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Foreword

The ten papers, five discussions, and two authors' closures, presented in this Record represent contributions to the alleviation of urban transportation problems. Primarily concerned with different applications and uses of origin-destination data, the authors have treated such diverse subjects as trip generation evaluation, traffic assignments, trip distribution procedures, land-use models, transit and highway interactions, relationship of traffic and floor space, and transit riders.

These papers should be of interest to personnel engaged in both the administration and day-to-day working procedures of urban transportation studies, transit officials, engineers and planners concerned with urban problems, and highway engineers involved in urban planning.

Black's paper evaluated some possible answers to the perennial question—"What is the best type of land use measurement from which to measure trips?" Although some insight and progress was made, additional questions needing investigation also were found.

Graham applied large network traffic assignments to smaller area route locations and found that accurate route assignments could be made with considerable savings in computer time. As a result of the study, some future urban assignment work in California will be based on this research.

Heanue and Pyers made an evaluation of trip distribution procedures in use by applying them to Washington, D. C., urban travel data taken seven years apart. The relative accuracies of the commonly used methods were compared. A result of the research was a recommendation concerning changes in calibration procedures. Prepared written discussions by Cleveland, Brokke, Vogt, and Howe testify to the importance of the paper and bring other significant thought to bear upon the problem.

Hill, Brand, and Hansen's paper describes a statistical land-use prediction model as employed in the Boston area and suggests its practicality. Accuracy levels obtained were comparable with other forecasting models presently in use.

Pyers has also evaluated the intervening opportunity trip distribution forecasting model using the 1948 and 1955 Washington, D. C., travel pattern data. The research provided insight as to how to obtain more reliable forecasts of future travel patterns using the model. Howe also has discussed this paper.

Quinby's paper deals with the planning and design of interchange stations between transit and auto users in the San Francisco area. The study describes the investigations conducted and the planning criteria developed for proper planning of the transit station areas.

Using the Chicago trip distribution and assignment model, Soltman has investigated the use of alternate loading sequences. It was determined that these had little effect on area-wide travel estimates but could have large effects on smaller units such as distance, links and specific movements which could influence design and economic analysis.

Walker has examined the effect that automobile ownership, family size, and occupational grouping of households has on travel production. Data from two different transportation studies confirmed previous relationships. Two measures of social status of the household were developed and their influence on travel production calculated.

The paper by Wright has extended previous knowledge of trip generation in business district areas to cities with a wide population range and other trip purposes. Models of some significance were developed for total traffic, work trips, shopping trips, and business trips. Social and recreational trips to CBD's were not found to be relevant to floor space use.

Zell's paper measured before and after effects of an exclusive bus lane on the San Francisco-Oakland Bay Bridge. It was found that the exclusive bus lane did not cause a major increase in bus patronage or reduce auto traffic. Changes in residence or employment caused large shifts in bus patronages and few users switched to buses from cars.

Contents

Comparison of Three Parameters of Nonresidential Trip Generation

ALAN BLACK, Research Associate, Tri-State Transportation Committee, New York

This paper attempts to answer the question, "What is the best type of land-use measurement from which to estimate trips?" This question is important not only for trip estimation, but also because it dictates what type of land-use surveys a transportation study must conduct, and these surveys are very expensive.

The estimating capabilities of the three most common measures of land use—land area, floor area, and employment—are compared. Using data collected by the Chicago Area Transportation Study, trip rates based on these three measures are examined for five nonresidential land-use categories using correlation and regression analysis. The resulting coefficients and equations are given.

The findings indicate that no one of these measures is best for all land-use categories. Floor area seems best for commercial, employment for manufacturing, and land area for public buildings, public open space, and transportation. Contrary to expectation, floor area does not seem consistently better than land area. Furthermore, floor area trip rates are not uniform throughout a metropolitan area, but increase as the density decreases.

The results suggest that further research on trip generation is needed; understanding of the subject is still quite fragmetary. Five specific approaches for deeper investigation are recommended. In addition, more comprehensive surveys of the three parameters are still required for research purposes.

ONE OF the major theoretical bases of modern transportation planning is the concept that the distribution of trip ends is related to the land-use pattern. Because of this belief, transportation studies devote a large amount of effort to collecting land-use data, relating trip ends to land use, and estimating future trip ends from land-use forecasts. It is generally conceded that the consideration of land use is a major advance in the science of transportation planning.

However, the study of trip generation is still in its infancy. Actually, no one is yet quite sure how to relate trips to land use. Studies of the past decade have shown that different types of land use generate trips at widely varying rates. Furthermore, the same type of land use may generate trips at different rates depending on where it is located in the metropolitan area. No one has analyzed and explained the variation in trip rates sufficiently to formulate a package of reliable techniques suitable for widespread adoption.

This paper describes an attempt to answer the question, "What is the best type of land-use measurement from which to estimate trips?" The answer to this has a significance beyond determining what kind of trip rate to use for an estimating problem. It also bears on what type of land-use data should be collected in a transportation

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study. In the absence of confidence about exactly what to measure, many studies decide to measure everything that might be of use. Later on, the researchers can select the factors which give the best results and ignore the rest of the data. This, of course, is very inefficient, and it is still possible that some pertinent data will not be collected.

It may be that some types of surveys now conducted are not really necessary and that some new types of surveys would assist more in accurate trip estimation. One point should be borne in mind: since the object of trip generation is to estimate trips for some future or assumed situation, trip rates must be based on a kind of data which can be forecast with reasonable accuracy.

Three measures of land use have commonly been used as bases for trip generation: land area, floor area, and employment. Probably land area is the most popular because it is the easiest to measure. This is what is measured in the typical land-use survey conducted by city planners, and a relatively large amount of land area data is available for large cities. However, floor area is thought to be a better basis for trip generation because it reflects the widely varying intensity of use of land. But floor area is rather difficult to survey thoroughly. It is customarily obtained from Sanborn maps which cover only densely built-up areas. Floor area can also be obtained by aerial photography or field survey, but both methods are laborious and expensive.

Detailed employment data are fairly difficult to obtain because employment is not a fixed physical object, clearly visible to a surveyor. An employment survey requires the cooperation of all employers. Furthermore, there are considerable problems in defining and measuring employment (for example, persons with two jobs and persons with part-time or sporadic employment).

ABOUT THIS STUDY

The data collected by the Chicago Area Transportation Study (CATS) in its 1956 surveys permit analysis of these three types of trip rates.[1] This paper compares the estimating capabilities of these three measures of land use for the five nonresidential land-use categories used by CATS. These categories are given in Table 1, together with the number of trips made to each.

Residential trip generation was excluded from this analysis because these three parameters are not customarily used for this land-use category. Residential trip-making is normally considered in terms of trips per capita or per dwelling unit. At CATS, an estimating equation was developed in which trips per capita was a function of auto ownership and net residential density.

The CATS measurement of these three types of data included a complete survey of land area for the entire study area. The floor area survey covered only those areas for which Sanborn maps were available—Chicago, a few close-in suburbs, and the downtown parts of several more distant suburbs. CATS made no direct survey of employment per se. However, first work trips were identified in the home interview survey and give an approximation of employment. In general, first work trips represent 70 to 90 percent of employment. However, the exact relationship between first work trips and employment is unknown; this makes rates based on first work trips somewhat questionable.

Within each land-use category, there is considerable variation in trip rates throughout the study area. Clearly something more than a land-use breakdown is needed to explain the variation adequately.

TABLE 1

ALL NONRESIDENTIAL PERSON TRIP DESTINATIONS IN CATS STUDY AREA

Land Use	No. Trips	Percent
Commercial	2,449,468	53.2
Public buildings	781,960	17.0
Manufacturing	779,340	16.9
Public open space	314,833	6.8
Transportation	280,270	6.1
Total	4,605,871	100.0

[1] The data used in this analysis were taken from unpublished tabulations of the results of the land-use and travel surveys made by CATS. These surveys are described in Final Report: Volume 1, Chicago Area Transportation Study, December 1959.

In this analysis, the rates have been related to net residential density (NRD). NRD tends to indicate (a) the intensity of use of land in an area, and (b) the accessibility of an area, i.e., the number of trip-makers located within a given radius of the site. NRD tends to indicate the intensity of use of nonresidential land as well as residential land. Of course, NRD declines with increasing distance from the central business district (CBD).

The CATS study area was divided into 44 districts, and statistics for the districts formed the data for this analysis. The two districts which include the CBD were omitted because (a) this is a special situation where general rules often do not apply, and (b) NRD figures for these two districts are artificial. NRD was measured in occupied dwelling places per 100,000 sq ft of residential land. Because land was classified according to first floor use, in the downtown area many buildings containing dwelling places were classified as nonresidential land.

In addition, two districts were not included in the floor area survey. In a few cases, none of the thing being measured was found in a district. In three cases, a few districts with very small amounts of land area or floor area were omitted from the calculations because they had highly aberrant rates which overly influenced the correlation.

ANALYSIS OF TRIP RATES

The three types of trip rates are expressed in the following terms:

1. The land area rate represents person trips (internal and external) per acre;
2. The floor area rate represents person trips (internal and external) per 1,000 sq ft of floor area, and only trips made to areas included in the floor area survey were counted; and
3. The first work trip rate represents the ratio of all person trips to first work trips (since the first work trips do not include external trips, the latter were also left out of the numerator).

Trips mean trip destinations, and the numbers are totals for a 24-hr period, an average weekday.

Table 2 shows the overall study area rates for the five land uses. These rates do not necessarily agree with the mean rates given later in the paper because the latter do not include the two CBD districts and are unweighted averages (i.e., they are the averages of district averages).

Table 3 gives the results of the correlation analysis of trip rates and NRD. Simple linear correlation was used for the land area and first work trip rates, and for floor area, the correlation was between the rate and the logarithm of NRD. The standard errors are adjusted for degrees of freedom. The variation coefficient is the ratio of the standard error to the mean, expressed as a percentage. Regression equations derived from the same data are also given in Table 3 for each type of land use.

Commercial

This is the most important category, since it attracts half of all nonresidential trips and has by far the highest land area and floor area trip rates. The floor area rate seems to be the best estimator, with a correlation of -0.93 and a variation coefficient of only 23 percent. The first work trip rate is almost as good.

Curiously, the land area rate has almost no relationship to NRD—it does not show a decline with movement from the CBD to the suburbs. This is the only land-use category for which this is true. Apparently the greater trip attraction per unit of floor area in the suburbs is bal-

TABLE 2

OVERALL TRIP RATES FOR CATS STUDY AREA

Land Use	Land Area Rate	Floor Area Rate	First Work Trip Rate
Commercial	181.42	5.87	3.54
Public buildings	52.82	3.82	4.70
Manufacturing	49.35	2.16	1.09
Public open space	4.28	—	17.49
Transportation	8.64	2.27	1.59

TABLE 3

RESULTS OF CORRELATION ANALYSIS OF TRIP RATES AND NRD

Land Use	Type of Rate	No. Districts	Correlation Coeff.	Mean Rate	Std. Error	Var. Coeff. (%)	Regression Equation[a]
Commercial	Land area	42	-0.024	153.82	59.60	38.7	$Y_1 = 155.355 - 0.0293X$
	Floor area	40	-0.927	11.02	2.54	23.0	$Y_2 = 33.800 - 14.642 \log X$
	First work trip	42	-0.781	4.96	1.18	23.8	$Y_3 = 6.549 - 0.0304X$
Public buildings	Land area	42	+0.711	75.69	30.03	39.7	$Y_1 = 43.085 + 0.6225X$
	Floor area	40	-0.674	5.37	2.80	52.2	$Y_2 = 14.657 - 5.971 \log X$
	First work trip	42	-0.624	7.94	3.75	47.2	$Y_3 = 11.141 - 0.0611X$
Manufacturing	Land area	42	+0.791	55.61	30.32	54.5	$Y_1 = 13.488 + 0.8042X$
	Floor area	38	-0.472	2.61	1.22	46.9	$Y_2 = 5.044 - 1.542 \log X$
	First work trip	42	-0.520	1.19	0.21	17.6	$Y_3 = 1.332 - 0.0026X$
Public open space	Land area	38	+0.560	12.61	12.47	98.9	$Y_1 = 4.354 + 0.1732X$
	First work trip	41	-0.532	25.71	15.01	58.4	$Y_3 = 36.087 - 0.1939X$
Transportation	Land area	42	+0.555	12.37	7.93	64.1	$Y_1 = 6.675 + 0.1087X$
	Floor area	34	-0.706	4.26	3.65	85.6	$Y_2 = 19.795 - 9.411 \log X$
	First work trip	42	-0.421	2.87	3.10	108.0	$Y_3 = 4.420 - 0.0296X$

[a] Y_1 = land area rate;
Y_2 = floor area rate;
Y_3 = first work trip rate; and
X = net residential density.

anced by the lower ratio of floor area to land area (parking lots and more horizontal buildings).

Public Buildings

There is not a great deal of difference among the three estimators, and none is especially good. The land area rate appears to be best, since it has the highest correlation coefficient and the lowest variation coefficient.

The ratio of all trips to first work trips is rather high because a large proportion of the trips to public buildings were made to schools, and trips by students heavily weight the nonwork trips. It seems reasonable that trips to schools might be based on enrollment, rather than any of the measures presented here. Unfortunately, CATS did not collect any enrollment data. Probably schools should be treated as a separate land-use category.

Manufacturing

The best predictor of the entire study is the equation relating all manufacturing trips to first work trips. Although the correlation with NRD is not high (-0.52), the initial variation in the trip rates is so low that the standard error is only 17.6 percent of the mean. It is logical that manufacturing trips are closely related to manufacturing employment because there are relatively few nonwork trips to manufacturing.

Public Open Space

There are no floor area rates for public open space, since normally this type of land contains no buildings. In the CATS survey, buildings located on public open space were usually classified under public buildings.

The results for this category are poor, undoubtedly because of the wide range in intensity of use of public open space. Hundreds of acres of forest preserve may attract almost no trips, whereas a small beach or playing field may attract thousands.

The first work trip rate appears to be better than the land area rate, since its correlation coefficient is almost as high and its variation coefficient is much lower. However, it might still be advisable to use the land area rate. Few people work on public open space and, therefore, first work trip rates are very high. It is probably difficult to measure employment accurately, and a small error in measuring employment would be magnified many times.

Transportation

The land area rate seems to be best for this category, which includes communications, utilities and other nonmanufacturing industrial uses. This is not surprising, since this category includes many extensive land uses in which floor area is not too significant. However, the variation coefficient is 64. 1 percent—rather high—and this is a troublesome category. Fortunately, there are relatively few trips made to this land use.

COMMENTS ON RESULTS

No one of the three types of trip rates appears to be consistently superior. As measured by the variation coefficients, land area rates are best for two land uses, floor area rates for one, and first work trip rates for two. In three cases the land area rate has the highest correlation; in two cases, the floor area rate has the highest.

It is interesting that the floor area rate is substantially better than the land area rate only for commerical land use. (For manufacturing, the floor area rate has a slightly lower variation coefficient but a much poorer correlation. For transportation, the floor area rate has a slightly higher correlation, but a poorer variation coefficient.) This is contrary to expectations since, in theory, floor area is supposed to be a better basis for trip generation.

Attention is also directed to the sign of the correlation coefficients. All of the land area correlations have positive signs except commercial, where the correlation is practically zero. This is according to theory: where the density is higher, land is used more intensively and more trips are made to it.

All of the floor area rates have negative correlations, meaning that more trips are made to a unit of floor area in the suburbs than in the central city. This is puzzling. It was theorized, before the CATS survey was made, that floor area rates would be about the same everywhere. Why they are not is not yet fully understood. One hypothesis is that in the denser areas, walking trips are substituted for auto or transit trips, and walking trips are not included in person trips. Another explanation is that in the low density areas, only part of the floor area was measured in the survey, and that part was usually in the CBD's of suburban cities. If all suburban land use were measured, the floor area trip rates might drop considerably. A third possibility is that the supply of nonresidential floor area in the suburbs has not caught up with the demand for it (or had not as of 1956). People living in the suburbs make more trips per capita than those living in the central city. In time it would be expected that the amount of floor area would increase to absorb this greater trip-making, but perhaps there is a time lag. This would mean that nonresidential construction in the suburbs does not keep up with residential construction. These hypotheses may be invalid, but it does not seem logical that floor area is more intensively used in the suburbs when land area is more intensively used in the central city.

The first work trip rate is definitely related to NRD, and in all cases the correlation is negative. There are probably two reasons for this. First, when people make more trips (as do suburban residents), the incremental trips tend to be nonwork trips. Second, walking trips may have something to do with it. Work trips (which tend to be the longest of any purpose) are seldom on foot, and even those working in dense areas tend to travel to work by auto or transit. Nonwork trips, however, are more apt to be on foot in dense areas, which would lower the first work trip rates there.

FURTHER RESEARCH

As is often the case, this investigation produced more questions than answers. To pursue this inquiry further, several things could be tried: (a) variables other than net residential density; (b) more sophisticated statistical techniques, such as multiple correlation; (c) a more detailed classification of land uses; (d) smaller geographical units; and (e) other parameters than the three discussed here. Some of these approaches were attempted with CATS data, but the results were not very rewarding. Land area rates for public buildings and manufacturing were correlated with many different variables, using all types of correlation—simple and multiple, linear and curvilinear.

For both land-use categories, the variable giving the highest simple correlation was gross population density (population divided by total land area). The coefficients were +0.791 for public buildings and +0.845 for manufacturing—both slightly higher than the coefficients for net residential density. However, gross population density is not a very satisfactory variable because vacant land is included and can distort the ratios. The density can be greatly affected by where the boundaries of the districts happen to fall.

Other variables were found to have rather high correlations with trip rates. However, all of these were highly correlated with NRD and explained very little of the variation which was not explained by NRD. The goal was to find a variable with a sound logical basis which is highly correlated with trip rates and not particularly correlated with NRD. No such variable was discovered, so it appears that NRD is still the best variable to correlate with trip rates.

The comparison described here could not be carried out for a finer classification of land uses. Although CATS made such a classification (about 90 categories), land area was not so classified. However, some investigation was made of floor area trip rates for detailed commercial land uses. All of the detailed categories produced lower correlations than the overall category. Apparently, the detailed rates contained many variations which were washed out when the categories were lumped together. Besides, when the classification becomes finer, sampling variability becomes a greater problem.

It would be desirable to use smaller and more uniform geographical units. CATS districts admittedly were not ideal; they vary greatly in size, and some are very large (as much as 146 sq mi). The alternative was to use zones, of which there are 582. Then the volume of calculations becomes overwhelming, and machine assistance is required. It might be possible to get around this problem by using a sample of zones. A warning is also in order; when smaller units are used, the variation is liable to increase. This is similar to the effect obtained when moving from general to detailed land-use categories.

It would also be worthwhile to experiment with parameters other than land area, floor area and employment. Certain possibilities come to mind: enrollment (for schools), number of beds (for hospitals), and number of seats (for churches and auditoriums). These suggest themselves more readily for individual application to specialized land uses than for general adoption for all land uses. Therefore, the data collection will become more complex, rather than simpler.

This analysis was handicapped by lack of adequate data, which points up the need for some more comprehensive surveys, for research purposes at least. The only complete survey made by CATS was the land area survey. It would be valuable to make a complete floor area survey of a metropolitan area, including suburbs and rural areas as well as the central city. This would be a considerable undertaking, of course, and would mean going beyond Sanborn maps. It would also be desirable to make a comprehensive, detailed employment survey of a metropolitan area as part of a transportation study. This has probably never been done, although many studies have used gross employment estimates. The Census Bureau does make such surveys, but whether detailed data would be available to a transportation study is not known. Careful attention should be given to the design of such a survey to make the resulting data as comparable as possible to data from the travel surveys.

CONCLUSIONS

Although all generalizations about trip generation must be regarded as tentative, several conclusions can be drawn from this study:

1. Present evidence does not suggest that there is a single best parameter for nonresidential trip generation. In the author's judgment, floor area rates are best for commercial, first work trip rates for manufacturing, and land area rates for public buildings, public open space, and transportation.

2. This indicates that, for the time being, transportation studies should continue to collect data for all three types. In fact, more comprehensive surveys of all three types would be beneficial.

3. Contrary to theory, it does not appear that floor area is necessarily a better basis for trip generation than land area.

4. It appears, from the limited data available, that floor area rates are not uniform throughout a metropolitan area but increase with decreasing density. This is also contrary to expectation.

5. As expected, land area rates decrease with decreasing density, except in the case of commercial land use where there is no relationship at all.

6. The ratio of total trips to first work trips is not stable throughout a metropolitan area but increases with decreasing density.

This has been a rather detailed investigation of a specialized subject. Nevertheless, it is of considerable importance because of the vital place that the land use-travel relationship occupies in the transportation planning process. So much has been made of this relationship, so much is ascribed to it, and so much is expected from it that it is a bit frightening to realize that as yet it is only dimly understood.

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The research described here was conducted while the author was employed by CATS. Many of the computations were performed by Noel Smith.

Application of Large Network Traffic Assignments to Small Area Route Location Studies

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Modern electronic computers have been very useful in the distribution of interzonal trips and in the assignment of these trips to large networks of streets and freeways. Once a freeway system has been selected, however, there still remains the problem of precisely locating individual freeway segments of the overall system. These location studies usually require the assignment of traffic to several alternate locations and economic comparisons of these alternates.

A method of utilizing output data from large network traffic assignments for small area route location studies is described. The method involves a procedure whereby the study area used for the distribution of trips is reduced in size for the purpose of assigning traffic to alternate route locations. Results indicate that this reduced network method can offer considerable savings in machine processing time without loss of accuracy in route location studies.

•MODERN ELECTRONIC computers have been very useful in the distribution of interzonal trips and in the assignment of these trips to large networks of streets and freeways. Once a freeway system has been selected, however, there still remains the problem of precisely locating individual freeway segments of the overall system. These location studies usually require the assignment of traffic to several alternate locations and economic comparisons of these alternates.

This paper reports on a method of utilizing output data from large network traffic assignments for small area route location studies.

