to introduce such a modification. It is obvious that this assertion bears momentous implications. With more than 200 urban areas in this country involved in transportation studies, a significant number must be using the gravity model. If they are abiding by the fundamental tenet, the results of applying the gravity model to future conditions must be considered erroneous.

Under its own impetus the practice of transportation studies is rapidly expanding and becoming more involved and complex. At the same time, in line with the "Great Society," the federal government is adding its impetus. We are no longer simply planning transportation systems, we are designing urban areas (or at least we think we are). The federal government is becoming wholeheartedly behind us, and indeed, is egging us on. Just reading the program for this year's HRB meeting and noting the number of sessions which bear upon this topic emphasize the growing interest and concern in urban design. While we in the transportation planning field are at the forefront in the urban design field, it is at a time when it is demonstrable that we cannot deliver a key element in the design process.

It is to the credit of the authors of this paper that they have attempted to solve the problem of the missing key element by showing how one might predict the manner in which the future trip length frequency distribution will differ from the present. Of course, if there is any truth at all to our contention that the formal properties of the model are such that when applied to a changed future structure of an urban area will develop spurious changes in the trip length distribution over and beyond that resulting from the change in the urban structure, it is obvious that the procedure suggested by the authors cannot provide the whole answer. This attempt by the authors is, again in our view and based only on the data presented in this paper, not successful, at least in the sense of being scientifically credible. Incidentally, our own solution to the problem, must be treated in the same way. We did something plausible, but our actions had no objective scientific basis.

The tenor of these remarks should make it clear that we believe, even at this late date, that we really do not know anywhere near enough about trip distribution models, except in the somewhat negative sense of being able to demonstrate that all available ones introduce as many questions as they seem to answer. In view of what we have been purporting to undertake, nothing less than the design of urban regions, this fundamental weakness of this most critical tool to transportation planners constitutes a crisis of awesome proportions. We need more and better research into a fundamental tool in our stock in trade and we need it immediately. To be useful such research must be more thoroughly documented than the paper at hand. Nor can such research be subject to the extraneous effects introduced by the mechanical properties of a model if the research is to be meaningful. Our needs are critical.

It is gratifying that this group of authors has developed a serious question as to the validity of the present day gravity model application. We in the Puget Sound Regional Transportation Study wish to join them in this. However, we are not satisfied that the research described in the paper under discussion has brought an answer nearer to hand.

To those engaged in the transportation planning field the earlier remark about the importance of this paper should now be obvious.

ALAN M. VOORHEES, SALVATORE J. BELLOMO, JOSEPH L. SCHOFER, and DONALD E. CLEVELAND, Closure—Keefer raises a relevant point with regard to the fact that the measurements of trip length need to be standardized. We know from transportation studies which we have conducted that different transportation zone configurations and varying procedures for estimation of intrazonal and terminal times greatly affect the measurement of work trip length distribution.

In response to Keefer's comments that we are talking in terms of "fixed time ranges" for average work trip lengths, we find no indication of this in the research we have conducted. In fact, we have found that the average work trip length can change upward, downward, or may change very little because some of the influencing factors may offset each other. We agree with Douglas Carroll that the trip length of the future depends upon many factors which are quite complex. However, our research has developed some guidelines which can be used to make estimates of how the trip length is likely to change in the future. Therefore we feel that it is no longer necessary to assume that trip length will remain static.

In reply to Dr. Tomazinis' comment that average urban density of development for the metropolitan area was not considered, it should be pointed out that we did consider average urban density. This variable, however, was eliminated because it did not add significantly to the multiple regression equations used to predict average work trip length. Overall urban density differences between the areas investigated did not account for observed changes in their respective work trip lengths. Density of development by location within the metropolitan area does influence the average work trip length. This was pointed out in Figure 3, which showed work trip opportunity distributions for selected zones in Washington, D. C. These three zones had different opportunity trip length distributions and, hence, had different density patterns surrounding them. It was also stated that the mean opportunity trip length and average work trip length were interrelated.

With regard to Dr. Tomazinis' comment that average regional income for the entire metropolitan area was not considered it should be noted that average regional income was not felt to be as meaningful a measure of work trip lengths as income by location within the metropolitan area. Table 2 points out the 1955 average work trip times for Washington, D. C., in the Northwest Corridor. Median family incomes of these workers were found to be directly related to average work trip lengths measured in minutes. Higher income areas were found to have longer average work trip lengths.

Dr. Tomazinis also mentions that the dispersion of employment was not considered in this analysis. We did consider it by the incorporation of the opportunity trip length distribution. This measure was quantified by calculating the mean of the trip length distribution generated by using employment as the attraction index and friction factors equal to one, along with standard gravity model trip distribution procedures. The variable was found to be significant and was included in the developed guidelines for predicting the mean work trip length.

Mladinov and Cowan expressed concern over substantiation of this research document. This paper has been documented by presentation of relevant tables, figures, and source materials. Inferences made from data available and based on professional opinion have been clearly stated and separated from the conclusions based on regression analyses, etc. Additional documentation of the simulation study methodology referred to by Mladinov and Cowan can be found in "Factors Influencing Work Trip Length," a document to be published by the Highway Research Board.

Mladinov and Cowan raise some very meaningful and serious questions about the gravity model itself. We feel that there are serious deficiencies both in the gravity model and opportunity model, which have been utilized thus far in many of our transportation studies. Based on changes in the opportunity distribution, both F travel time factors and L factors can change. This finding was recognized in an earlier work by Tomazinis and Wickstrom in the development of a comprehensive transportation flow model for the Penn-Jersey Transportation Study. Trip distribution models should consider not only traveler cost impedances and opportunity distributions but also land activity forecasts. The transportation planning process works by a series of interconnecting feedbacks. Much of the work done on transportation studies we are presently conducting points to this intricate feedback in trip generation, mode split trip distribution, and assignment.

In response to Mladinov and Cowan's comments concerning simulation studies and their validity in this analysis, it should be noted that it is difficult to put a city in a test tube and observe changes in it over time. It is very difficult to reach precise conclusions because of the complexities of the many cities analyzed. Inferences were made from available data and the results of this simulation study to produce the guidelines outlined in this paper.

If a metropolitan area changes dramatically in terms of network speeds and structure, careful checks should be made on the forecasted work trip lengths using the guidelines presented in this paper. We have found that extreme care must be exercised in the development of future network speeds in the gravity model so that proper travel time factors can be applied for any given zone-to-zone movement.

The real issue raised by all discussants seems to be one of sensitivity of the trip distribution model, which determines future trip length, to errors incurred in projection of its basic parameters. How sensitive is the trip transfer matrix to changes or errors in using travel time factors for tomorrow's conditions? This sensitivity is important to know and understand because it affects major decisions about transportation planning. The continuing programs of the transportation studies will monitor and check over time the reasonableness of the model parameters and assignment procedures so that planning capital works programs can be accelerated or decelerated based on their periodic evaluations.