BACKGROUND

The distribution of trips by gravity model methods requires that the study area be large enough that a complete universe of trips is included in the analysis. Because the gravity model principle is based on the relative competition of all zones for the attraction of trips, the study area usually includes an entire self-contained community. For a small area study, encompassing only a portion of a larger urban area, distribution of trips on a gravity model may be done in one of two ways:

1. Assume traffic volumes at the external cordon stations and distribute trips to and from these cordon stations as if they were internal zones. The difficulty in this method is the selection of an appropriate travel time from each internal zone to the cordon station, since the cordon station location is not truly representative of the actual geographic location of the external end of the trips.
2. Expand the study area boundary so that a portion of the external area can be divided into additional zones. By moving the external boundary far enough out, most

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of the trips crossing the original cordon boundary now become internal trips, and any inaccuracy in the method of handling external cordon stations is thus reduced to a minimum. This expansion of the study area usually results in a large network of street and freeway links, requiring considerable computer time for determining minimum paths and the assignment of trips. In addition to the computer time involved, the resulting difference in user costs between alternates may appear insignificant as the total user cost for each alternate will include a large amount of vehicle miles and minutes for network links that are approximately equal for all alternates.

The following paragraphs describe a procedure whereby an expanded study area is used for the distribution of trips by gravity model methods and the area is then reduced in size to assign traffic to alternate route locations.

STUDY METHOD

The procedure was tested on a typical route location project in a metropolitan area. Shown in Figure 1 is the portion of the route under study and its relationship to other segments of the freeway system. For the purpose of trip development, the entire area within the dashed line (divided into 212 traffic zones) was included in the gravity model trip distribution. The area was then reduced in size to a small sector consisting of only 38 of the original 212 zones (outlined by shading in Fig. 1) for assignment of trips to the various alternates. The other 174 zones outside the reduced sector were replaced by 9 external cordon stations at points where street or freeway links crossed the reduced sector cordon boundary. The following steps were required to develop a triangular table for this reduced area and to assign trips to alternate route locations.

Figure 1. Complete and reduced study areas.

1. A triangular table was developed for the entire 212 zone area of Figure 1 using gravity model methods of trip distribution. For this step an assumption had to be made as to the location of the route under study to calculate interzonal travel times.
2. Traffic was assigned, based on time and distance savings, using the California diversion curve, to the full area network. This was the same network used in the previous step for the gravity model trip distribution.
3. A cordon boundary was drawn around the smaller area, and external cordon stations were established at points where links of the network crossed the cordon line (Fig. 2). The selection of the cordon boundary was based on judgment, considering natural barriers and also the effect the alternate route locations would have on trips assigned to links crossing the cordon boundary.
4. A reduced triangular table was developed for the small area inside the cordon boundary. Three categories of trips made up this reduced triangular table: those with one end inside the cordon boundary and the other end outside the cordon boundary (external-internal), those with both ends outside the cordon boundary but assigned to links crossing the boundary (external-external), and those with both ends inside the cordon boundary (internal). These trips were developed separately and then combined to form the completed triangular table, consisting of all the interzonal transfers for the 38 zones plus 9 external cordon stations, as outlined in the following:
   a. External-internal trips—From a selected link analysis program on the large network traffic assignment, there was available, for each link crossing the reduced sector cordon boundary, the number of trips for each of the many individual zone-to-zone transfers assigned to the cordon link.

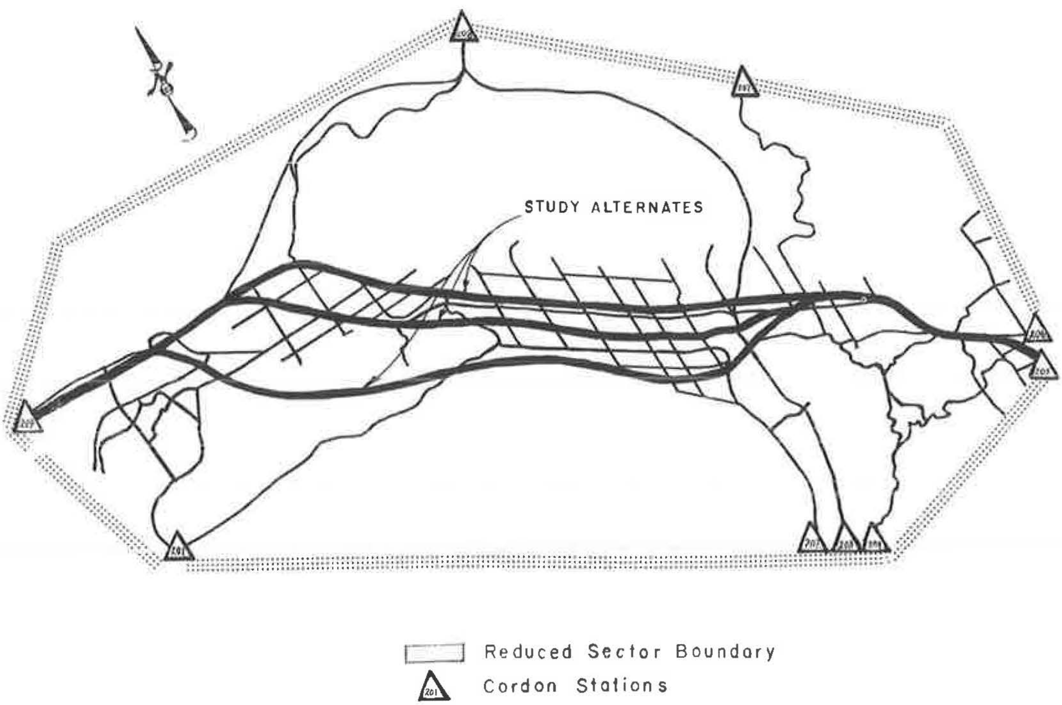


Figure 2. Study alternates.

With this information and a list of the zones which remained inside the cordon boundary, trips passing through each cordon link were sorted and totaled, by internal zone, to produce a table of trips between the 9 external cordon stations and the 38 internal zones.

b. External-external trips—Those trips which had neither origin nor destination at one of the 38 internal zones had to cross the cordon boundary twice. With knowledge of which transfers were assigned to each cordon link from the selected link analysis on the large network, a search was made by the computer of the records for each of the other cordon station links to locate where these trips crossed the opposite cordon boundary. By totaling all the zone-to-zone transfers common to each pair of cordon station links, a triangular table of trips between each of the 9 external cordon stations was developed.

c. Internal trips—Trips with both ends inside the cordon boundary were obtained by sorting out the appropriate zone-to-zone transfers from the large area triangular table.

d. The final reduced sector triangular table was developed by combining the tables from steps a, b, and c.

5. The network was reduced in size to include only the links within the cordon boundary, and minimum time paths were computed for the alternates on this reduced network.

6. Trips from the reduced sector triangular table were assigned to the reduced networks for each of the alternate locations of the freeway by means of the California diversion curve.

Although it is possible to produce a reduced triangular table by subjectively grouping external zones around the reduced sector cordon stations and adding up the trips from the large network triangular table, the method outlined here eliminates this judgment by making use of traffic assignment data to assign these external trips to the appropriate cordon stations. Because a diversion curve is used in the traffic assignment procedure, this method also allows for a split between two or three cordon stations of the trips between some of the pairs of zones.

ANALYSIS

Three alternates were studied—two involving freeway locations (alternates B and H, Fig. 2) and a hypothetical existing system (alternate X) in which all other freeways were considered to be constructed except the portion of the route under study. For test purposes, traffic was assigned to all three alternates utilizing two different networks of streets and freeways, one based on the large area used for gravity model trip distribution and the other for the reduced sector within the cordon boundary.

As the traffic assignment program produces both profile volumes and total vehicle-miles and minutes of travel by type of facility, the accuracy of the reduced network concept can be evaluated by comparing, on the full and reduced network basis, profile volumes and 20-year user savings.

Table 1 compares, by both methods, the 20-year user cost and savings for the alternates studied. It can be seen that although the total user costs are considerably

TABLE 1

COMPARISON OF 20-YEAR USER COSTS AND SAVINGS[a]

Alt.	Full Network		Reduced Network	
	Tot. User Cost ($)	User Saving over X ($)	Tot. User Cost ($)	User Saving over X ($)
X	12,821,315,000	—	1,287,817,000	—
B	12,678,509,000	142,806,000	1,144,083,000	143,734,000
H	12,693,065,000	128,250,000	1,157,095,000	130,722,000

[a]At 0 percent interest.

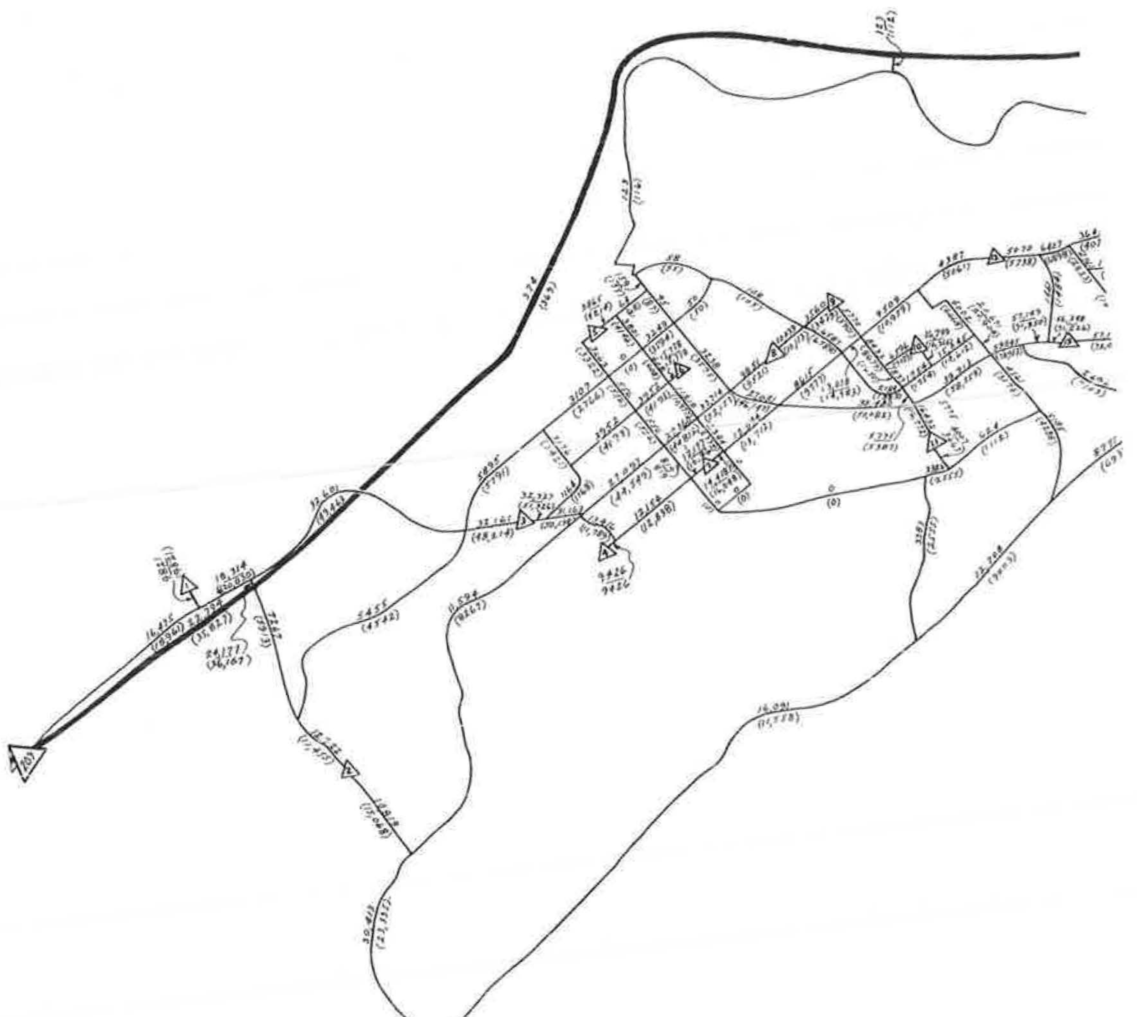
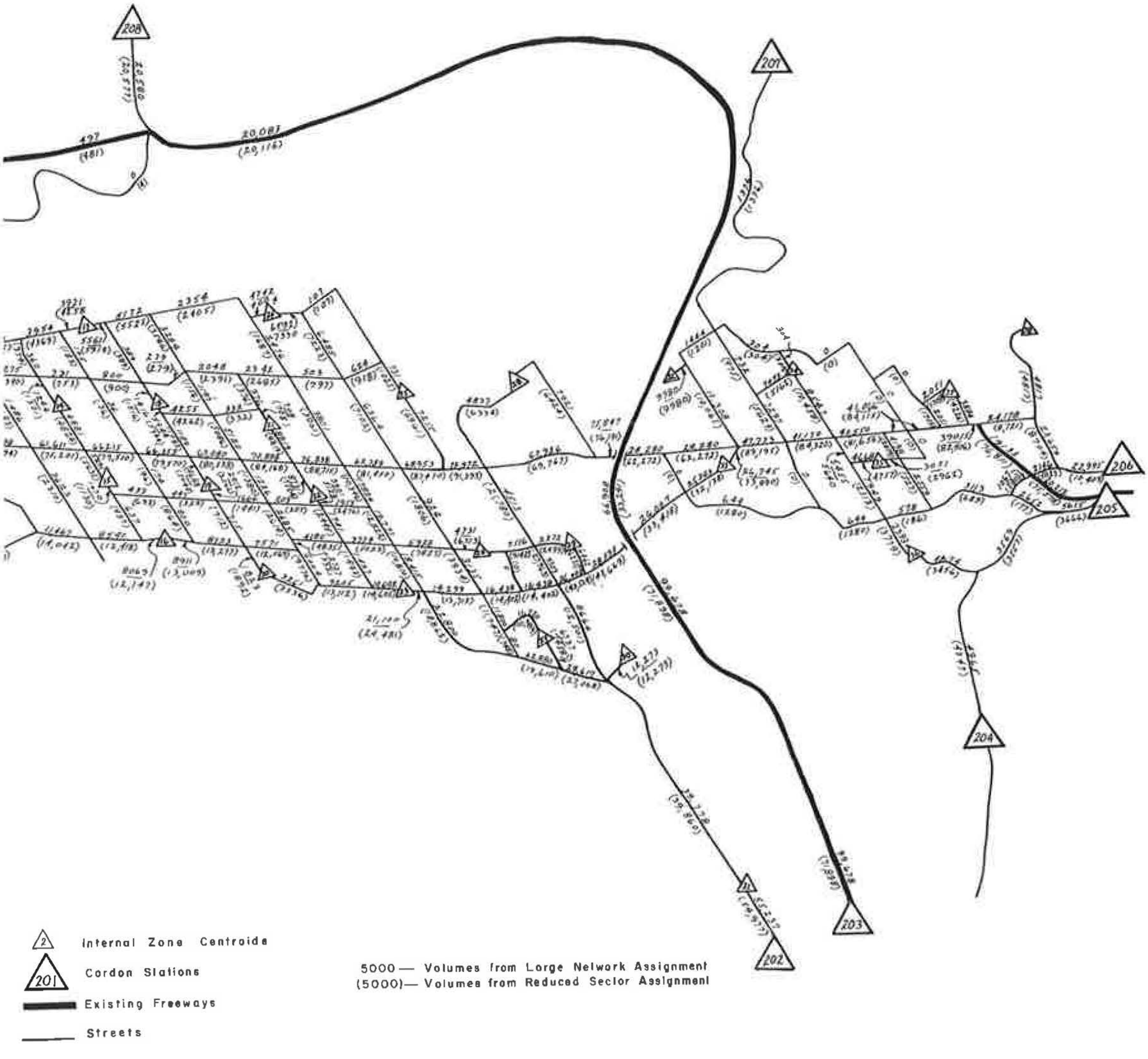
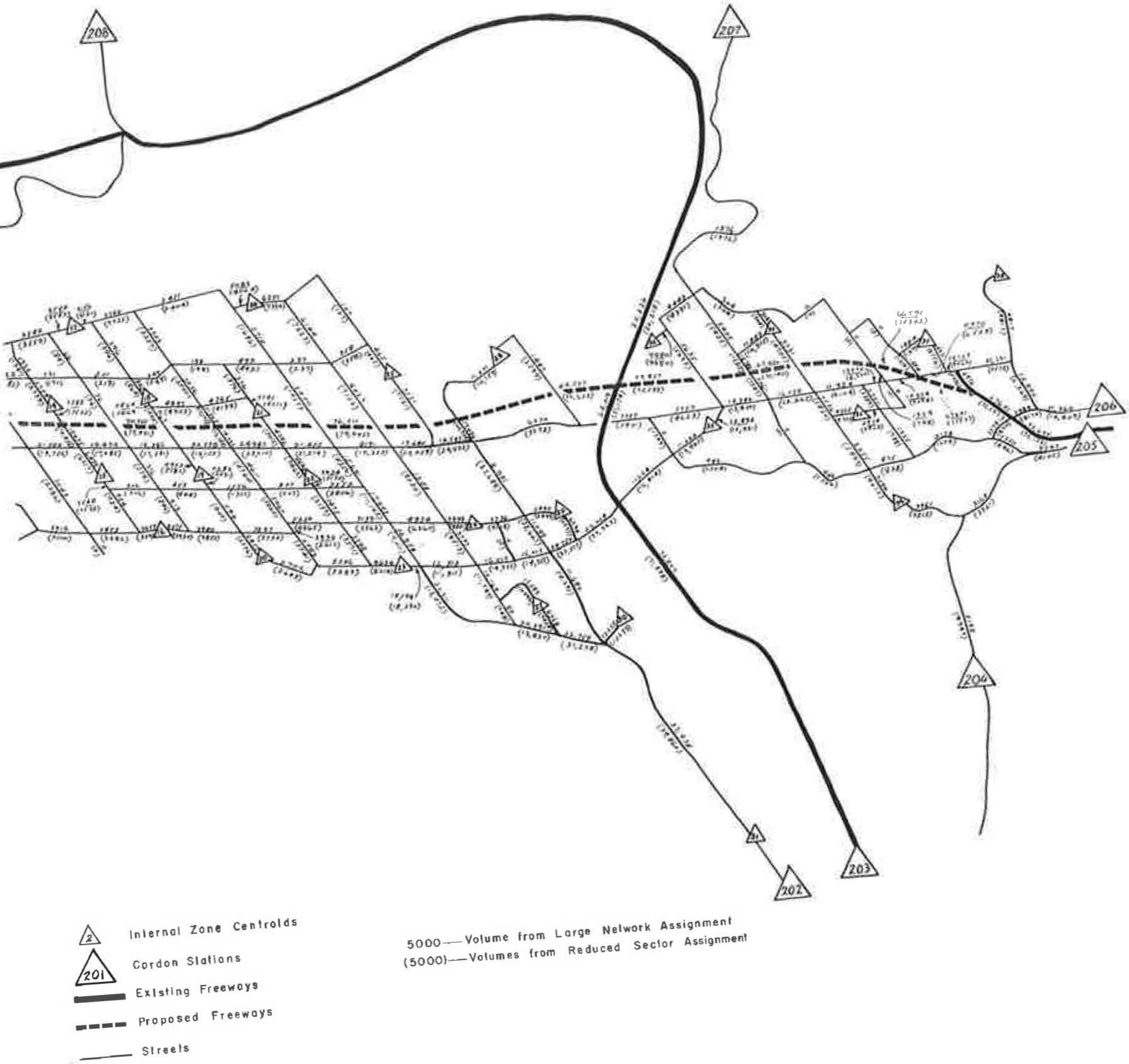


Figure 3. Comparison of traffic volumes assigne



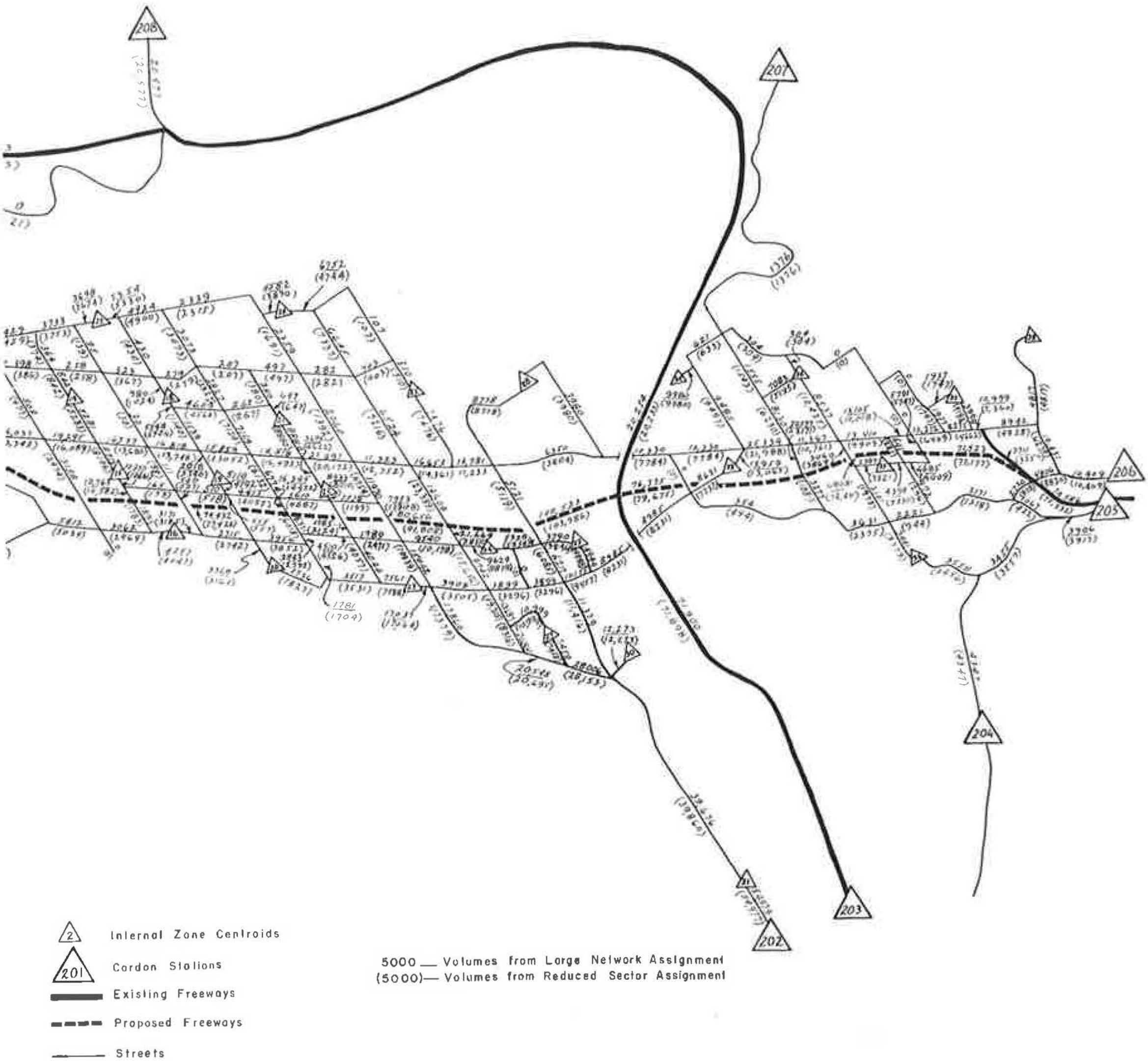
large network and reduced sector bases, alternate X.

Figure 4. Comparison of traffic volumes assigned on



large network and reduced sector bases, alternate H.

Figure 5. Comparison of traffic volumes assigned on



large network and reduced sector bases, alternate B.

different because of the size of the network in the traffic assignment, the user savings of alternates B and H when compared to X are close enough to be within the normal accuracy of traffic forecasting. This comparison also shows that the difference (user savings) is significant, regardless of how small a percentage it is of the total user cost. Using alternate B as an example, the $142, 806, 000 20-year savings on the full network represents only 1. 1 percent of the total user cost, but the $143, 734, 000 on the reduced network represents 12. 5 percent of the user cost. Yet, these two values of user savings are within 1 percent of each other, indicating that the $143, 000, 000± user savings is a real value. It would be erroneous to round out the 20-year user cost on the full network to 2 or 3 places and call all the alternates equal.

Figures 3, 4, and 5 show, on network maps for the three alternates, comparisons of profile volumes for individual links within the reduced sector as assigned by the two methods. For alternates B and H, the volumes compare very closely by both the full and reduced network methods. In this regard it should be noted that the outlined method makes one important assumption: that the alternates to be studied are close enough to the alignment assumed in distributing trips so as not to change the basic corridors to which trips were assigned on the full network basis.

There was quite a large variation, however, in the two profiles for alternate X. This is due to the fact that alternate X has no freeway in the corridor under study, whereas the triangular table for the small area was developed on the assumption that a freeway existed. (The reduced network triangular table was based on trips assigned to alternate B.) Therefore, when assigning to alternate X on the full network, trips through the area were apparently assigned on other freeways outside the reduced sector; however, on the reduced network these trips were assigned along existing streets within the cordon boundary.

A minor technical problem occurred in assigning traffic to alternate B on the reduced network. A large variation in traffic volume resulted on a segment of the freeway just inside the cordon line as compared to the assignment on the full network. This was found to be due to a street link which closely paralleled the freeway and tied in at the same cordon station, pulling too many of the cordon station trips away from the freeway. An adjustment was made to the distance on this street link and the assignment was rerun, resulting in the freeway volume matching closely the volume from the full network. It is believed that this problem could have been avoided if the cordon boundary had been moved farther from the study area. As stated earlier, the cordon boundary was chosen by judgment; to take advantage of natural barriers and thus reduce the number of links crossing the cordon to a minimum, the boundary was kept rather close to the alternates being studied. It is suggested in future studies using the reduced network method that the cordon boundary be moved farther away from the study alternates to inclose a larger area.

CONCLUSION

The results of this study indicate that the reduced network method can offer considerable savings in machine processing time without loss of accuracy in route location studies. Because the diversion curve method of assignment used by California compares time and distance along three routes between each pair of zone centroids (requiring three separate runs through the minimum path program), approximately 10 hours of processing time was required on an IBM 704 computer for each alternate on the full 212-zone network. This was cut down to only 1 hour for the 38-zone reduced network.

Another advantage is the elimination from the output of much data for the many interzone transfers outside the small area which are not affected by alternates within the cordon area. More experience is needed, however, in the selection of appropriate cordon boundaries for the small area.

It should be noted that the reduced network concept is not limited just to projects where trips were distributed on a gravity model. The same procedure can be applied to any large network traffic assignment, regardless of the method of trip distribution.

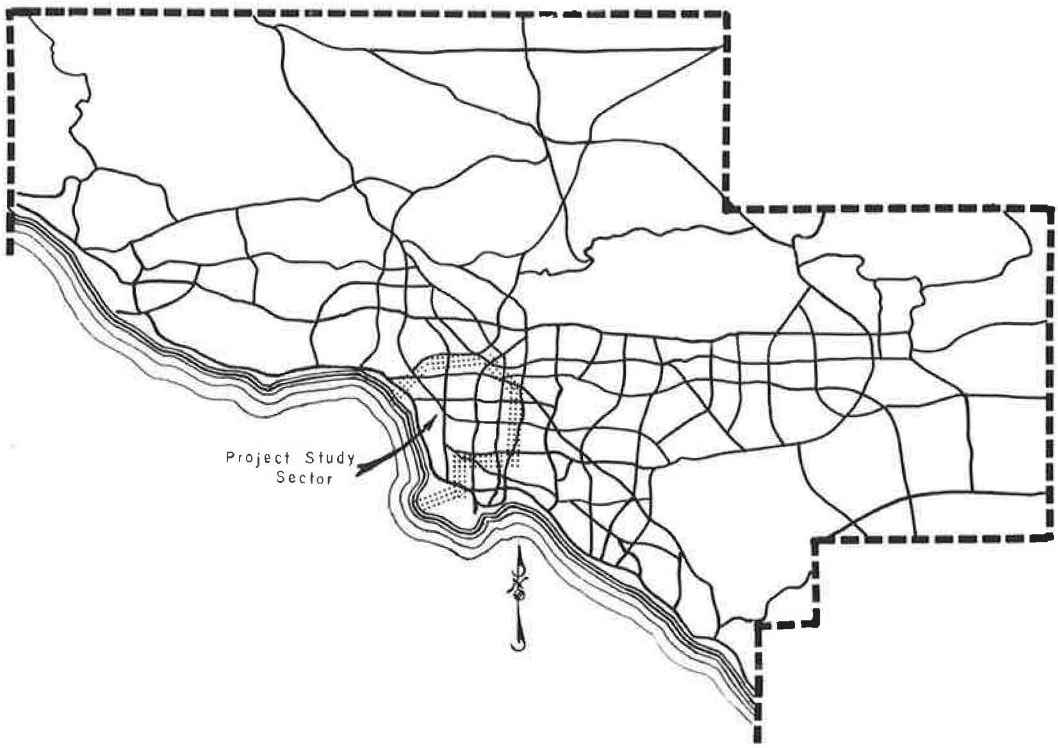


Figure 6. LARTS 1980 freeway system.

FUTURE APPLICATIONS

This same method can be used to isolate and study in more detail small segments of a large urban transportation network. For example, as part of the Los Angeles Regional Transportation Study (LARTS), trips were assigned to the system of freeways shown in Figure 6. Route location studies are currently under way on several individual segments of this system.

Some of the previous route adoption studies for freeway segments of this system involved a complete gravity model analysis on a large network basis for each individual project. Now that LARTS trip data are available, they are being used, where possible, in making these route location studies. On several current projects where the variations in alternate freeway locations are not enough to affect the basic corridors to which trips were assigned by LARTS, the output data from the LARTS traffic assignment will be used to develop reduced triangular tables for small study areas.

In one of these projects, a cordon boundary was drawn around a 200-sq mi sector of the 9,000 sq mi LARTS study area. Figure 6 shows the LARTS study network and the reduced sector area used in this project. The reduced sector contains only 87 zones plus 55 cordon stations, as compared to a total of 710 zones and cordon stations for the entire LARTS area. A reduced triangular table for this sector was developed, using essentially the same method outlined in this report. Traffic was assigned, with satisfactory results, to various study networks within the reduced sector cordon boundary.

A Comparative Evaluation of Trip Distribution Procedures

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The results of a research project designed to evaluate on a common basis the Fratar, gravity, intervening opportunities and competing opportunities trip distribution procedures are reported. Each of the procedures was calibrated using the 1948 Washington, D.C., O-D survey travel data as a base. Projections were made to 1955 using the procedures recommended by the principal developers of the techniques. The 1955 projections were then comprehensively tested against the 1955 Washington, D.C., O-D survey travel data.

Each procedure is evaluated for travel pattern simulation ability as well as the forecasting stability of the parameters. Various methods evaluate the accuracy of the models including trip length frequency duplication, screenline checks, specific movement checks and overall statistical evaluations of the estimated movements. These tests are performed for each technique and comparisons of the relative accuracies are also made. Appropriate changes in the calibration procedures are recommended.

•THE RAPID evolution of computer-oriented trip distribution techniques coupled with the pressing deadlines of the major urban transportation studies has made it difficult for the studies themselves to mount a comprehensive program for testing and evaluating the most widely used trip distribution techniques. Individual applications of trip distribution models have often involved a certain amount of research, and as a by-product of these applications, revisions and improvements in each of the techniques have been made. In the last 2 years, however, the rate of evolutionary development has slackened to the extent that most of the techniques are now considered to have reached a somewhat mature status.

This paper reports on the results of a research project conducted by the Urban Planning Division of the U.S. Bureau of Public Roads to test, evaluate, and compare four major trip distribution techniques: (a) the Fratar growth factor procedures as developed by Thomas J. Fratar and utilized by many transportation studies (1); (b) the so-called "gravity model," currently the most widely used of the mathematical travel formulas (2); (c) the intervening opportunities model developed by Morton Schneider of the Chicago Area Transportation Study (CATS) and since utilized by several other major studies (3); and (d) the competing opportunities model suggested by Anthony Tomazinis of the Penn-Jersey Transportation Study (PJ) but not yet utilized in an operational study (4, 5).

The mathematical model techniques present interesting contrasts in their approach to the trip distribution problem. These models can be classified into two categories: growth factor procedures and interarea travel formulas. The growth factor procedures utilize growth factors reflecting land-use changes in the zones to expand a known

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travel pattern to some future year. The interarea travel formulas simulate travel distributions by relating them to characteristics of the land-use pattern and of the transportation system. The interarea travel formulas require calibration—i. e., determining the effect of spatial separation on travel—before their actual application as forecasting tools.

STUDY PROCEDURES

An attempt was made to establish a standard set of test conditions for evaluating the four procedures. It was not possible to adhere to strictly comparable conditions in all instances, but each variation from a common base is fully discussed.

Basic data sources for the analysis were the 1948 and 1955 home interview travel surveys conducted in Washington, D. C. The 1948 survey covered 5 percent of the dwelling units in the metropolitan area. In 1955 a repeat survey was conducted. In the repeat survey, occupants of 3 percent of the dwelling units were interviewed within the District of Columbia. Elsewhere in the area, occupants of 10 percent of the dwelling units were interviewed. Figure 1 shows a map of the study area.

The boundaries of the 1948 and the 1955 study areas were not exactly matched. Every attempt was made, however, to make the 1948 and 1955 analysis zones compatible. This was not a critical problem with respect to the interarea travel formulas since the only variable projected directly is the effect of spatial separation on tripmaking. This variable is independent of zone configuration. The Fratar procedure, however, requires compatible zones for base and projection years. For the Fratar analysis it was necessary to reduce the 400 zones utilized in the standard analysis to 362 more comparable units. In most instances this involved eliminating zones which were external to the 1948 study area but internal to the 1955 area and thus having zero trips ends in 1948. Certain irregularities in zonal boundaries still were present; however, their effect was not serious. Because of changes in the location of external cordon stations between 1948 and 1955, all trips crossing the cordon—i. e., external trips—were omitted from the analysis. The basic trips considered were the total person trips by all modes expanded from the home interview surveys. Trips recorded in the special truck and taxi surveys were not included.

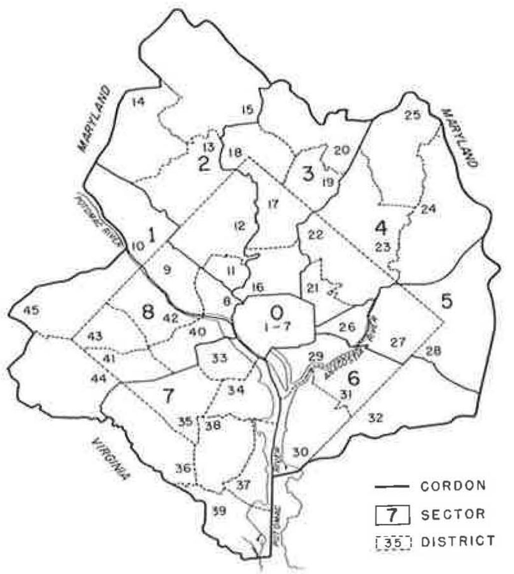

Figure 1. Study area, Washington, D. C., 1948 and 1955.

Although the test period covered by this analysis was only 7 years, the characteristics of the area experienced significant changes in this period of time. The total population increased 38 percent to almost 1. 5 million. The number of person trips increased by over 42 percent. During the same interval, the number of passenger cars owned by residents almost doubled, increasing by 96 percent.

Probably the most significant change in the study area within the 7-year period was the decentralization of many activities. Residential, employment, and shopping activities were all relatively less oriented to the central business district (CBD) in 1955 than in 1948 (6). Total trips to the CBD likewise showed a relative decrease from 28 to 21 percent of the total person trips.

The study was designed so that the 1948 survey data would be used as the base year travel pattern for the Fratar procedure and as a calibration source for the interarea travel formulas. The 1955 travel survey data were used as a control against which all forecasts were checked. The trip ends reflecting the 1955 characteristics were taken directly from the 1955 O-D survey trip ends to establish the Fratar growth factors. In addition, they were used directly as producing and attracting powers of the zones when calculating the synthetic distributions with the interarea travel formulas. The 1955 trip ends were used, rather than estimates developed in a land use-trip generation analysis, to restrict the possible sources of error to those inherent within each of the distribution procedures.

TRAVEL MODELS

Fratar

The Fratar procedure has been proven to be computationally the most efficient of the growth factor techniques (7). The basic premise of the Fratar procedure is that the distribution of trips from a zone is proportional to the present movements out of the zone modified by the growth factor of the zone to which the trips are attracted. The future volume of trips out of a zone is determined from the present trips out of the zone and the growth factors developed for the zone. Most earlier applications of the Fratar procedure considered only one general trip purpose. The Urban Planning Division of the U.S. Bureau of Public Roads in 1962 developed a Fratar procedure that considers up to 10 trip purposes. This program also allows the application of growth factors by mode, time of day, or separately for trips entering or leaving a zone. The basic formula for the directional purpose Fratar procedure is

$$T_{ij}^{(p,q)} = t_{ij}^{(p,q)} \cdot G_i^{(p)} \cdot G_j^{(q)} \cdot \frac{L_i^{(p)} + L_j^{(q)}}{2} \tag{1}$$

where

$L_i^{(p)}$ = locational factor = $\dfrac{t_i^{(p)}}{\sum_{j=1}^{n} t_{ij}^{(p,q)} \; G_j^{(p)}}$;

$T_{ij}^{(p,q)}$ = future year trips from zone i to zone j with a purpose p at zone i and purpose q at zone j;

$t_i^{(p)}$ = base year trip ends at zone i for purpose p;

$t_{ij}^{(p,q)}$ = base year trips between zone i and zone j with a purpose p at zone i and a purpose q at zone j; and

$G_i^{(p)}$ = growth factor for zone i, purpose p.

The purpose Fratar allows the procedure to be sensitive to the type of land-use changes that are occurring in a given zone. For example, work trips can be expanded as a function of employment changes only. Before the development of the new computer program, all trips, irrespective of their purpose, were expanded by a measure of the overall growth of the zone.

Gravity Model

The gravity model is the most thoroughly documented of the trip distribution techniques (8-11). This approach, loosely paralleling Newton's gravitational law, is based on the assumption that all trips starting from a given zone are attracted by the various traffic generators and that this attraction is in direct proportion to the size of the generator and in inverse proportion to the spatial separation between the areas. This research study utilized the Public Roads computer program battery gravity model program. The basic gravity model formulation of this program is

$$T_{ij} = \frac{P_i A_j F_{ij} K_{ij}}{\sum_{j=1}^{n} A_j F_{ij} K_{ij}} \tag{2}$$

where

T_{ij} = trips produced in zone i and attracted to zone j;
P_i = trips produced in zone i;
A_j = trips attracted to zone j;
F_{ij} = empirically derived travel time factors (one factor for each 1-min increment of travel time) that are a function of the spatial separation between the zones and express the average areawide effect of spatial separation on trip interchange;
K_{ij} = specific zone-to-zone adjustment factor to allow for the incorporation of the effect on travel patterns of defined social or economic linkages not otherwise accounted for in the gravity model formulation.

The travel time factors F_{ij} are developed in an iterative procedure which is continued until the synthetic trips calculated for each trip length interval closely match the surveyed trips reported for the same intervals. Any convenient set of travel time factors may be used to start the iteration procedure.

Intervening Opportunities Model

The intervening opportunities model utilizes a probability concept which in essence requires that a trip remain as short as possible, lengthening only as it fails to find an acceptable destination at a lesser distance. An equal areawide probability of acceptance for any origin is defined for all destinations in a given category. All trip opportunities or destinations are considered in sequence by travel time from zone of origin. In operation, the first opportunity considered is the one closest to the origin and has the stated areawide probability of acceptance. The next opportunity has the same basic probability of acceptance; however, the actual probability is decreased by the fact that the trip being distributed has a chance of already having accepted the first opportunity. The procedure continues with each successive opportunity having, in effect, a decreased probability of being accepted.

Thus, spatial separation for the intervening opportunities model is measured, not in terms of the absolute travel time, cost, or distance between one zone and the other, but rather in terms of the number of intervening opportunities. These intervening opportunities (destinations) are determined by arraying the available destinations in all zones by travel time from the zone of origin. The formulation for the procedure is

$$T_{ij} = O_i \left[e^{-LD} - e^{-L(D + D_j)} \right] \tag{3}$$

where

T_{ij} = trips originating in zone i with destinations in zone j;
O_i = trip origins in zone i;
D = trip destinations considered before zone j;
D_j = trip destinations in zone j;
L = measure of probability that a random destination will satisfy the needs of a particular trip; it is an empirically derived function describing the rate of trip decay with increasing trip destinations and increasing length of trip; and
e = base of natural logarithms (2.71828).

This model is calibrated by varying the probability values until the simulated trip distribution reproduces the person-hours of travel and percent intrazonal trips of the surveyed trip distribution.

Competing Opportunity Model

Essentially, the basic concept of the competing opportunity model is that opportunities or destinations compete for trips within equal travel time, travel distance, or travel cost bands as measured from the zone of origin. Within a given band, every opportunity has an equal probability of acceptance. The probability that trips will distribute to a certain zone is the product of two independent probabilities. The first, called the "probability of satisfaction," reflects the chances that a trip will be of a particular length and is a function of the opportunities at a greater distance than the time band under consideration. The determination of the specific destination within this trip length is quantified by a "probability of attraction" related to the available opportunities which fall within the area up to and including the time band considered.

The mathematical formulation for this procedure is

$$T_{ij} = O_i \rho_{a_j} \rho_{s_j} \tag{4}$$

where

T_{ij} = trips produced in zone i and attracted to zone j;
O_i = trip origins in zone i;
ρ_{a_j} = probability of attraction = $\frac{\text{destination available in zone j}}{\text{sum of dest. avail. in time bands up to and incl. band m}} = \frac{D_j}{\sum_{k=0}^{m} D_k}$
ρ_{s_j} = probability of satisfaction =

$$1 - \frac{\text{Sum of dest. avail. in time bands up to and incl. band m}}{\text{sum of total destinations in study area}} = 1 - \frac{\sum_{k=0}^{m} D_k}{\sum_{k=0}^{n} D_k};$$

k = any time band;
m = time band into which zone j falls;
D_k = destinations available in time band k;
n = last time band as measured from origin zone i; and
D_j = destinations available in zone j.

This model is calibrated by varying the width of the attracting bands until the trip length characteristics of the synthetic trips correspond to the trip length characteristics of the surveyed trips.

BASIC TESTS USED TO EVALUATE DISTRIBUTION MODELS

Four basic tests were employed to measure the ability of the various procedures to reproduce the total person trip movements of the known travel patterns: (a) ability to match the trip length frequency distribution from the O-D survey; (b) ability to produce river crossing volumes that match O-D survey volumes; (c) ability to match O-D survey trip movements by corridor to and from the CBD; and (d) accuracy of model as measured by statistical comparison of O-D survey and model of trips assigned to a "spider network."

No 1948 tests could be made with the Fratar procedure because its base is the survey data. However, in the case of the other travel formulas, some validation was accomplished against base conditions. Such validation is an essential part of calibrating the models before moving to projections. The accuracy of this base year simulation is typically the most important check in the calibration procedure. This check follows from an assumption that if the calibrated travel model will accurately simulate a base year travel pattern, the same model will also accurately simulate a future year travel pattern.

The trip length frequency comparisons were made by 1-min time intervals. A consideration of the trip length frequency curves and the mean trip lengths provides a measure of the accuracy of the person-hours of travel estimate for the total area as well as an indication of the accuracy of the trip distribution.

The river crossing tests were made on the basis of screenlines set up on both the Potomac and the Anacostia Rivers. Because of the trip definition, the base screenline values were the O-D survey person movements rather than actual vehicle counts.

The analysis of movements by corridor to and from the CBD was designed to detect any bias in the estimated travel patterns. The gravity model computer program provides for the use of adjustment factors to correct for bias. With the other techniques it is usually assumed that the procedure adequately distributes trips without need for adjustment.

The final test was the statistical analysis of trips assigned to a "spider network," a network consisting of airline distance connections between adjacent zone centroids. The resulting differences between the O-D and model assignments are arrayed by volume group and the root-mean-square error (RMSE) is calculated. This test provides a measure of the overall accuracy of the final trip distribution.

CALIBRATION OF INTERAREA TRAVEL FORMULAS

Gravity Model

Prior gravity model research with Washington data used the 1955 O-D data as a calibration base rather than the 1948 data (8, 9). The model parameters were, in effect, forecast backward from 1955 to 1948. For the subject research, the gravity model was recalibrated using the 1948 O-D data as a base and these 1948 model parameters were used to forecast 1955 travel patterns. The research showed that the same travel time factors held good for both 1948 and 1955 and that the K factor (socioeconomic adjustment factor) also maintained the same relationship with average family income by district for both periods. One somewhat questionable point was whether the river crossing time impedances, which varied from 5 and 3 min for work and nonwork trips, respectively, in 1948 to 6 and 5 min for these same trip categories in 1955, could have been properly forecast without the knowledge gained in the research. The 1955 river crossings were forecast from 1948 on the basis of the relative congestion levels for the 2 years (9, p. 93). For purposes of the present comparisons, however, it was assumed that the river barriers could be properly forecast. The travel time factors for each of the six trip purposes used for both 1948 and 1955 are given in Table 1.

TABLE 1

TRAVEL TIME FACTORS BY TRIP PURPOSE
WASHINGTON, D. C., 1948 AND 1955

Travel Time	Home-Based Trips					Nonhome-Based Trips
	Work	Shopping	Social-Rec.	School	Misc.	
1	1,000	8,700	2,000	4,200	2,600	1,600
2	1,000	8,700	2,000	4,200	2,600	1,600
3	1,000	8,700	2,000	4,200	2,600	1,600
4	1,000	8,700	2,000	4,200	2,600	1,600
5	1,000	8,700	2,000	4,200	2,600	1,600
6	1,000	8,700	2,000	4,200	2,600	1,600
7	1,000	8,700	2,000	4,200	2,600	1,600
8	1,000	8,700	2,000	4,200	2,600	1,600
9	680	5,400	1,475	2,800	1,700	1,100
10	500	3,600	1,100	2,000	1,200	780
11	400	2,300	820	1,475	875	580
12	320	1,600	640	1,075	650	440
13	270	1,120	500	800	500	340
14	235	800	400	625	390	265
15	205	580	320	480	300	215
16	180	420	260	370	235	170
17	160	310	220	280	190	140
18	145	235	180	215	150	110
19	130	180	152	165	125	92
20	120	140	130	135	105	78
21	110	105	110	110	87	65
22	100	95	95	90	72	54
23	93	70	82	70	60	46
24	87	58	72	57	51	40
25	82	45	64	47	43	33
26	77	38	56	40	38	29
27	70	32	49	32	32	25
28	63	26	42	26	28	22
29	58	21	38	22	24	20
30	53	17	34	18	21	17
31	49	13	30	15	18	15
32	44	10	27	12	15	13
33	40	8	24	10	13	12
34	37	6	21	9	12	10
35	34	5	19	7	10	9
36	29	4	17	6	8	8
37	27	3	15	5	7	6
38	24	2	13	4	6	5
39	22	2	11	4	5	4
40	19	1	10	3	4	3
41	17	—	8	3	3	2
42	15	—	7	2	3	1
43	13	—	6	2	2	—
44	11	—	5	2	1	—
45	9	—	4	1	1	—
46	7	—	3	1	—	—
47	6	—	3	1	—	—
48	5	—	2	1	—	—
49	4	—	1	—	—	—
50	3	—	1	—	—	—
51	3	—	—	—	—	—
52	2	—	—	—	—	—
53	2	—	—	—	—	—
54	1	—	—	—	—	—
55	1	—	—	—	—	—

Intervening Opportunities Model

Several methods of calibration of the intervening opportunities model were tried for the 1948 Washington area. The best procedures and the final calibration parameters were incorporated into this study. The several methods of calibration and the resulting findings are documented elsewhere (12). The method of calibration and forecasting of the model examined here are very close to those used previously in Chicago and elsewhere, with the exception that procedures were developed to insure that the model would both send and attract approximately the correct number of trips for each zone in the study area. Without these adjustments only 84 percent of total trips were distributed and trips to the CBD were overestimated by 20 percent.

Trip ends were stratified into long residential, long nonresidential, and short. Both long and short L values were developed through an iterative process to insure that when the final L values were applied to the appropriate trip ends, a satisfactory average trip length, trip length frequency curve, and number of intrazonal trips would be obtained for the total trips (all three trip types combined).

River crossing time impedances were shown to be needed for the intervening opportunities model, in the same manner as for the gravity model. The additional bridge crossing time required for the 1948 intervening opportunities model calibration was 5 min. The use of procedures developed in the gravity model research to forecast the impedance for the intervening opportunity model estimated the impedance required in 1955 at 8 min. Although the use of this 8-min forecasted time penalty did materially improve model accuracy, estimated Potomac River crossings were still approximately 16 percent high. The differing forecasted values of the gravity model and the intervening opportunity model impedances were caused by the differing trip purpose categories which required different weighting of peak hour trips. The basic structure of the models also necessitated the use of differing 1948 impedances.

An increase in the total number of trip destinations or opportunities requires that the probability that any one of these destinations will be acceptable to any given origin be reduced. Therefore, because of the growth in total and intrazonal trips in the study area, the 1948 L (probability) value required reduction for use in 1955. The final 1948 long and short L values are 2.50×10^{-6} and 13.00×10^{-6}, respectively. They were reduced to 1.65×10^{-6} and 10.80×10^{-6} for the 1955 forecasts. These adjustments were made on the basis of the growth in total destinations between 1948 and 1955 (<u>12</u>).

Competing Opportunity Model

This model proved to be very difficult to calibrate. Because no systematic calibration procedures were available, it was necessary to try many alternate approaches for obtaining a simulated trip distribution with the same trip length characteristics as the 1948 Washington survey data. Initially, equal time bands were tried for work trips with little success (Fig. 2). Next, varying width time bands were utilized and the results became more meaningful. It appears that the best simulation for work trips was obtained when the first time band incorporated the majority of the opportunities in the study area. This broad band was followed by equal 2-min bands. Even with this approach, however, it was not possible to obtain a trip length frequency distribution approaching the O-D trip length frequency. As shown in Figure 3, the curve A peaks are much too high, whereas curve B, similar in shape to the O-D curve, is offset approximately 4 min to the right. No grouping of time bands was found that would fit the O-D curve.

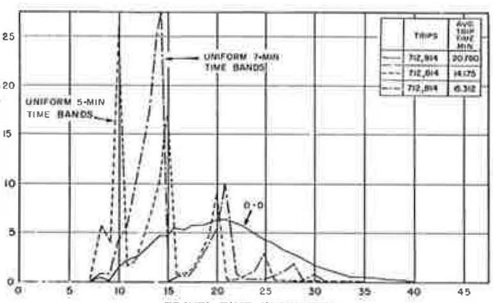

Figure 2. Comparison of trip length distribution (O-D vs competing opportunities model, uniform time bands), work trips, Washington, D. C., 1948.

The calibration of this model in the PJ area involved a district rather than zonal analysis. This, in effect, restructured the grouping of opportunities by greatly increasing the number of intrazonal trips. To date a calibration at the zonal level has not been attempted at PJ. For purposes of the subject research it was felt that the model would have to prove operational at the zonal level to be of universal

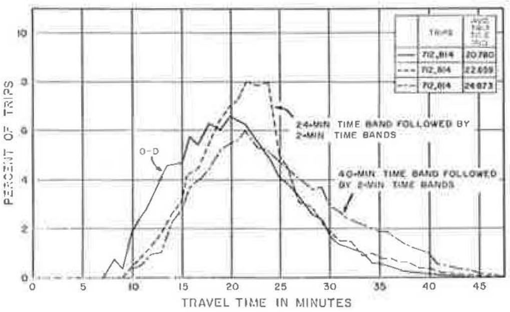

Figure 3. Comparison of trip length distribution (O-D vs competing opportunities model, variable time bands), work trips, Washington, D. C., 1948.

value. District analysis was not attempted as a part of the subject research. The only other difference from the PJ application involved the measure of spatial separation.

Because of the grossness of the measure, particularly with respect to the first opportunity band, where all trips in a ±20-min time band would be treated equally, the use of travel time rather than travel costs as the measure of spatial separation appears justified.

ANALYTICAL TESTS

The analytical tests, when viewed as a group, show not only measures of accuracy of the various procedures but also yield insight into the theoretical differences underlying the techniques. Do urban residents maintain a continuum of travel patterns over time modified only by the growth of the area as reflected in the Fratar procedure? Or, when considering making a trip, do they follow gravitational concepts weighting all attractors in direct proportion to the size of the attractors and in inverse proportion to the spatial separation as measured by the travel time between the zones? Or can travel patterns be best explained by opportunity concepts in the intervening opportunity model which assumes that people do not consider time directly, but rather consider opportunities in sequence by travel time and proceed on to any specific opportunity only after having considered and rejected all closer opportunities. Or does a person consider all opportunities in rather broad time or cost bands with all opportunities in a given band having an equal probability of acceptance as in the competing opportunity model.

One can be sure that people as social beings do not order their lives according to strict physical or mathematical laws and that no single model could ever be expected perfectly to match reality. However, one should expect that certain "theories" will be more explanative than others. With this in mind, the following tests should then be viewed in several lights. Is the particular procedure rational? Is the application simple enough that the procedure may be applied by urban planning studies lacking the experience in the procedure gained by research or earlier applications? Does the specific procedure fit the urban area to be studied; for example, are there local conditions such as relatively slow or rapid growth, inherent socioeconomic trip linkages, and large analysis units that might make one or more of the procedures more applicable?

Certain underlying differences in the procedures might best be described at this time. One of the most relevant differences is the weight placed on the role of travel time as an influence on trip distribution.

The Fratar procedures expand the existing travel patterns by considering growth in each portion of the study area without any specific consideration of the transportation network. If changes in the travel time between zones are sufficient to bring about change in travel patterns in the forecast year, the Fratar or any other growth factor technique would not reflect this.

However, each of the interarea travel formulas considered (gravity, intervening opportunity, and competing opportunity) uses time separation as a key variable. Thus, changes in the transportation system and the concomitant changes in accessibility between certain portions of the study area are directly reflected in the models.

The gravity model uses a travel time factor for each 1-min increment and, therefore, makes the most explicit use of absolute travel time of any of the procedures. These travel time factors are adjusted in the calibration process until there is close agreement between the estimated trip length frequency curve and the actual curve at all increments of travel time. These factors, or relative weights of making trips of certain lengths, are then assumed to remain constant over the forecast period.

In contrast to the gravity model, the intervening opportunities model does not make such explicit use of absolute travel time. Travel time is used instead to rank all possible destination zones from a particular origin zone. This ranking then is used to determine the number of intervening opportunities, i.e., the number of destinations already considered before a particular destination zone is considered. Changes in the transportation system and accessibility between zones over the forecast period are thus reflected in the forecasting model. Two probability factors generally described as the long and short L values are used in conjunction with the intervening opportunities model to determine trip interchanges between zone pairs.

The procedure of ranking used in the intervening opportunity model does bring about certain situations unique to this model. Consider a small community on the fringe of the study area 5-min distance from the nearest developed area. From zones in the center of the study area, the intervening opportunity model would consider all opportunities in this fringe community immediately after considering the opportunities in the nearest developed area. In effect, the 5-min separation would be ignored. The gravity model would have considered the 5 min and thus decreased the possibility of a trip crossing the gap.

The competing opportunity model is somewhat unique, approaching the gravity model if small time bands are used and tending to ignore spatial separation when large time bands are used.

In evaluating and comparing the results of the following tests, consideration should be given to the formulation and parameter makeup of each of the procedures. The amount of the actual O-D data used for the base calibration and the number of parameters requiring forecasting are important in weighing the results of one model against others. The Fratar procedure uses all of the base year travel data from the home interview survey. The travel models, however, all require less O-D data than the Fratar. However, the amount of data used and the number of parameters used to represent these data vary to a considerable degree between the travel models tested.

Trip Length Frequency Comparison

Base Year.—Comparisons of the final calibrated model trip length frequency curves to actual trip length frequency curves for the gravity model, the intervening opportunities model, and the competing opportunities model are given in Figures 4 through 6. Each of these plots is shown on a slightly different basis due to the manner in which the research was carried out. However, each is compatible with the survey data with which it is compared.

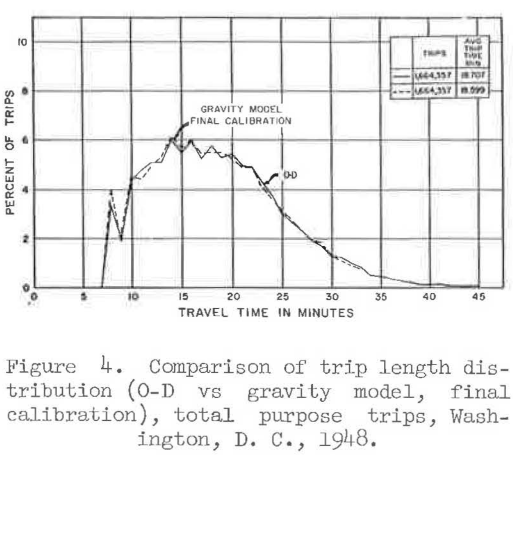

Figure 4. Comparison of trip length distribution (O-D vs gravity model, final calibration), total purpose trips, Washington, D. C., 1948.

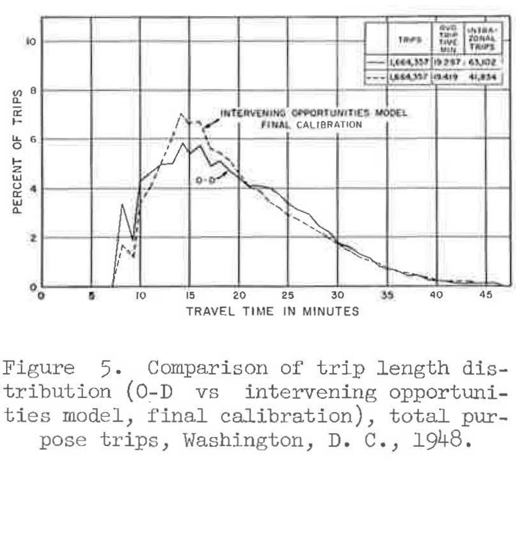

Figure 5. Comparison of trip length distribution (O-D vs intervening opportunities model, final calibration), total purpose trips, Washington, D. C., 1948.

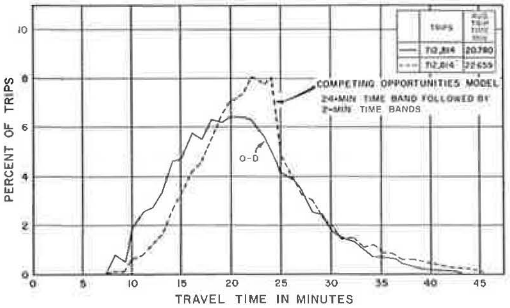

Figure 6. Comparison of trip length distribution (O-D vs competing opportunities model, best calibration), work trips, Washington, D. C., 1948.

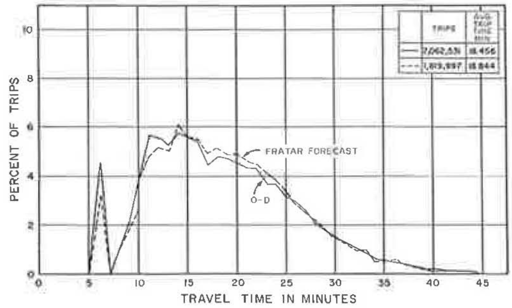

Figure 7. Comparison of trip length distribution (O-D vs Fratar forecast, total trips), Washington, D. C., 1955.

The curves in Figure 6 for the competing opportunities model are for work trips only. Due to calibration problems, a full analysis of this procedure could not be made. The information in Figure 6 was selected as the best calibration achieved with this procedure.

As expected, due to the refined degree of adjustment during the calibration phase, the gravity model shows the best agreement through most portions of the trip length frequency curves. Both the gravity and intervening opportunities models show good duplication of the total hours of travel in that both models agree with the appropriate average trip length.

Even though the two curves in Figure 6 for the competing opportunity model show some agreement, no rational method could be found to adjust toward a more satisfactory model.

Forecast Year. —The trip length frequency curves from the travel patterns as estimated by each of the procedures are compared to the appropriate O-D information in Figures 7 through 9. No forecast was made for the competing opportunities model and, therefore, no information is included for this model.

The Fratar procedures provided a good duplication of average trip length for 1955 as shown in Figure 7, even though approximately 195,000 trips out of the total available of 2,012,947 trips were not distributed because of zero trip ends for certain purposes in particular zones in 1948. The average trip length of the expanded patterns for 1955 of 18.8 min compares favorably with that of 18.5 min from the surveyed information.

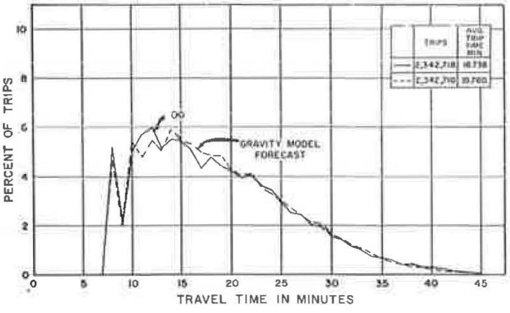

Figure 8. Comparison of trip length distribution (O-D vs gravity model forecast), total purpose trips, Washington, D. C., 1955.

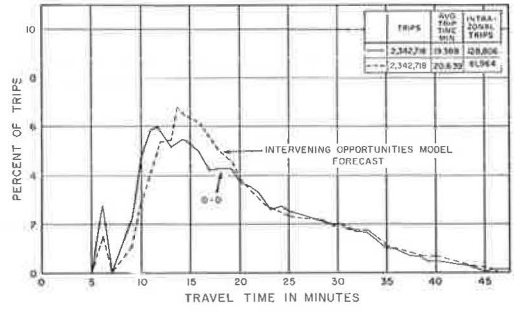

Figure 9. Comparison of trip length distribution (O-D vs intervening opportunities model forecast), total purpose trips, Washington, D. C., 1955.

Travel patterns forecast with the gravity model also provide an extremely good duplication of the average trip length as well as close agreement with the trip length frequency curve as shown in Figure 8. The average travel time for the forecast gravity model results of 18.8 min compares quite well with 18.7 min for the surveyed data.

The intervening opportunities model forecast is shown in Figure 9. The average travel time (driving time plus terminal times) of 20.6 compares with the actual of 19.4. These figures include the use of a river impedance.

River Crossings

The tests of estimated river crossings made on the various model results were developed because definite bias in the simulated trip distributions of two of the models became apparent during the calibration of the models. Both the gravity model and the intervening opportunities model required the use of time penalties on the Potomac River in the base year and in the forecast year. Different impedances were required for the two models. The gravity model research was completed first and procedures to forecast these time penalties were developed at that time. These procedures, when applied during the intervening opportunities research, reduced the error substantially in the forecast year, but not completely. The penalties required in the gravity and intervening opportunities models were different and the fact that different methods were required to forecast the time penalties is likely related to the different manner in which time is used by each. Of course, the effect of the impedance to free travel in the form of the Potomac River bridges was present in the 1948 surveyed trip crossings which were expanded to 1955 by the Fratar procedures. Table 2 gives the relative accuracies of river crossing estimates for the Potomac and Anacostia Rivers for each of the models for both the calibration and forecasting phases. The effect of the use of time impedances for the gravity and intervening opportunities model is included.

Movements by Corridor to and from CBD

This test was developed to isolate any geographical bias present in model results. The incorporation and need for adjustment for geographical bias has been shown for the gravity model through the use of K factors. No such adjustments were found to be necessary in the Fratar or intervening opportunity procedures. Tables 3 and 4 give information relating the estimated patterns to and from the CBD by corridor to the actual patterns from the O-D survey for 1948 and 1955, respectively. Factors to adjust for geographical bias have been used for the work trips to the CBD in the gravity model.

TABLE 2

COMPARISON OF TOTAL TRIPS CROSSING POTOMAC AND ANACOSTIA RIVERS (SURVEY VS MODEL) FOR THE VARIOUS DISTRIBUTION PROCEDURES, WASHINGTON, D. C.

Year	Data Source	Potomac River		Anacostia River	
		Total Trips[a]	Diff.[b] (%)	Total Trips[a]	Diff.[b] (%)
1948	O-D survey	196,255	N.A.	183,696	N.A.
	Gravity model	202,237	+ 3.05	184,188	+ 0.27
	Intervening opportunities	188,134	- 4.14	193,398	+ 5.28
1955	O-D survey	246,268	N.A.	287,452	N.A.
	Fratar[c]	279,055	+13.31	281,881	- 1.94
	Gravity model	230,949	- 6.22	296,830	+ 3.26
	Intervening opportunities	287,447	+16.72	318,269	+10.72

[a]In thousands.
[b]Survey data used as base.
[c]Adjusted to common O-D survey base.

TABLE 3

COMPARATIVE ANALYSIS OF CALIBRATION ACCURACY OF VARIOUS MATHEMATICAL MODELS IN DUPLICATING HOME INTERVIEW DATA, WASHINGTON, D. C., 1948

Movements Between Zero Sector and Sector No.	Survey Trips	Gravity Model[a]		Intervening Opportunities[b]	
		Trips	Diff. (%)	Trips	Diff. (%)
0	134,951	141,105	+4.56	142,595	+ 5.66
1	44,771	46,110	+2.99	45,407	+ 1.42
2	72,206	66,494	-7.91	59,710	-17.31
3	195,114	181,860	-6.79	184,815	- 5.28
4	93,542	92,027	1.62	94,923	+ 1.48
5	62,484	58,550	-6.30	64,999	+ 4.02
6	80,275	83,684	+4.25	91,174	+13.58
7	67,835	68,898	+1.57	58,299	-14.06
8	42,833	43,505	+1.57	36,297	-15.26
Total	794,011	782,233	-1.48	778,219	- 1.99

[a]Includes K factors.
[b]Does not include K factors.

TABLE 4

COMPARATIVE ANALYSIS OF FORECASTING ACCURACY OF VARIOUS MATHEMATICAL MODELS IN DUPLICATING HOME INTERVIEW DATA, WASHINGTON, D. C., 1955

Movements Between Zero Sector and Sector No.	Survey Trips	Gravity Model[a]		Intervening Opportunities[b]		Fratar		
		Trips	Diff. (%)	Trips	Diff. (%)	O-D Survey[c]	Trips	Diff. (%)
0	112,471	123,243	+ 9.58	119,613	+ 6.35	112,007	113,972	+ 1.75
1	52,391	53,830	+ 2.75	53,680	+ 2.46	52,213	47,485	- 9.06
2	100,710	87,896	-12.72	82,498	-18.08	88,865	79,388	-10.66
3	197,167	182,558	- 7.41	187,026	- 5.14	191,362	181,933	- 4.93
4	102,384	105,943	+ 3.48	108,668	+ 6.14	97,906	98,860	+ 0.97
5	64,788	62,019	- 4.27	70,485	+ 8.79	64,623	63,348	- 1.97
6	95,461	100,579	+ 5.36	107,037	+12.13	92,087	84,960	- 7.74
7	69,221	64,911	- 6.23	66,541	- 3.87	62,125	62,161	+ 0.06
8	57,847	54,652	- 5.52	53,258	- 7.93	51,154	49,653	- 2.93
Total	852,440	835,631	- 1.97	848,806	- 0.43	812,342	781,760	- 3.76

[a]Includes K factors.
[b]Does not include K factors.
[c]Contains information from 362 zones only as used in Fratar analysis.

Statistical Analysis of Assigned Trips

As a common measure of the accuracy of each of the model distributions, the total person trip output for the calibration and forecast runs of each model were assigned to a spider network and compared by link with the O-D survey assigned to the same network. All trips are defined as going from origin zone to destination zone. To achieve uniformity, the gravity model trips had to be redefined. Standard gravity model procedures were used to adjust the production to attraction trip tables to true origin to destination trip tables for directional assignments. To do this, a 50/50 split was assumed of all production to attraction zone-to-zone transfers to get back to true origin to destination tables. For example, in determining the number of trip productions and trip attractions in any zone, the home end of any home-based trip is always called the production and the nonhome end the attraction. All trips with the general purpose "work" would be considered as going from home to work, the work to home portions, in effect, being reversed. After the model simulates trips by this definition, again assuming work trips, all home-based trips are then converted to directional volumes by assuming 50 percent are from work to home trips and 50 percent are the reverse.

The comparisons are of directional link volumes assigned to a spider network, with differences recorded by volume group. Statistical analyses were made of these comparisons with the RMSE calculated for each model for each O-D volume group. The results of these analyses for the calibration or base year gravity and intervening opportunities models are shown in Figure 10. This figure illustrates the accuracy attained in the final research 1948 calibrations. Each model output includes the river time penalties. The gravity model used K factors to adjust the work trips to the CBD.

Next, shown on Figure 11, are the comparisons of RMSE by volume group for the forecasted travel patterns for each of the models. The Fratar output is compared with O-D from only the 362 zones where compatability for 1948 and 1955 could be achieved.

The results indicate that the gravity model forecasts compare best with the O-D assignments in most volume groups up to 1,500 trips with the Fratar procedure and the intervening opportunity model showing slightly better accuracy in the very highest volume groups. River impedances were used with both the gravity and intervening opportunities models. However, the opportunities model could not be adjusted as closely as the gravity model to conform with actual river crossings.

The results of the Fratar as assigned and compared are biased in that there are 195,000 trips which the Fratar, through one cause or another, could not expand. It might be expected that the Fratar procedures would produce results which have increasing error as the forecast period lengthens and land-use changes increase in significance. But, even over such a relatively short time period as 7 years, the Fratar results are not significantly better than the model results.

SUMMARY AND ANALYSIS

An attempt was made to test on a common basis the four available procedures to distribute and forecast urban travel patterns. When dealing with large masses of data with a series of formulations requiring different definitions and calibration procedures, variations in the base conditions are bound to occur. These variations in the test conditions did not seriously detract from the analysis of the relative merits and weakness of each of the procedures.

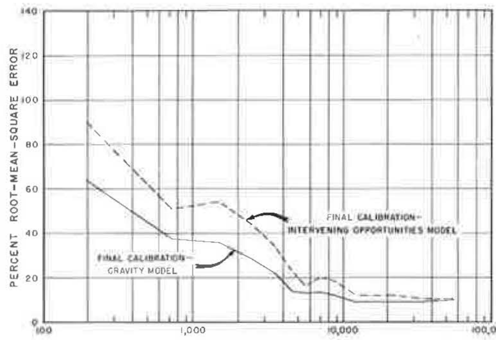

Figure 10. Comparison of RMSE (O-D vs model) by volume group, directionally assigned volumes on spider network, total purpose trips, Washington, D. C., 1948.

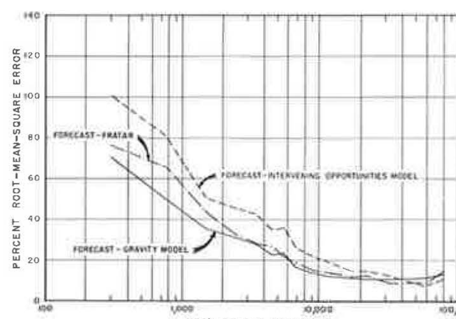

Figure 11. Comparison of RMSE (O-D vs model) by volume group, directionally assigned volumes on spider network, total purpose trips, Washington, D. C., 1955.

Fratar

This procedure, requiring no calibration, performed essentially as expected. Six trip purposes—home, work, shop, social-recreation, school, and miscellaneous—were utilized. Over the 7-year period, the Fratar procedure demonstrated a high level of accuracy in all analytical tests. It was not, however, tested specifically in one most critical area—the correct expansion of trips from zones changing from essentially undeveloped rural land uses to full urban development. Most zones in this class had to be eliminated from the analysis because of incompatibility of 1948 and 1955 zone boundaries. The model by its nature does not require any type of adjustment due to the already built-in socioeconomic trip linkages in the travel patterns expanded. It was surprising, therefore, that the Fratar procedure was only moderately better in estimating trips to and from each of the eight sectors to the CBD than the gravity and intervening opportunity models. This particular test is the most sensitive indicator of socioeconomic bias.

The multipurpose Fratar, although having distinct advantages in the proper expansion of trips by purpose, also has certain drawbacks when compared with a single-purpose Fratar. By expanding the number of trip categories to six, the possibility of zero volumes in the trip tables increases as the square of the number of trip categories. In the Washington area, 242, 000 trips were "lost" in the expansion because for certain zones and trip categories no trips were made in 1948, but in 1955 in the same zones and for the same trip purposes 242, 000 trips were made. This amounted to over 10 percent of the 1955 trips. Had it been possible to include all fringe area zones in the analysis, the problem would have been much more serious. Again, the most serious problems are in the urban fringe areas where, for example, shopping centers and golf courses are developed on farm or vacant land. Correct trip distributions cannot be achieved in these instances unless base year trips are first synthesized for these areas with an interarea travel formula and then artificially superimposed on the base year travel pattern before the Fratar expansion.

Gravity Model

This model proved adequate in most respects. It is particularly strong in the calibration phases, that is, in having an orderly procedure allowing for fine adjustments in the travel time factors and the direct adjustment for socioeconomic or geographic bias. The travel time factors have been shown to be stable over the 7-year period.

One problem inherent in the procedure is the necessity found for socioeconomic adjustment factors. Thirty-four factors ranging from 2. 23 to 0. 29 were utilized. Developing relationships between these factors and characteristics of the districts of residence or attraction can present problems in forecasting these characteristics. In Washington, the factors used to adjust work trips to the CBD were highly correlated with the average incomes of the residence zones. Another problem is the forecast of "river impedances." These topographical impedances most likely related to historical deficiencies of capacity, including the complete lack of facilities, can be projected on the basis of present and projected volume-capacity ratios. River barriers are a problem in that they require a detailed, though not complex, analysis and because they relate to such a critical area in terms of the analysis of future transportation system needs.

Intervening Opportunity Model

This model, although not previously utilized operationally by the researchers, performed very well. Several methods of calibration were tried and after selection of the best procedures, the model was calibrated with little difficulty. No socioeconomic adjustment factors were necessary for Washington, D. C. —a very strong point in this model's favor.

The trip purposes are defined in such a manner that directional trips are maintained at all times. Fairly high river impedances were required and, as with the gravity model, their projection, although requiring detailed analysis, is straightforward. Even with the projected river impedance of 8 min, the 1955 model overestimated Potomac River crossings to a considerable extent. Examination of the results and the skim trees indicated that very little further improvement could have been made even with a higher impedance value.

One drawback to this model is the fact that the L values change with time. In this analysis, the change in L value was forecast as a function of the change in the number of trips. Refinement in methods of forecasting these L values will require refinements in methods to project future trip length. Such a projection was not attempted in the application reported here. Although considerable research is currently under way on trip length trends, they are presently the subject of much discussion. For example the Institute for Urban Studies at the University of Pennsylvania, in cooperation with the Urban Planning Division of the U.S. Bureau of Public Roads, has recently completed one research project and is currently undertaking a second on these trends.

An additional point for consideration is the fact that in the calibration phase, the intervening opportunity models for the individual trip purposes do not necessarily reproduce the trip length frequency characteristics of the corresponding O-D trips. When the individual purposes are summed to a total purpose, the trip length frequency characteristics are good because of compensating deviations in the individual trip purposes.

The explanation given for this situation is that the opportunity model does not consider trip purposes per se, but rather uses the survey trip purposes as a convenient way of grouping trip ends to apply individual L values. There may be problems when desiring to distribute trips by purpose, for example, when performing a modal split analysis. The L value derived to treat a single purpose would differ from the L value used if the trip purpose were to be combined with others to form a total trip distribution. In essence, the trip distributions by purpose are only meaningful when summed to a total trip purpose distribution.

Competing Opportunity Model

It was disappointing that this model could not be calibrated with the Washington, D.C., O-D data and on a zonal basis. Time bands of uniform width were not at all applicable, and no simple procedure could be derived for selecting nonuniform time bands. Many different combinations of time bands were tried before a set was obtained which even approached giving correct trip length characteristics.

When the various trial-and-error approaches of arriving at appropriate time bands proved futile, a theoretical approach to the problem was attempted. The required type of probability curve for selected Washington, D.C., zones was derived as a plot of the percent of trips remaining to be distributed vs the accumulated available opportunities. Working within the framework of the model, it was not possible to duplicate this probability curve derived from the selected zonal O-D data. Figure 12 illustrates the degree to which two different time band groupings approach the actual O-D probability groupings.

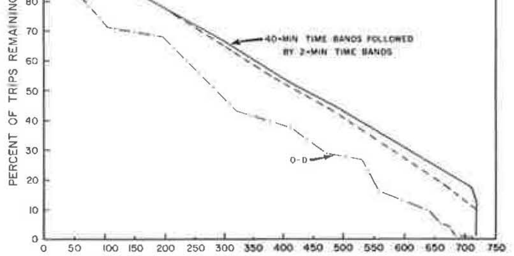

Figure 12. Distribution of 10,687 home-based work trips from zone 48, Washington, D.C., 1948, competing opportunities model.

SUMMARY

The overall accuracy of the gravity model proved to be slightly better than the accuracy of the intervening opportunity model in base year simulation and in forecasting ability. This fact must, however, be considered in light of the need for and use of socioeconomic adjustment factors in the gravity model for the work trip calibration. In effect, more parameters were used in the gravity model calibration.

With the use of these adjustment factors, the gravity model exhibited less error than the intervening opportunities model when trips by sector to the CBD were examined. However, the opportunity model was better than the unadjusted gravity model. It is not clear whether this is due to the conceptual basis of the models or to the trip purpose stratifications used.

Due to the fewer parameters used, the intervening opportunities model proved slightly less difficult to calibrate. However, adjustments necessary in future L values reduce this advantage in making the forecasts. Considering all factors, the gravity and intervening opportunity models proved of about equal reliability and utility.

The Fratar growth factor procedure demonstrated a good ability to expand trips correctly for stable areas but showed significant weaknesses in areas undergoing land-use changes. Even by eliminating zones of completely new growth from the O-D test data, approximately 10 percent of the total 1955 trips were lost through the expansion. This 10 percent amounted to a much more significant portion of the increase in trips between 1948 and 1955. The concentration of error in areas experiencing growth in trips points up the need for supplemental procedures to provide a base year synthesized trip pattern in such areas. The magnitude of this problem, when examined in the light of the favorable results attained with the gravity and intervening opportunity models, indicates that the use of a travel model provides a more direct and efficient approach to trip distribution for growing urban areas.

CONCLUSIONS

1. The gravity model and the intervening opportunity model proved of about equal reliability and utility in simulating the 1948 and 1955 trip distribution for Washington, D. C.

2. The Fratar growth factor procedure demonstrated a good ability to expand trips correctly for stable areas but showed significant weaknesses in areas undergoing land-use changes.

3. It was not possible to calibrate adequately the competing opportunities model for use in determining trip distributions between areas as small as the traffic zones used in Washington, D. C. Its use in exploratory work in the PJ study at the district level (groupings of zones) offered promise which this particular research study has not been able to reproduce in Washington, D. C.

FUTURE RESEARCH

Several areas for future research were uncovered when the models were analyzed on a common basis. The use of different trip purpose categories as input to the gravity model trip distribution procedure should be explored as a means of eliminating the socioeconomic adjustment factors. As a first attempt, a five-purpose true O-D purpose definition model consisting of (a) home to work trips, (b) work to home trips, (c) home to other trips, (d) other to home trips, and (e) nonhome-based trips should be tried.

Research is needed to develop more sophisticated procedures to adjust the base year L values to the future year for the intervening opportunities model. Certainly, better information on future trip length in terms of either miles or minutes would be very helpful in this regard. Also, some work is required to test the effect of the trip universe used on accuracy and the need to make adjustments to force all the trips to be sent. For instance, the inclusion or exclusion of the external trip ends creates a slightly different set of intervening opportunities for any given origin zone.

Additional research is also needed to examine the impedance effect of physical or topographical features on travel. More insight into basic causes of the impedance is essential to the development of comprehensive techniques for projecting the impedance.

The advantages of the purpose Fratar—that is, the more direct consideration of land-use changes—must be investigated in view of the resulting highly significant loss in expanded trips.

Finally, research is required to develop calibration procedures for the competing opportunities model.

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Discussion

DONALD E. CLEVELAND, Department of Civil Engineering, University of Virginia—The need for a comparative study of the relative and actual effectiveness of the principal techniques of trip distribution has been apparent for some time. Those who have had the opportunity to study this paper will generally agree that the topic is timely, the results are of interest, and the conclusions are justified from the study and useful to the profession.

Unfortunately, the authors were able to study only one city, but this city, Washington, D. C., experienced a growth not significantly different from that expected in the planning period in many cities. This makes their findings of particular interest.

Trip distribution models attempt to explain rationally the movement of persons from one place to another, a phenomenon that depends on sociological, psychological, and economic effects and interactions. It could be asserted that efforts to develop such a model are bound to be unsuccessful or lead to brittle formulations requiring complex manipulations to reproduce reasonable patterns. The pragmatic practitioner is interested in successful models. The techniques tested by the authors include those classed as successful. The detailed methods used are of interest to the skeptic.

What characteristics should a trip distribution model possess? It must first be remembered that trip distribution does not carry the entire burden in developing reasonable estimates of transportation network usage. However, trip distribution models should respond satisfactorily to the following types of changes characteristic of urban areas: (a) varying transportation networks, (b) changing locations and magnitudes of activities within the citywide framework, and (c) changing determinants of individual trip-making. It is believed that an effective trip distribution model should have a simple structure supported by a data management capability adequate to estimate the necessary constants or parameters. The parameters of a trip distribution model should be developable with a minimum amount of data, forecastable in the sense that future estimates of their values follow naturally from the studies and forecasting processes of urban transportation planning, reponsible in producing satisfactory results for known conditions, and minimal in the sense that effective models do not usually require elaborate parameter sets.

The authors have clearly described in some detail their steps in "calibrating" the models. Others faced with the calibrating task will benefit from studying the art as described in the paper. The careful reader may have questions concerning some of the procedures used and results obtained. It would be helpful to many if comments can be made on the following few questions occurring to the reader.

1. Does the Washington, D. C., metropolitan area itself have any characteristics that make it unusually good or poor as a study city for the comparison of trip distribution techniques? Has the long usage of this area in trip distribution research possibly biased the network characteristics? Would the authors speculate on the general validity of their conclusion regarding the relative effectiveness of the gravity and intervening opportunity models?
2. The Fratar technique cannot respond to the unbalanced improvement of access resulting from most transportation improvement programs. What results were obtained for stable areas where accessibility was improved?
3. The introduction of network impedances at river crossings is unsatisfying. Do the authors feel that the assignment of 24-hr person trips to an off-peak automobile travel time network could have contributed to the need for this additional impedance? How should the need for such adjustments be determined and how should this activity be incorporated in the formulation of the general model?
4. Do the authors believe that the differences among the models tested would have influenced a transportation facility planning decision?
5. Unsatisfactory trip length distributions were obtained in the calibration of the competing opportunities model. Could these results have cancelled out in the total person trip distribution as they apparently did to a lesser extent in the application of the intervening opportunities model?

As a further comment, innovations have been and are being made in the application of each of the models tested. Each of these changes resulted from the necessity to cope with unsatisfactory behavior of the parent model or a desire to strengthen the basis for utilization of the model. The Fratar technique has had reasonable and reproducible techniques developed to improve predictions to and from new areas. The intervening opportunity model as used has undergone changes at the Chicago and Pittsburgh studies. There are indications that the gravity model may become more flexible as significant trip-making determinants are more completely understood. The competing opportunity model may now respond better to varying city and analysis zone sizes based on a recently developed calibration procedure.

Where does the profession stand in the development of trip distribution models? There have been several generations of observe-formulate-predict-test and this activity continues. We know that we are doing better than we were 5 years ago. We may even be doing well enough. I have seen no analysis that tells us this. Relations among trip generation, distribution, and assignment should be sought. Meanwhile, sharpening existing models proceeds and efforts should be devoted to seeking the elusive and simple law which will describe this aspect of traffic behavior.

ROBERT S. VOGT, Vogt, Ivers and Associates, Cincinnati, Ohio—Any discussion of existing trip distribution procedures should consider the direction of current research and technology, the limitations of present techniques, and the need for additional technical capability in the future. After slightly more than a decade of concerted effort in the science of urban transportation planning, we can take some pride in the results which have been accomplished. However, there seems to be an air of finality about the trip distribution techniques in current use. Such confidence should be avoided.

In the paper under discussion, four procedures are described. The gravity model procedure as currently used places heavy weight on the structure of the present community, yet we are well aware that the same model parameters do not apply with equal reliability in all communities. The Fratar forecasting procedure relies so heavily on the existing structure that future development patterns seemingly can never be predicted without special techniques. Although the intervening opportunity model appears to account well for the changing structure of the community without overweighting the effect of the existing structure, it is evident that this model, too, does not properly nor consistently distribute trips between subareas. This inconsistency is particularly evident for trip patterns between the main urban mass and separate satellite communities in the region.

In the use of the gravity model procedures, there is a strong tendency to object to the iterative procedure of calculating the travel time factors ($F_{t_{i-j}}$). Admittedly, it assists in improving the calibration but it tends to say that the community in many respects is homogeneous insofar as trip distribution is concerned. To modify any lack of homogeneity which seems apparent to the analyst, K factors are applied, travel time barriers are added, and terminal times are varied. Although this can be done with some finesse with experience, the procedure lacks the identification of community functions and structure which define different urban areas. Why is it logical to use the same travel time factors for 1964 and 1990 if it is not logical to use the same travel time factors and terminal times in Cleveland as in Baltimore for the same or different projection years?

Actually, the urban area is a changing and diverse organism, subject to subregional variations which can only be determined by subregional analysis. If we consider the difference between the small community (less than 50,000 population) and the large metropolitan areas, it is evident that the same travel time factors do not apply. Why do we consider it logical to hold the travel time factors in the analysis of the larger communities through time?

A more realistic view is to develop interarea travel formulas which are sensitive to changing social value factors and, therefore, to the changing structure of the urban area. Using this philosophy it is assumed that trip end generation is a function of the characteristics and affluence of the population and may be specifically calculated, given specific data concerning those characteristics. (To a large extent this is current practice). Distribution then is assumed to be a function of the characteristics of people where those characteristics are based on evaluation and analysis of existing travel patterns. Essentially, this view theorizes that the gravity model distribution technique or the intervening opportunity distribution technique are only mathematical procedures, either of which may provide a significant distribution process. The important aspects of trip distribution which would be recognized in this procedure include the following:

1. Some trip patterns can be more accurately predicted than others;
2. Trips once distributed reduce the trip end total at both the origin and destination so that the attraction function in the gravity model formula is constantly reduced until all trips are distributed; and
3. Trip patterns can be related to community characteristics so that changes in characteristics over time can be the basis for estimating future trip patterns.

The difference between these suggested criteria and current practices is the belief that trip patterns between some areas are much more stable than between others; therefore, they are easier to predict with reliability and should be distributed first.

An additional variation is that the suggested criteria assume that the travel time factors vary from zone to zone and from one time period to another for a similar zone. Finally, it is assumed that these change statements are predictable. These conclusions are based on considerable study of the results of interarea trip distribution in a number of communities of different size.

Often it seems that the gravity model distribution procedure raises nearly as many questions as it answers. Following are a few of the more apparent.

1. Why does it take travel time barriers at major river crossings to calibrate the model? Are they reasonable inclusions in trip distribution procedures?
2. How do we know whether a travel time barrier is more realistic than K factors in the calibration of certain trip patterns?
3. To what extent are terminal times a realistic function of trip distribution and to what extent are they used only as a means of calibration?

As is well known, K factors reduce the attraction of the destination zones so that the trips from all zones where K factors are applied are reduced or increased by a factor equal to the K factor. The application of travel time barriers between the same zones has a different effect. Since the travel time barrier is uniformly applied to every trip transfer which crosses the barrier, the effect on trip distribution is related to the length of the trip and the travel time factors ($F_{t_{i-j}}$) which are applied. The resulting effect is to impede the shorter trips more drastically than the longer trips. Increases in terminal times are similar to the travel time barrier in that the shorter trips are impeded to a greater extent than the longer trips. Using the curves shown in Figure 2 of the paper, it is interesting to consider the changes in trip values which occur under certain logical changes in travel time barrier times, terminal times and K factors. The original data between zone pairs can be assumed to be the following (using the travel time factors for nonhome-based trips):

Zone$_{1-2}$—travel time 20 min, original transfer 100 trips;
Zone$_{1-3}$—travel time 10 min, original transfer 100 trips;
Using K-5, the transfers become T_{1-2} = 50 trips, T_{1-3} = 50 trips;
Using travel time barrier of 5 min, $T_{1-2} = 100 \times 0.9/2.0 = 45.0$ trips, $T_{1-3} = 100 \times 6.0/17.5 = 34.4$ trips; and
Using travel time barrier of 10 min, $T_{1-2} = 100 \times 0.48/2.0 = 24.0$ trips, $T_{1-3} = 100 \times 2.0/17.5 = 11.4$ trips.

The number of trips computed is not important since that computation depends on the number of transfers so affected. The important consideration is the relative proportion of trips distributed in each case. Thus, in the gravity model development, numerous modifiers have varying effects on the final distribution. Until we clearly define how these modifiers should be applied, we do not have a "mature" procedure. Can we really reason with assurance that the adjustments are consistent? Can we justify their application to large blocks of zonal interchanges, as is current practice?

If this discussion has seemed critical, it is not meant to be. We have been consistent users of the gravity model and have used the results as the basis for many design recommendations. Although our concerns are based on the previous discussion, our confidence in the current procedure also has some factual basis. In Dayton, in 1957, a postcard O-D survey was synthesized by first accepting the trip ends from the survey and then distributing the trips between zone pairs using the gravity model. Purposes were established as follows:

Purpose 1—all trips with origin or destination in the CBD;
Purpose 2—all trips with an origin or destination in home zone; and
Purpose 3—all trips with neither origin nor destination in home zone.

Even with these minimum purpose descriptions and an exponential function ($x = 0.6$ for purpose 1, $x = 2.0$ for purpose 2, and $x = 2.2$ for purpose 3), a comparison of assignments gave the following results by volume groups:

Volume (2-999)—mean O-D volume (430), RMS (310);
Volume (1,000-1,999)—mean O-D volume (1,460), RMS (615);
Volume (2,000-3,999)—mean O-D volume (2,900), RMS (700);
Volume (4,000-5,999)—mean O-D volume (4,840), RMS (1,000); and
Volume (6,000-7,999)—mean O-D volume (6,880), RMS (1,250).

Since this model fit (Fig. 13) is at least equal to that shown in Figure 11 of the paper with considerably fewer purpose categories, one is inclined to question the need for the greater detail.

In Muncie, Ind., a basic external cordon survey with screenline interviewing (1957) was synthesized except that trip production by purpose (four purposes developed) was computed as the input to the gravity model. Purposes were established as follows on an O-D rather than production-attraction basis:

Purpose 1—total home-based auto trip ends with "work" as a purpose;
Purpose 2—total of all other home-based auto trip ends;
Purpose 3—total of all other nonhome-based auto trip ends; and
Purpose 4—total of commercial trip ends.

Again, with these minimum purpose descriptions and an exponential function (x = 2.5 purpose 1, x = 2.5 for purpose 2, x = 1.8 for purpose 3, and x = 2.0 for purpose 4), a comparison of assignments gave the following results by volume groups:

Volume (2-199)—mean O-D volume (88), RMS (88);
Volume (200-399)—mean O-D volume (282), RMS (142);
Volume (400-599)—mean O-D volume (500), RMS (186);
Volume (600-799)—mean O-D volume (707), RMS (155);
Volume (800-999)—mean O-D volume (908), RMS (265);

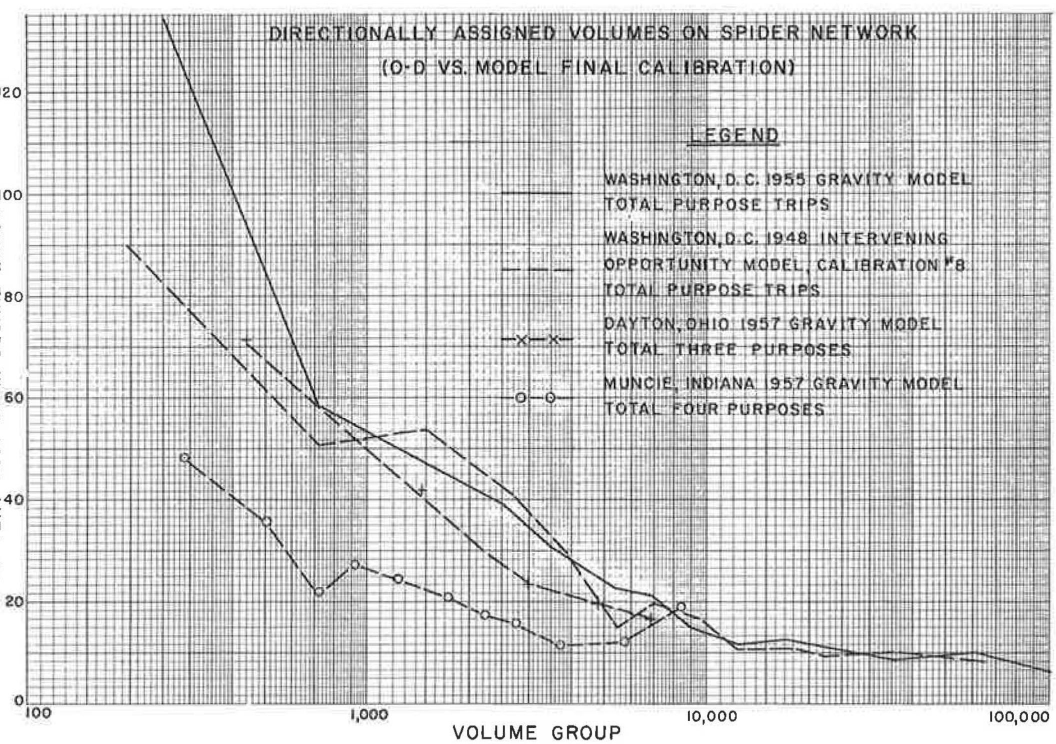

Figure 13. Comparison of root-mean-square error by volume groups.

Volume (1,000-1,499)—mean O-D volume (1,223), RMS (325);
Volume (1,500-1,999)—mean O-D volume (1,753), RMS (363);
Volume (2,000-2,499)—mean O-D volume (2,241), RMS (376);
Volume (2,500-2,999)—mean O-D volume (2,745), RMS (450);
Volume (3,000-4,999)—mean O-D volume (3,712), RMS (460);
Volume (5,000-6,999)—mean O-D volume (5,768), RMS (765); and
Volume (7,000-8,999)—mean O-D volume (8,171), RMS (1,560).

The results are again considerably better than those reflected in Figure 11, although in this case it must be noted that a small percentage (20 percent) of the total trips in the O-D values were synthesized to provide a complete trip matrix. The O-D survey procedure did not provide this information directly from the survey data.

To carry this discussion one step further, the same O-D survey was synthesized using a one-purpose model which was the sum of all purposes previously described. An exponential function (x = 2.5) was used. A comparison of assignments gave the following results by volume groups:

Volume (2-199)—mean O-D volume (88), RMS (78);
Volume (200-399)—mean O-D volume (282), RMS (118);
Volume (400-599)—mean O-D volume (500), RMS (169);
Volume (600-799)—mean O-D volume (707), RMS (148);
Volume (800-999)—mean O-D volume (908), RMS (242);
Volume (1,000-1,499)—mean O-D volume (1,223), RMS (305);
Volume (1,500-1,999)—mean O-D volume (1,753), RMS (354);
Volume (2,000-2,499)—mean O-D volume (2,241), RMS (354);
Volume (2,500-2,999)—mean O-D volume (2,745), RMS (422);
Volume (3,000-4,999)—mean O-D volume (3,712), RMS (438);
Volume (5,000-6,999)—mean O-D volume (5,768), RMS (874); and
Volume (7,000-8,999)—mean O-D volume (8,171), RMS (1,770).

Although these results are not quite as good as with the four-purpose model, the difference is so slight as to raise questions concerning the need for the additional detail.

The purpose of interarea travel formulas is to provide procedures which predict future travel. The fact that these methods will reproduce an existing O-D survey is only a first step in the process. Since our ability to reproduce the present is only fair and to produce the future is worse, more study of the many varied aspects of trip distribution is necessary.

G. E. BROKKE, Research Assistant, Urban Planning Division, U.S. Bureau of Public Roads—The task accomplished by the authors is one of considerable magnitude. Although it may appear that the data were fed into a computer and the results poured forth, there were, in reality, several dozen programs involved. Each of them has the possibility of introducing spurious results, and the constant checking and evaluations to guard against this eventually might have discouraged less tenacious and understanding authors.

The tests of the models are certainly objective and, in my opinion, the authors are equally objective. Yet there remain various acts of loving kindness and tender care that are perhaps somewhat unequally divided. For example, considerable experimentation was conducted to select appropriate "river barrier" factors and a set of 34 K factors ranging in value from 2.23 to 0.23 for the gravity model. Similar techniques were not tried with the Fratar or Chicago model, although in the case of the Fratar, it has been shown that the majority of the "lost" trips can be accommodated by aggregating zones into districts to obtain the interchange potential. To some extent this uneven care is probably due to the ability of the gravity model to accommodate hindsight and perhaps also to the deep understanding of the authors in the use of the gravity model.

The paper correctly states that the Fratar procedure is consistently low in the accumulation of trips on the spiderweb network. However, the discrepancy is not as large as might be supposed, as shown in Figure 14. The lower dashed line indicates the average error in each of the several traffic volume groups for the Fratar method, and the solid line indicates the average error for the gravity model. As a matter of fact, the consistency of the Fratar in underestimating is very close to the 10 percent mentioned in the paper. If the "lost" trips had been apportioned to the network in accordance with the assigned volumes, the results of the Fratar would have been measurably improved.

On the same graph, the average error in assigning present trips to the present system is shown for each of the several volume groups in Salt Lake City, Utah. It would have been preferable to show the data from Washington, D. C., but the necessary count and capacity information were not available. Coincidently or otherwise, it happens that the number of directional links in the spiderweb for Washington, D. C., is very nearly equal to the number of two-way highway links in the Salt Lake City network for all traffic volume groups up to about 17, 500 veh/day. Above this volume there are more links in the Washington, D. C., network.

Because it will be significant at a later stage, it should be noted that both the gravity model and the assignment process are high, up to about 15, 000 veh/day, whereas the Fratar method is low over this entire range. In addition, the assignment and both distribution procedures are significantly low in the 20, 000 to 25, 000 range.

It seems worthwhile to inquire into the relative accuracy of the assignment and distribution processes and, inasmuch as these are independent occurrences, combine the error of the two events. Figure 15 shows the error in the various procedures. In general, it shows that the error in using either the gravity model or the Fratar method is roughly half the error of assignment.

In addition, the figure shows that the addition of the error in the forecasting distribution by either method is hardly noticeable except at the higher traffic volume ranges.

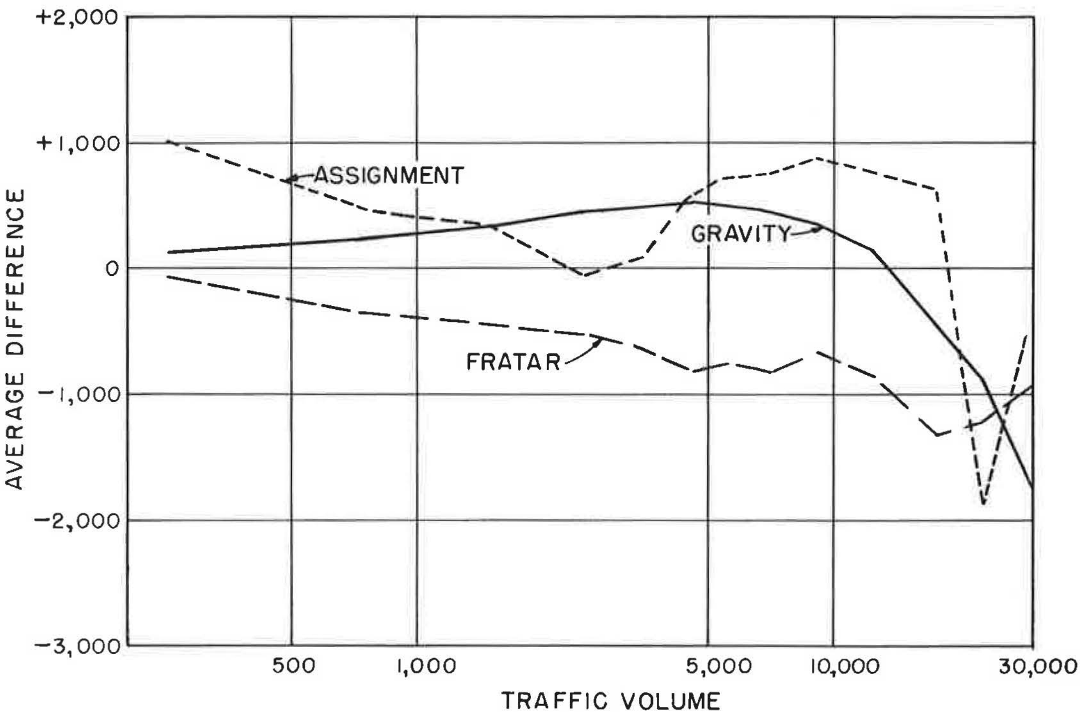

Figure 14. Average error in assignment and forecasting.

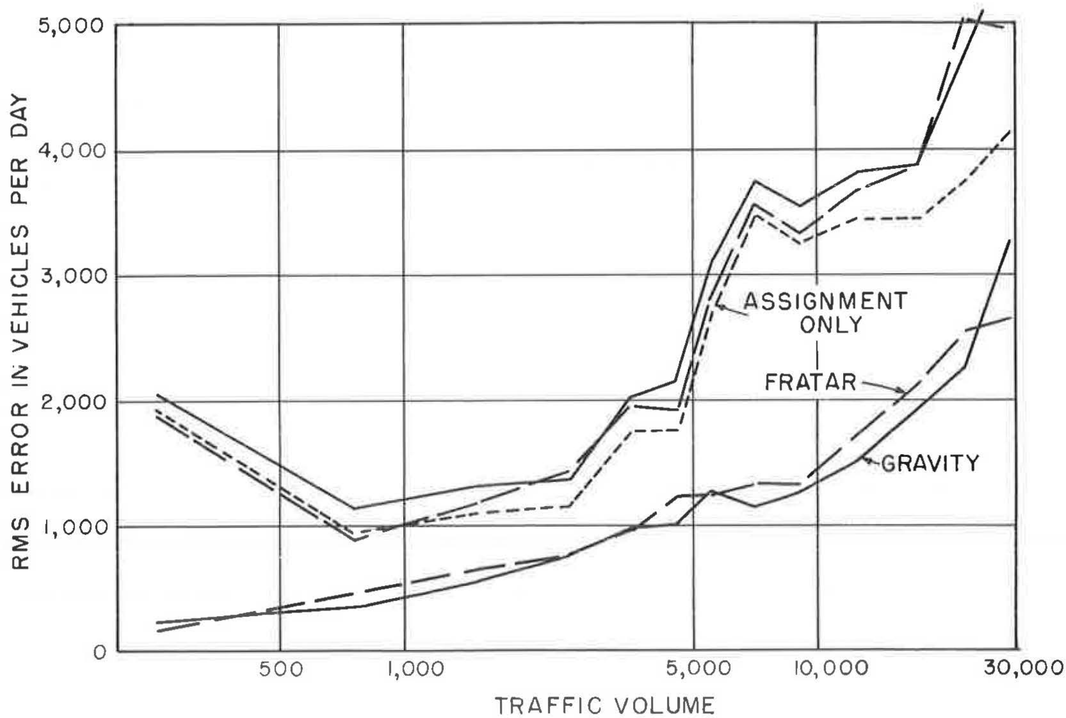

Figure 15. RMS errors in assignment and forecasting.

The procedure used in adding the errors for the two events of forecasting and assignment was to take the square root of the sum of the squares of the standard deviation and adjust this error to the average of the mean of the two events. As may be recalled, the average error for the Fratar method was consistently low for the entire range of traffic volumes. Both the gravity model and the assignment are high in the volume ranges up to about 15, 000 veh/day, and all methods are consistently low in the volume ranges above 20, 000 veh/day. This feature explains some of the anomalies of the graph. For example, the gravity model is slightly better than the Fratar method when viewed alone but slightly worse when viewed in combination with assignment. The consistently low mean volumes above 20, 000 veh/day also explain, at least to some extent, the rather sharp rise in the RMS error above 20, 000 veh/day.

As previously stated, these tests represent two cities of the more than 200 cities in the United States having populations over 50, 000. The assignments were made to an existing network in a city of about ⅓ million population and the test of the distribution procedures to a spiderweb network in a city of about 1. 8 million population. At this point in time, it is rather difficult to establish which characteristics of the procedures are inherent properties and which are accidental occurrences.

Yet I believe at least a tentative set of conclusions can be reached. It seems likely that the gravity model, the Fratar method, or the Chicago method could be used as a trip distribution procedure without inordinately affecting the error in the assignment procedures. I think we can also safely assume that, insofar as these two processes are concerned, improvement in the end product is primarily concerned with increasing the accuracy of the assignment procedure.

Is there any likelihood of this occurring? I think there is. At the moment the assignment procedures are capable of adding refinements but are "bogged down" by our inability to find in one place such prosaic items as a highly accurate O-D survey, a comprehensive transportation network, reliable traffic counts by direction and by peak hours on most of the network, and reliable capacity values on practically the entire arterial and freeway network.

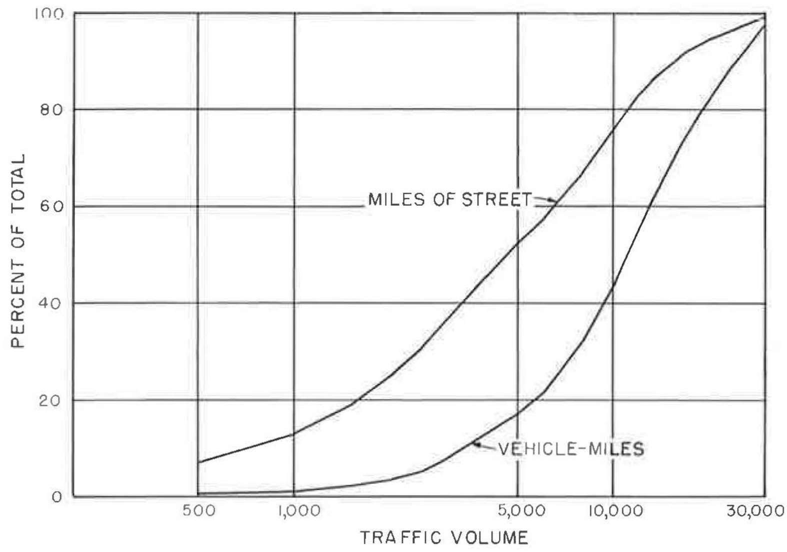

Figure 16. Distribution of street-miles and vehicle-miles in Salt Lake City, Utah.

With these errors such as they are, where does this leave us? Figure 16 indicates the composition of the street system in Salt Lake City. The top line indicates the cumulative percentage of miles of streets by increasing traffic volume groups. The lower line indicates the cumulative percentage of vehicle-miles on these same links. Thus, the highway administrator will have a tendency to feel that he has done an adequate job on a majority of the highway networks, but the public with its much greater probability of using the heavy volume links will have a tendency to be more critical of the mistakes on the heavily loaded links. For example, half the street-miles consist of links with less than 4,600 veh/day, but half the vehicle-miles are traveled on links with more than 11,000 veh/day.

It might be noted that between Figures 15 and 16 we have the elements we need to compute the probability of over- or underdesigning at any increments we might choose. This, however, is clearly beyond the scope of this discussion.

There are two major sources of error in forecasting traffic that have not yet been mentioned. One is the trip generation and attraction rates for various types of land uses and socioeconomic factors. This is receiving intensive study at the present time, and results should be available within a year. The second is the forecasting of the distribution of land use and the associated socioeconomic characteristics. The evaluation of this field is yet largely untouched. The principal problem is the lack of standardization of the factors that require forecasting. The view in this field is not particularly promising.

In summary, therefore, the distribution process by any of the models reported seems satisfactory. The error when combined with that of assignment is substantial, but the results are useful. It must be remembered that today's results are about twice as accurate as those of 3 years ago and perhaps more than 4 or 5 times as accurate as those of 10 years ago.

ROBERT T. HOWE, Associate Professor of Civil Engineering, University of Cincinnati—The authors have made a major contribution to the art of transportation planning by laying bare the limitations of several popular methods of trip forecasting. This commentator believes that certain further limitations of these methods are implicit in the report and wishes to bring these to the surface for discussion.

In the section on study procedures, the statement is made: "In addition, they [the 1965 characteristics] were used directly as producing and attracting powers of the zones when calculating the synthetic distributions with the interarea travel formulas." This evidently means that for work trips, for example, the number of trips originating in a zone was taken to be 20 times the auto and transit work trips found in the 1948 O-D survey and 33⅓ times those found in the 1955 survey without considering the actual number of workers living in that zone. Even more important, it would seem that no check was made to compare the expanded number of work trip destinations in a zone with the actual number of jobs available in that zone. Without such checks it is conceivable that the travel models actually produced more valid results than did the O-D surveys against which they were "calibrated."

The authors introduce a discussion of analytical tests with a series of speculations on how individual persons may decide on their trip patterns; they conclude that "people as social beings do not order their lives according to strict physical or mathematical laws.... However,... certain 'theories' will be more explanative than others." This commentator has previously pointed out that there are three elemental types of trips and each type satisfies certain conditions which the other two types do not satisfy: (a) the type in which a certain number of trips must originate in each zone at the same time a certain number must be destined for each zone, e.g., work trips; (b) the type in which a certain number of trips must originate in each zone but no exact number need be destined for any zone, e.g., shopping trips; and (c) the type in which no trips must originate in any particular zone and yet a definite number of trips do indeed end in a particular zone, e.g., recreation trips (13). It would seem that only those theories which take into account these three types of trip patterns can have any hope of being "more explanative than others."

The authors then pose the following criterion for a satisfactory theory: "Is the application simple enough that the procedure may be applied by urban planning studies lacking the experience in the procedure gained by research or earlier applications?" It would seem that the authors' applications of the four techniques tested in Washington, D.C., indicate that no one of the four can produce a positive answer to this question since the coefficients for the same city over a span of a mere 7 years had to be adjusted to give, in effect, post facto predictions. Another way of stating this would be to ask: how constant are the constants in the gravity model and the intervening opportunities model?

When giving the basic tests to evaluate distribution models, the authors state, "However, in the case of the other travel formulas, some validation was accomplished against base conditions. Such validation is an essential part of calibrating the models before moving to projections." If only some validation can be accomplished despite the fact that such validation is essential, there would appear to be a factor of safety of less than 1 in forecasting with these models.

Fratar Method

The authors' summary of the Fratar method—i.e., "The Fratar growth factor procedure demonstrated a good ability to expand trips correctly for stable areas but showed significant weaknesses in areas undergoing land-use changes"—should sound the death knell for this technique. A fundamental weakness of this method, over and above its inability to deal with formerly undeveloped areas, is the fact that movements between two zones may increase because of more direct means of transportation without any real change in the size of the "attraction."

Gravity Model

This commentator has a great deal of difficulty in following the authors' use of the gravity model. In the first place, he cannot determine how many of the variables in the equation are "fixed" and how many are subject to "adjustment." The travel time, F_{ij}, from one zone to another would appear to be known for the base year and hypothesized for the forecast year, and yet this seeming "constant" was evidently juggled to account for "river impedance." Under analytical tests, it is stated that the gravity model "makes the most explicit use of absolute travel time of any of the procedures" but there is no indication of how this travel time is found for the future. At one point, K_{ij} is defined as a "specific zone-to-zone adjustment factor to allow for the incorporation of the effect on travel patterns of defined social or economic linkages not otherwise accounted for in the gravity model formulation." Nowhere can this commentator find how these social or economic linkages are defined. In the discussion of movement by corridor to and from the CBD, the statement is made that "The incorporation and need for adjustment for geographical bias has been shown for the gravity model through the use of K factors." It is evident that different values of K_{ij} for any given movement from i to j were needed in 1948 and in 1955, but there appears to be some intimation that a given K_{ij} may have been varied for the several "checks," i.e., river crossings, corridors, etc. If K is chosen on the basis of defined conditions, why must it be changed so much?

In the statistical analysis of assigned trips, the statement is made that "Standard gravity model procedures were used to adjust the production to attraction trip tables to true origin to destination trip tables for directional assignments." To one who is not familiar with these "standard procedures" it is not clear whether adjustments are made to the time factors, or to the K's, or to both. But again, if there are known travel times and defined social and economic conditions, how can these be "adjusted"? In the summary and analysis the authors acknowledge that "Developing relationships between these factors and characteristics...can present problems," but they offer no suggestions for resolving these problems in an area which has never before been "fitted" for a gravity model—and, indeed, they indicate that they could not "fit" the same model to the same city in two different years. In addition, it is startling to inspect Table 1 and find that as the travel time increases from 8 to 10 min, the travel time factors are cut in half!

Intervening Opportunities Model

This section of the paper should really be read together with Mr. Pyers' "Evaluation of The Intervening Opportunities Trip Distribution Model" (12), but the paper presently under discussion raises some serious questions about the method.

In the explanation of the terms of the basic equation, L is said to be "an empirically derived function describing the rate of trip decay with increasing trip destinations and increasing length of trip." The authors further state that "This model is calibrated by varying the probability values until the simulated trip distribution reproduces the person-hours of travel and percent intrazonal trips of the surveyed trip distribution." No indication is given, however, as to how "length of trip" is found. Does it include mass transit trips? Does it include walking to and waiting for mass transit? Do the intrazonal trips include walking trips? Are trips simulated by purpose, or all trips combined?

As with the gravity model above, the authors found it necessary to "adjust" the river impedance from a 1948 value to a 1955 value to improve the fit. How can such post facto adjustments be considered valid? If the impedance value for 1948 was 5 min and that for 1955 was 8 min, will the value for 1969 be a linear projection of this change with a value of $8 + 3 + 3 = 14$ min or a geometric projection with a value of $8 \times 1.6 \times 1.6 = 20.5$ min?

In the checks of the gravity model and intervening opportunity model shown in Figures 8 and 9, it is most interesting to note that the Washington area has so few trips of 9-min duration. It is even more interesting to note that the O-D curve in Figure 8 is quite different from that in Figure 9. Could one curve actually be from 1948 and the other from 1955?

In the summary and analysis, the statement is made that "In this analysis the change in L value was forecast as a function of the change in the number of trips." But if the purpose of travel pattern models is to predict changes in trip patterns, and L which "predicts" these trips while being dependent on them would seem to be intolerable!

Conclusions

In proposing future research, the authors indicate that the gravity model might better be calibrated by trip purpose. Since this paper reports on trip stratification used with the Fratar method, and since Mr. Pyers' companion paper mentions stratifying the intervening opportunities model, why was the gravity model not stratified herein if such a step might be expected to improve the results or to stabilize the K value?

Other calls for further research really appear to be admissions that the techniques used could not be juggled to give reasonable predictions even when using post facto "constants." As Colen Clark and G. H. Peters have said: "It may be said in conclusion that the principle of 'intervening opportunities' appears to be an important step forward in our knowledge relating to travel habits. At the very least it must further undermine our faith in the effects of distance, and it must surely force us to recast our thinking concerning the potential usefulness of gravity models" (14).

What is needed is research into a technique not tied to time or city, but only to land-use patterns and, perhaps, key points in a transportation system. This commentator believes that the electrostatic field theory (13, 15, 16, 17), which is tied only to land use and certain a priori assumptions now merits more thorough testing than it has yet been given.

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KEVIN E. HEANUE and CLYDE E. PYERS, Closure—Dr. Cleveland, in addition to placing this research in perspective, has raised several questions aimed at providing the reader with additional insight into travel model development. Comments directed at his specific questions are as follows:

1. Washington, D.C., was not selected because it was an "ideal" city on which to base this research but rather because of data availability. It does, however, have certain characteristics which make it somewhat appropriate, namely, significant population growth, large increases in car ownership, and decentralization of many retail and business functions. This last factor is particularly appropriate to the analysis of travel patterns over time.

No attempt is made to claim "general validity" for the study findings. We would not, however, hesitate to apply the general findings when selecting a travel model for use in other urban areas. At the same time, we urge other researchers to undertake similar analyses in other cities, hopefully using data for a longer period of time.

2. There were not sufficient data to relate the Fratar forecast accuracy to changes in accessibility. It would be most interesting to analyze the performance of each of the procedures in geographic locations where accessibility varied significantly between 1948 and 1955. Unfortunately, this would be difficult in that part of the study area

where actual trips had to be eliminated from the Fratar tests. Most of the zones eliminated were in the areas with the greatest changes in accessibility.

3. Network impedances, particularly their forecast, are among the weakest phases of urban trip distribution model work. Certainly the variance between 24 hr and peak hour travel time is a major contributing factor. A more difficult part of this so-called "impedance" is the portion due to historical bias against making a trip involving a river crossing. This type of bias has been noted in most all urban areas with river crossings. Improvement in accessibility modifies this factor, but not enough so that a bridge crossing link can be treated as any other link in the system. We offer no improvements to the present methodology based on a trial-and-error approach, but again state that the present methodology, though lacking computational elegance, does do the job in a straightforward manner.

4. The question of whether the authors believed that the differences among the models tested would have influenced a transportation facility planning decision is most difficult to answer. The Fratar procedure certainly has inherent weakness that could cause serious underestimates of trips in areas undergoing land-use changes. Most analysts undertake steps to overcome this weakness. These modifications or adjustments were not tested in the subject research.

Analysts should gain insight into tendencies for the gravity or intervening opportunities models to over- or underestimate trips in given portions of the study area during the calibration phase. Hopefully, such insight applied during the systems analysis would result in essentially the same system, irrespective of which of these two models were used.

5. The unsatisfactory trip length distributions obtained in the calibration of the competing opportunities model were too significant to have canceled out in the total person trip distribution. When using small time bands, the trip length curves were not even similar; when broader time bands were used, the trip length curves, though attaining the characteristic trip length frequency curve shape, were significantly offset from the comparable O-D survey data curves.

Mr. Vogt has contributed the background of one who has had practical experience in the use of gravity models. We share his uneasiness over the necessity to assume that travel time factors remain constant through time and to apply river impedances and socioeconomic adjustment factors. In spite of this uneasiness, the fact that such adjustments and impedances can be both logically and quantitatively derived and that the final model results can be quantitatively verified allows us to recommend the use of these procedures with a certain degree of confidence. Mr. Vogt has presented results from certain studies in which he was involved to demonstrate a reason for confidence in current procedures. These results were attained with significantly less than comprehensive data. With comprehensive survey trip data available, calibration results should be expected to attain a RMSE accuracy of less than 10 percent for the high volume groups, regardless of city size.

Mr. Brokke suggests that we may have treated the travel models with more "kindness" than we treated the Fratar procedure. He would have modified the basic purpose Fratar procedure by aggregating zones into districts to obtain interchange potential in areas where there is no base year travel pattern. The major difficulty with this approach is that there is no satisfactory procedure for bringing the analysis back to the zonal level.

A procedure that is more often recommended is to create a base year travel pattern in presently undeveloped areas through the use of a gravity or opportunity model and then to expand this synthetic pattern through the use of the Fratar procedure. This type of Fratar "adjustment" offers little appeal to the authors. This procedure accepts the validity of travel models and uses them as a crutch in determining a synthetic base year travel pattern in presently undeveloped areas. The synthetic pattern is fully reflective of land use and the transportation system. The procedure proceeds to ignore this inherent land-use transportation system-travel linkage in making projections. We suggest that it is far more logical to start with a travel model and to utilize it fully.

Mr. Brokke's point that "the consistency of the Fratar in underestimating is very close to the 10 percent mentioned in the paper" refers to a comparison between the Fratar results and base data where 38 zones in undeveloped areas were eliminated from the comparison. If this comparison had been made using the full universe of O-D trips, certainly the amount of error would have risen and be concentrated in the areas of significant land-use changes.

Mr. Brokke's quantitative relationships of the accuracy of trip distribution to the accuracy of traffic assignment is most interesting. In effect, he shows that had the final comparisons of travel models been made after a traffic assignment including capacity restraint, all the variation between the procedures would have disappeared. His findings should provide an impetus to the much needed improvements in traffic assignment techniques and to a quantitative evaluation of the several key technical phases of the transportation planning process. Such an evaluation will result in a much better appreciation of the accuracy of the total process as well as an indication of the sensitivity of the individual phases with respect to the final product.

Professor Howe's comments are difficult to handle. He raises several well-taken points about weaknesses in the use of these techniques with which the authors are quick to agree. Underlying these comments, however, the professor appears to be making a sales pitch for his own approach to trip distribution, namely, the electrostatic field theory. His model is essentially a gravity model which utilizes airline distance as the measure of spatial separation. No exponent is used to raise this distance measure to a higher power. The fact that he would use labor force as the measure of work trip generation, rather than the O-D survey results, is not pertinent to this discussion since our comments would apply should perfect trip generation data be available. What concerns us most is the use of airline distance as the sole measure of spatial separation. We cite the professor's own words, included in his comments on the Fratar procedure, to criticize his model. A fundamental weakness of this method is the fact that it fails to recognize that "movements between two zones may increase because of more direct means of transportation without any real change in the size of the attraction." Airline distance, totally insensitive to system and level of service, is a very weak attempt to overcome the Fratar's basic weakness.

In his admittedly skeptical reading of the portions of the paper dealing with the gravity and intervening opportunities models, Professor Howe has read between the lines and found all forms of "juggling." It may be helpful if we reduce the calibration and projection procedures to their essentials by summarizing changes in key parameters for the gravity model. The travel time factors were developed for 1948 and held constant to 1955. The river "impedances" were developed for 1948 and forecast to 1955 on the basis of the change in the level of service on the river crossings. The socioeconomic adjustment factors (K_{ij}) were developed for 1948 and related to 1948 district incomes. They were applied in 1955 on the basis of 1955 district incomes. The 1955 transportation system was used to determine the time inputs for the 1955 gravity model application. The travel time factors, river impedances and socioeconomic factors were developed and applied in that order. This involved no juggling, merely the same procedures used operationally by dozens of urban studies.

The point raised by Professor Howe regarding adjustments in L values for the forecast in the intervening opportunities model also deserves comment. He quotes from our paper: "In this analysis the change in L value was forecast as a function of the change in the number of trips." In his discussion he states, "But if the purpose of travel pattern models is to predict changes in trip patterns, an L which 'predicts' these trips while being dependent on them would seem to be intolerable!" We fail to see the problem. The total number of trips and the travel patterns in an area are two completely different things. The fact that one parameter in the distribution model is made a function of an areawide characteristic is appropriate rather than intolerable.

Prototype Development of Statistical Land-Use Prediction Model for Greater Boston Region

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Traffic Research Corporation has developed and tested a prototype model for the subregional distribution of population and employment growth in a metropolitan area. The model, called the EMPIRIC model, requires externally specified regional growth totals for population and employment categories to be projected. The development work was carried out in conjunction with the efforts of the Boston Regional Planning Project to prepare a comprehensive development plan for the Boston region.

Validity checks have been carried out by applying the model to forecast five categories of population and employment from 1950 to 1960 for 29 subregions and then comparing the observed and calculated subregional activity levels for 1960. Root-mean-square error ratios obtained with prototype EMPIRIC Model Application III were about 1 and 3 percent for total population and total employment, respectively.

The results seem to confirm the hypothesis that urban land use may be predicted on a subregional level, using an "associative" or "statistical" model of the EMPIRIC type, with sufficient accuracy for land-use and transportation planning purposes. The use of such a model enables planners to study systematically the effects of transportation facilities, land-use controls, and other policies on urban development and to produce staged plans and policies which take these interactions into account.

•THE UNDERLYING concept of the EMPIRIC model is that the development patterns of urban activities are interrelated in a systematic manner which provides a reasonable basis for their prediction. The model provides the formal mathematical mechanism for evaluating the extent of these interrelations between activities. The only restriction imposed by the model is that the interrelationships be expressed so that the influences of variables are additive. Accordingly, the model assumes a linear form. Any desired combination or transformation of variables may be introduced to describe the urban activities whose locational pattern we wish to measure and predict. The model requires exogenous specification (i.e., external predictions) of regional growth totals for all urban activities to be projected.

To describe the model, it is convenient to define a number of quantities as follows:

1. The region is divided into a number of small areas called subregions (Fig. 1).
2. The purpose of the model is to predict the amounts of several urban activities in each subregion at the end of a given forecast period. These activities are called

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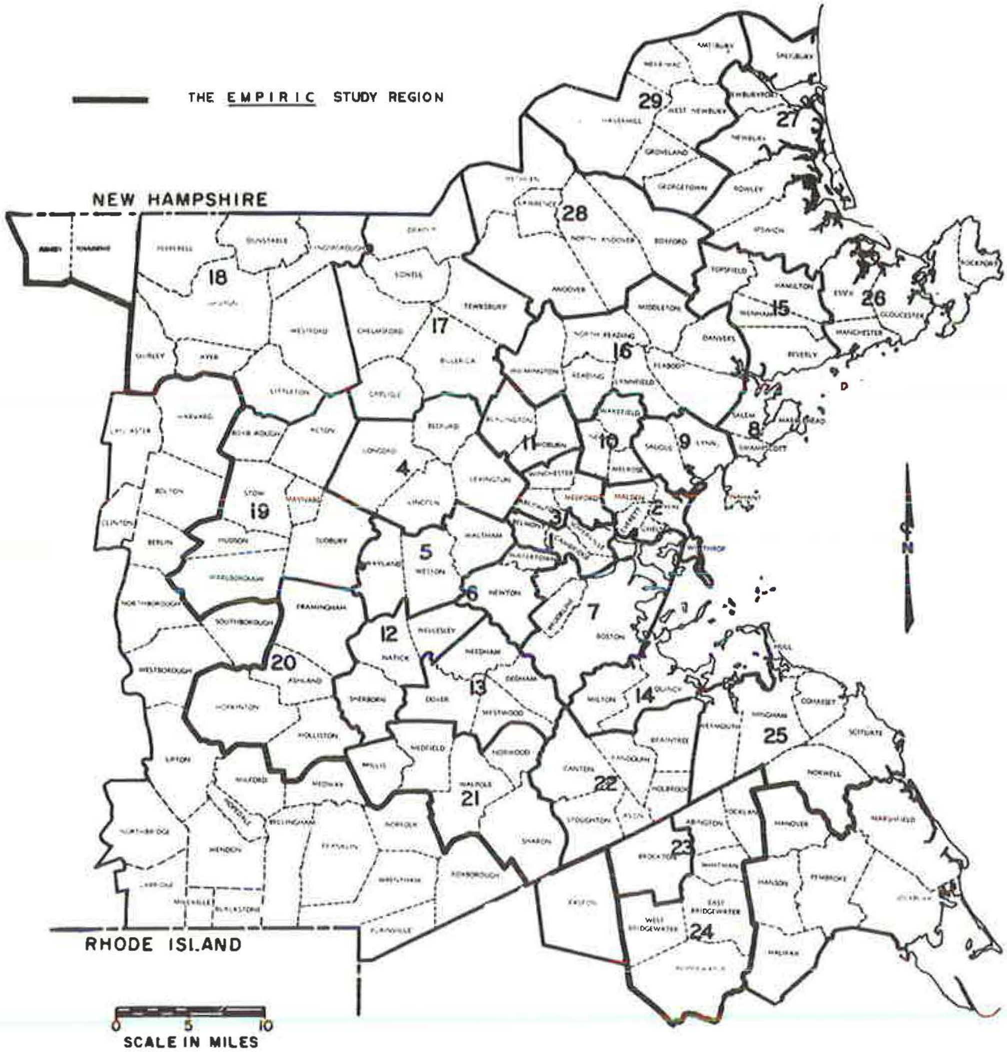

Figure 1. Subdivided EMPIRIC study region, Boston Regional Planning Project.

located variables, signifying that the task of the model is to allocate given regional totals of these variables at the end of the forecast period to the subregions comprising the region.

3. It has been found that the locations and intensities of several urban activities are related to development patterns of one or more variables in a casual manner, that is, whose presence or absence in a subregion, or whose ease of accessibility to the subregion, may be said to influence the amounts of one or more located variables in each subregion. These influencing variables are called locator variables.

The model is formulated to explain changes in activity levels of urban subregions over one or more time periods. Accordingly, the concept of the model may be stated as follows: the change in the subregional share of a located variable in each subregion is proportional to the change in the subregional share of all other located variables in the subregion, the change in the subregional share of a number of locator variables in the subregion, and the value of the subregional shares of other locator variables.

The concept of model may be stated by:

$$\frac{R_{i\ell}^{(t+1)}}{\sum_{\ell=1}^{L} R_{i\ell}^{(t+1)}} - \frac{R_{i\ell}^{(t)}}{\sum_{\ell=1}^{L} R_{i\ell}} = \sum_{\substack{j=1 \\ j \neq i}}^{N} a_{ij} \left[\frac{R_{j\ell}^{(t+1)}}{\sum_{\ell=1}^{L} R_{j\ell}^{(t+1)}} - \frac{R_{j\ell}^{(t)}}{\sum_{\ell=1}^{L} R_{j\ell}^{(t)}} \right] +$$

$$\sum_{k=1}^{M-m} b_{ik} \left[\frac{Z_{j\ell}^{(t+1)}}{\sum_{\ell=1}^{L} Z_{k\ell}^{(t+1)}} - \frac{Z_{k\ell}^{(t)}}{\sum_{\ell=1}^{L} Z_{k\ell}^{(t)}} \right] +$$

$$\sum_{k=M-m+1}^{M} b_{ik} \left[\frac{1}{L} - \frac{Z_{k\ell}^{(t)}}{\sum_{\ell=1}^{L} Z_{k\ell}^{(t)}} \right] \qquad (1)$$

where

$R_{i\ell}$ = level of located variable i in subregion ℓ;
$Z_{k\ell}$ = level of locator variable k in subregion ℓ;
L = number of subregions, $\ell = 1, 2, \ldots, L$;
N = number of located variables, $i = 1, \ldots, i, j, \ldots, N$;
M = number of locator variables, $k = 1, 2, \ldots, M$;
$(t + 1)$, (t) = (located and locator) variables at end and beginning of forecast or calibration interval, respectively; and
a_{ij}, b_{ik} = coefficients expressing interrelationships among variables.

There is one Eq. 1 for each located variable i. The coefficients a and b are determined by simultaneous regression analysis of the data from two past points in time (i.e., the model is calibrated).

After determining the coefficients, the equations are used to estimate future subregional shares of each located variable by substituting into each equation the pertinent values of the locator variables for that subregion and solving the equations simultaneously for the subregional located variables. To obtain the forecast in absolute rather than relative values, the subregional shares at the end of the forecast interval are multiplied by the exogenous (i.e., externally forecast) control figure for the total of each located variable in the study region.

DEVELOPMENT OF EMPIRIC MODEL

Development of the EMPIRIC model required detailed analyses of cause and effect relationships between development patterns of all land-use categories, as well as detailed analyses of the independence and interdependence of locational groupings of urban activities at the subregional level. An associative or statistical model rather than a true behavioral model was the goal, since it was felt that existing theories of urban development and data sources were not far enough advanced to permit the development of a suitable behavioral type of land-use model (2). Four methods of study were followed to achieve the necessary appreciation of urban development:

1. A graphical analysis of a large number of relationships between subregional growth rates of population and employment, and a large number of causal (locator) variables which were thought to be important;
2. An investigation of the changes and trends in population and employment that have taken place during the 1950-1960 decade;
3. An analysis of population and employment data (using factor analysis techniques) to determine to what extent variables can be grouped according to their tendency to locate in proximity to one another, or to exhibit similarities in their influence on the locational tendencies of other variables; and
4. Development of multiple regression equations which demonstrate the relationships between growth rates of population and employment and a large number of variables determined to be significant in their effect on locations of population and employment.

The findings of these studies provided the necessary insight to formulate the model for use as a prediction tool (3).

The method selected for expressing growth rates in Eq. 1 (subregional shares or normalized values) was found to be most suitable in that the predictive model incorporating shares demonstrated the highest coefficients of determination in explaining development during the calibration period (1950-1960). In all, three measures of growth were tested: (a) change in absolute value of an activity, (b) change in intensity of activity on land (density), and (c) change in proportion (share) of activity in each subregion (normalized value of an activity). The latter measure was chosen. There are definite mathematical conveniences associated with this measure. The aggregate of growths forecast for all subregions will always match the control figure for the region. Accordingly, iterative procedures are not necessary to obtain a forecast where the aggregate equals some control figure.

CALIBRATION OF MODEL

Calibration of the EMPIRIC model proceeded with 1950-1960 data for the 29 subregions comprising the Greater Boston region. The specified subregions, each comprising several towns or cities, are shown on the map in Figure 1.

Selected Located Variables

The set of located variables, R_i, selected for inclusion in the model was as follows:

1. White collar population (PW), the resident population participating in the white collar labor force (workers and families), including professional, technical, managerial, clerical and sales workers;
2. Blue collar population (PB), the resident population participating in the blue collar labor force, including craftsmen, foremen, operatives, service workers, laborers and occupation not reported;
3. Retail plus wholesale employment (RW), covered by the Massachusetts Division of Employment Security;
4. Manufacturing employment (M), covered by the Massachusetts Division of Employment Security; and
5. All other employment (OE), including employment not covered by Massachusetts Division of Employment Security plus all others.

Selected Locator Variables

Three sets of locator variables, Z_k, were selected for calibration of the prototype EMPIRIC model (Table 1). The first set of 12 locator variables was used in Model Application I and comprised densities of urban activities and automobile accessibilities to urban activities. The prototype EMPIRIC Model Application II is defined by the

TABLE 1

LOCATOR VARIABLES FOR CALIBRATION OF EMPIRIC MODEL

No.	Name	Symbol of Normalized Variable
	(a) Application I	
1	Difference between standardized[a] residential population density (at practical holding capacity) and gross residential population density at time t (serves as a zoning variable).	$\frac{STN\ PLR}{\sum_{\ell} STN\ PLR} - \frac{PLR(t)}{\sum_{\ell} PLR(t)}$
2	Difference between standardized manufacturing employment density and the gross density at time t.	$\frac{STN\ MLR}{\sum_{\ell} STN\ MLR} - \frac{MLR(t)}{\sum_{\ell} MLR(t)}$
3	Difference between standardized non-manufacturing employment density and the gross density at time t.	$\frac{STN\ NMLR}{\sum_{\ell} STN\ NMLR} - \frac{NMLR(t)}{\sum_{\ell} NMLR(t)}$
4	Value of subregional gross residential population density at time t.	$\frac{1}{L} - \frac{PLR(t)}{\sum_{\ell} PLR(t)}$
5	Value of subregional gross manufacturing employment density at time t.	$\frac{1}{L} - \frac{MLR(t)}{\sum_{\ell} MLR(t)}$
6	Value of subregional gross non-manufacturing employment density at time t.	$\frac{1}{L} - \frac{NMLR(t)}{\sum_{\ell} NMLR(t)}$
7	Change over the time period in automobile accessibility to white collar residential population at time t.	$\frac{A^V(t+1)PW(t)}{\sum_{\ell} A^V(t+1)PW(t)} - \frac{A^V(t)PW(t)}{\sum_{\ell} A^V(t)PW(t)}$
8	Change over the time period in automobile accessibility to blue collar residential population at time t.	$\frac{A^V(t+1)PB(t)}{\sum_{\ell} A^V(t+1)PB(t)} - \frac{A^V(t)PB(t)}{\sum_{\ell} A^V(t)PB(t)}$
9	Change over the time period in automobile accessibility to total employment at time t. (TE(t)).	$\frac{A^V(t+1)TE(t)}{\sum_{\ell} A^V(t+1)TE(t)} - \frac{A^V(t)TE(t)}{\sum_{\ell} A^V(t)TE(t)}$
10	Value of subregional automobile accessibility at end of period (t+1) to white collar residential population at time t.	$\frac{1}{L} - \frac{A^V(t+1)PW(t)}{\sum_{\ell} A^V(t+1)PW(t)}$
11	Value of subregional automobile accessibility at end of time period (t+1) to blue collar residential population at time t.	$\frac{1}{L} - \frac{A^V(t+1)PB(t)}{\sum_{\ell} A^V(t+1)PB(t)}$
12	Value of subregional automobile accessibility at end of period (t+1) to total employment at time t.	$\frac{1}{L} - \frac{A^V(t+1)TE(t)}{\sum_{\ell} A^V(t+1)TE(t)}$
	(b) Application II	
1-12	Same as above.	Same as above.
13	Change over the time period in transit accessibility to white collar residential population at time t.	$\frac{A^Q(t+1)PW(t)}{\sum_{\ell} A^Q(t+1)PW(t)} - \frac{A^Q(t)PW(t)}{\sum_{\ell} A^Q(t)PW(t)}$
14	Change over the time period in transit accessibility to blue collar residential population at time t.	$\frac{A^Q(t+1)PB(t)}{\sum_{\ell} A^Q(t+1)PB(t)} - \frac{A^Q(t)PB(t)}{\sum_{\ell} A^Q(t)PB(t)}$
15	Change over the time period in transit accessibility to total employment at time t.	$\frac{A^Q(t+1)TE(t)}{\sum_{\ell} A^Q(t+1)TE(t)} - \frac{A^Q(t)TE(t)}{\sum_{\ell} A^Q(t)TE(t)}$
16	Value of subregional transit accessibility at end of time period (t+1) to white collar residential population at time t.	$\frac{1}{L} - \frac{A^Q(t+1)PW(t)}{\sum_{\ell} A^Q(t+1)PW(t)}$
17	Value of subregional transit accessibility at end of time period (t+1) to blue collar residential population at time t.	$\frac{1}{L} - \frac{A^Q(t+1)PB(t)}{\sum_{\ell} A^Q(t+1)PB(t)}$
18	Value of subregional transit accessibility at end of period (t+1) to total employment at time t.	$\frac{1}{L} - \frac{A^Q(t+1)TE(t)}{\sum_{\ell} A^Q(t+1)TE(t)}$
	(c) Application III	
1-18	Same as above.	Same as above.
19	Change in quality of water supply over the time period.	$\frac{W(t+1)}{\sum_{\ell} W(t+1)} - \frac{W(t)}{\sum_{\ell} W(t)}$
20	Change in quality of sewage disposal service over the time period.	$\frac{S(t+1)}{\sum_{\ell} S(t+1)} - \frac{S(t)}{\sum_{\ell} S(t)}$
21	Value of subregional quality of water supply at time t.	$\frac{1}{L} - \frac{W(t)}{\sum_{\ell} W(t)}$
22	Value of subregional quality of sewage disposal service at time t.	$\frac{1}{L} - \frac{S(t)}{\sum_{\ell} S(t)}$

[a]This is the maximum net density of each pertinent activity in each subregion observed over the calibration period.

addition of transit accessibilities as locator variables to the previous 12 input variables for a total of 18 input variables. Prototype Model Application III is defined by the addition of quality of water supply and sewage disposal service (4 locator variables) to the 18 previous input variables.

The gross density variables employed above were calculated by dividing the appropriate subregional activity levels by the subregional effective area. This was the area suitable for development by any of the located variables. The areas selected comprised the land in use in 1960 for residential, commercial, manufacturing and wholesaling, plus the agricultural or vacant land which was either suitable (having less than 15 percent slope and not swampy) or which in 1960 was under development for commercial or industrial uses. Data availability was a prime factor in the selection of this definition of effective area.

The standardized densities were based on development trends during the decade 1950-1960 and were set equal to the maximum of the 1950 or 1960 activity levels in each subregion divided by the appropriate area in use in 1960 in that subregion. The areas used were residential land for standardized residential population density, commercial land for nonmanufacturing standardized density, manufacturing-wholesaling land for standardized manufacturing employment density.

The accessibilities were based on the formulations:

$$A^V_{\ell k} = \sum_{\ell=1}^{L} Z_{k\ell}\, e^{-BT^V_{\ell p}} \qquad (2a)$$

and

$$A^Q_{\ell k} = \sum_{\ell=1}^{L} Z_{k\ell}\, e^{-BT^Q_{\ell p}} \qquad (2b)$$

where

- $A^{V \text{ or } Q}_{\ell k}$ = accessibility of subregion ℓ to variable k in all L subregions (ℓ = 1, 2, . . . , ℓ, p, . . . , L; k = 1, 2, . . . , M), by highway (V) or transit (Q);
- $Z_{k\ell}$ = level of locator variable k in subregion ℓ;
- e = base of natural logarithms (2.71828. . .);
- $T^V_{\ell p}$ = auto travel time plus terminal time between subregions ℓ and p (p = 1, 2, . . . , ℓ, p, . . . , L);
- $T^Q_{\ell p}$ = transit travel time plus terminal time between subregions ℓ and p; and
- B = parameter measuring degree to which propensity for interaction between urban activities decreases with increasing travel time between them. (Graphical and bivariate correlation analysis of the interactions between population and employment in the Boston region indicated that the value B = 0.05 was most representative of this effect.)

Travel times were calculated by tracing shortest time paths between pairs of subregions and adding the subregional terminal times at both ends. Shortest time paths were derived from networks representing highway, street and mass transportation systems for 1950 and 1960. The procedure followed was similar to that employed in area transportation studies where networks are constructed and travel times between subregions are obtained by tracing minimum time paths (in this case for peak hour traffic loadings).

The 1950 and 1960 ratings of quality of water supply and sewage disposal service ratings were based on the following scale:

1 = Metropolitan District Commission (MDC) system.
1.5 = partial MDC system.
2 = supplied by community.
3 = not publicly supplied.

When a combination of these four possibilities occurred for some subregion, intermediate values to the 1, 1.5, 2 or 3 ratings were calculated, weighted by zonal areas.

FORECASTING WITH EMPIRIC MODEL

All three applications of the calibrated model were used to project 1960 subregional activity levels from corresponding 1950 land-use data, 1960 regional totals of the projected activities and 1960 values of the variables coming under external control (policy variables). The projected (located) variables were the two classes of population (white collar and blue collar population) and three classes of employment (retail plus wholesale, manufacturing and all other employment). The input (locator) variables for the three model applications may be summarized as follows:

Application I—1950 subregional levels and densities of the two classes of population and two groupings of employment; changes in the highway transportation system between 1950 and 1960 and the system in 1950.

Application II—locator variables of Application I; changes in the mass transportation system between 1950 and 1960 and the system in 1950.

Application III—locator variables of Application II; changes in the subregional quality of water supply between 1950 and 1960 and the quality in 1950; changes in the subregional quality of sewage disposal service between 1950 and 1960 and the quality in 1950.

The subregional values of the two classes of population and three classes of employment projected were aggregated by subregion to form the additional located variables, total population and total employment, respectively.

Figures 2 and 3 present the observed and projected 1960 subregional values of population and employment obtained with Model Application II. The accuracy with which the model simulated subregional development in the Boston region in the decade 1950 to 1960 is shown by the close correspondence of the subregional values presented for each subregion in these figures.

Three numerical indices were calculated to measure the correspondence attained between observed and predicted 1960 subregional values. These indices, defined in the following paragraphs, summarize the accuracy obtained over all subregions and result in a single reliability measure for each output variable.

Root-Mean-Square Error

The root-mean-square (RMS) error expresses the deviation from corresponding observed values of the predicted values produced for each located variable. Statistical theory indicates that for about 67 percent of the subregions, the observed value will not differ from the predicted value by more than plus or minus the RMS error. The RMS error is computed by:

$$\text{RMS error} = \sqrt{\frac{\sum_{\ell=1}^{L} \left[R_i(O) - R_i(C)\right]^2}{L}} \qquad (3)$$

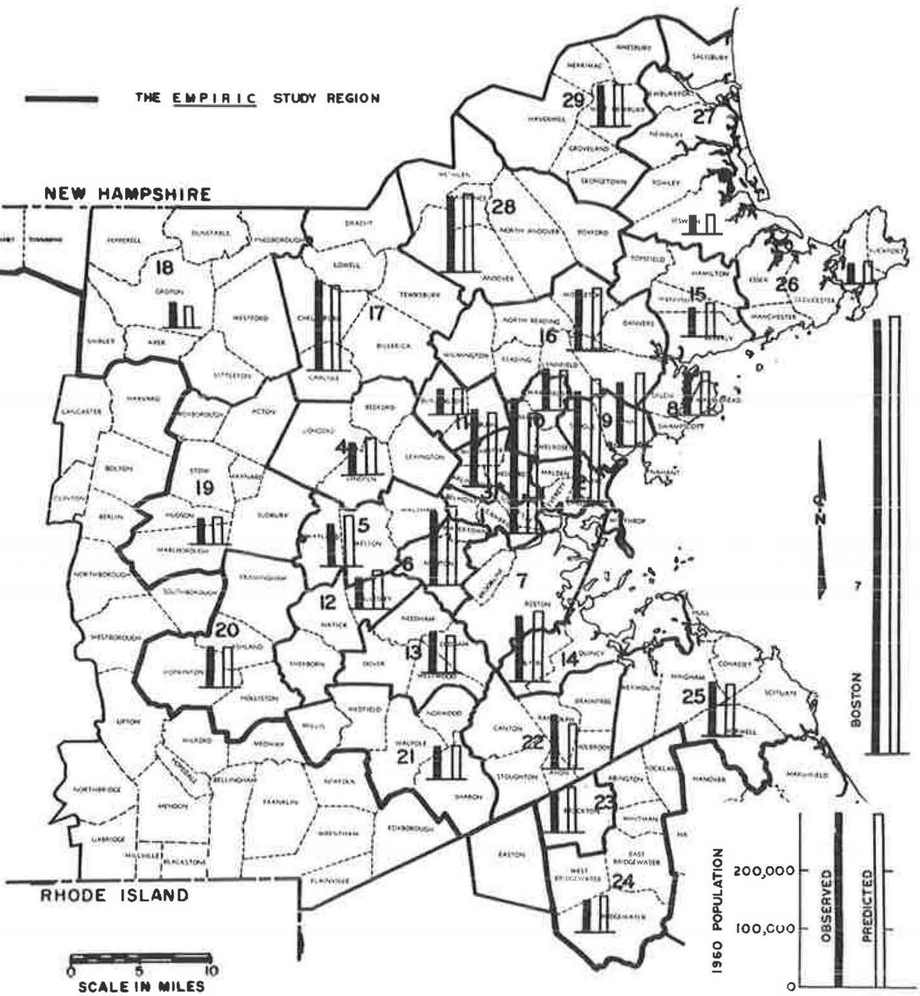

Figure 2. Comparison of observed 1960 population levels with those predicted by EMPIRIC land-use model (Application II).

where

$R_{i\ell}$ (O) = observed value of located variable i in subregion ℓ, and

$R_{i\ell}$ (C) = predicted (calculated) value of located variable i in subregion ℓ.

RMS Error Ratio

The RMS error ratio is the ratio of the RMS error to the arithmetic average of the observed output activity values, $\overline{R}_i$ (O). The RMS error ratio is computed as follows:

$$\text{RMS error ratio} = \frac{\text{RMS error}}{\overline{R}_i(O)} \quad (4)$$

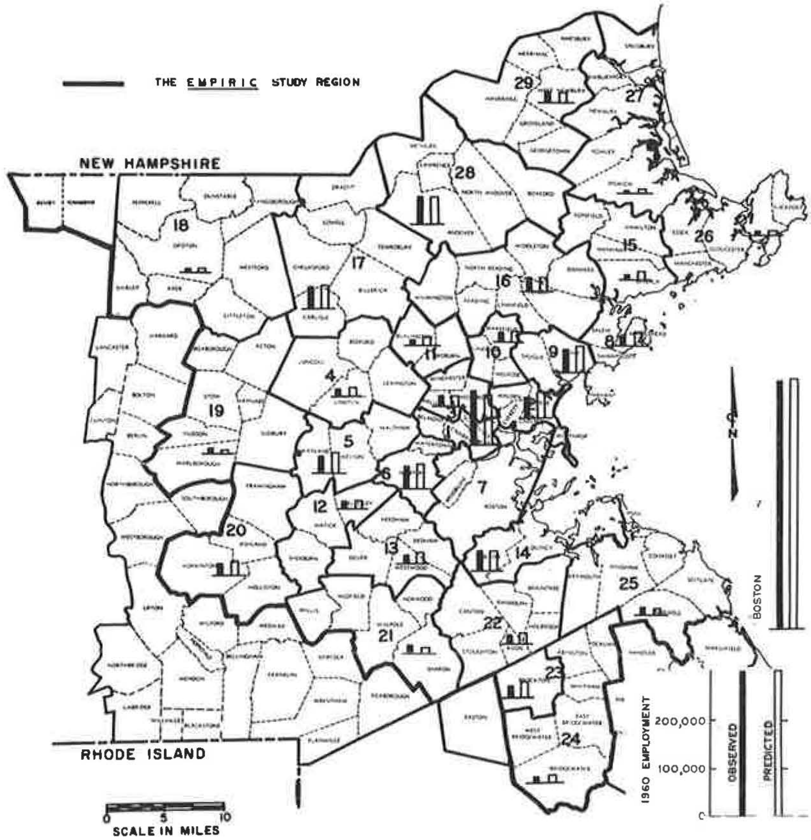

Figure 3. Comparison of observed 1960 employment levels with those predicted by EMPIRIC land-use model (Application II).

where

$$\overline{R}_i(O) = \frac{\sum_{\ell=1}^{L} R_{i\ell}(O)}{L}.$$

Coefficient of Determination

The coefficient of determination, R^2, a third summary measure for each located variable, represents the proportion of the sum of squared deviations of the observed subregional located variable levels and the mean subregional level, that is explained by the model, and is computed as follows:

$$R^2 = \frac{\sum_{\ell=1}^{L}\left[R_{i\ell}(O) - \overline{R}_i(O)\right]^2 - \sum_{\ell=1}^{L}\left[R_{i\ell}(O) - R_{i\ell}(C)\right]^2}{\sum_{\ell=1}^{L}\left[R_{i\ell}(O) - \overline{R}_i(O)\right]^2} \quad (5)$$

As R^2 approaches 1, the reliability of the model is regarded to be quite high; conversely, as R^2 approaches 0, the reliability is considered to be quite low. There are, however, instances where R^2 is a poor measure of reliability and, therefore, should not be regarded critically. One of these instances occurs as one of the observations (activities for subregion 7) is much larger than the mean $\overline{R}_i(O)$. Accordingly, the first two summary measures more accurately reflect the reliability of the model.

The summary measures, calculated using the subregional values obtained with Model Application II and presented in Figures 2 and 3, are contained in Table 2.

INVESTIGATIONS OF EFFECT ON MODEL FORECAST ACCURACY OF VARYING INPUT CONDITIONS

Several tests have been conducted with the EMPIRIC model to evaluate its accuracy as a forecast tool. Some of the tests involved the investigation of effect on forecast accuracy of varying the number of locator variables or the size and number of subregions. The tests involved both recalibrations and forecasts with the model.

Varying Number of Locator Variables

A comparison of the results of the three model applications illustrate the effect on model forecast accuracy of increasing or decreasing the number and types of input variables. The conditions under which the three applications were made are the same except for numbers and types of input variables. As described in the previous section, Model Application I deletes transit accessibilities as input variables, whereas Model Application III adds water supply and sewage disposal services as input variables to those used in Model Application II. The effect of this decrease and increase in the number of input variables is reflected in the three summary measures calculated using 1960 subregional values predicted with Model Applications I and III. These results are contained in Table 3.

The results presented in Table 3 indicate that greater forecast accuracy is obtainable when increased information becomes available on transportation systems and other planned variables. Additional tests will be carried out incorporating additional information on planned variables into sets of locator variables. Such tests will enable an evaluation of the effect on forecast accuracy of increased information per variable, as well as of the effect of increased total information.

Varying Sizes and Numbers of Subregions

In an attempt to measure the model's error sensitivity to an increase in the number of subregions and a consequent decrease in subregion size, the prototype Model Application III was calibrated with data for the 123 cities and towns in the specified study region. The model was calibrated again with data for the 123 cities and towns, but the city of Boston was divided into 12 areas giving a total of 134 subregions.

Table 4 presents values of RMS errors for total population and total employment. It appears that the errors increase as subregions become smaller. Further, it is noted that with more uniform distribution of subregional activity levels (R_i) in the case of the 134 subregion test, the fore-

TABLE 2

SUMMARY RELIABILITY MEASURES OBTAINED WITH MODEL APPLICATION II

Output Variable	RMS Error[a]	RMS Error Ratio	R^2
Total population:	3,439	0.03	0.99
White Collar	3,031	0.06	0.99
Blue Collar	1,686	0.03	0.99
Total employment:	1,512	0.03	0.99
Retail and wholesale	564	0.06	0.99
Manufacturing	1,128	0.08	0.99
Other	955	0.05	0.99

[a]People or jobs.

TABLE 3

SUMMARY MEASURES, OTHER APPLICATIONS

Model Application	Output Variable	RMS Error[a]	RMS Error Ratio	R^2
I	Population	7,825	0.07	0.99
	Employment	3,631	0.08	0.99
III	Population	1,259	0.01	0.99
	Employment	1,306	0.03	0.99

[a]People or jobs.

TABLE 4

RMS ERRORS OBTAINED WITH 29, 123 AND 134 SUBREGION PROJECTIONS, 1950 TO 1960 MODEL APPLICATION III

No. of Subregions	Activity	RMS Error
29	Population	1, 259
	Employment	1, 306
123	Population	5, 673
	Employment	3, 715
134	Population	3, 479
	Employment	2, 755

cast accuracy is greater than the 123 town test but remains less than the accuracy of the 29 subregion tests.

The losses in forecast accuracy with more subregions are expected to be minimal when the EMPIRIC model is used on a production basis with large numbers of small subregions. Although the data analyses preceding the formal calibration of the model will be carried out in detail with the small subregions (600), the data are expected to be available for subregion sets whose levels of population and employment are more uniform than those used for the tests reported on in Table 4. Further, it is expected that new sets of locator variables which reflect locational decisions at a finer areal basis will be introduced and they will help to improve the forecast accuracy of the EMPIRIC model.

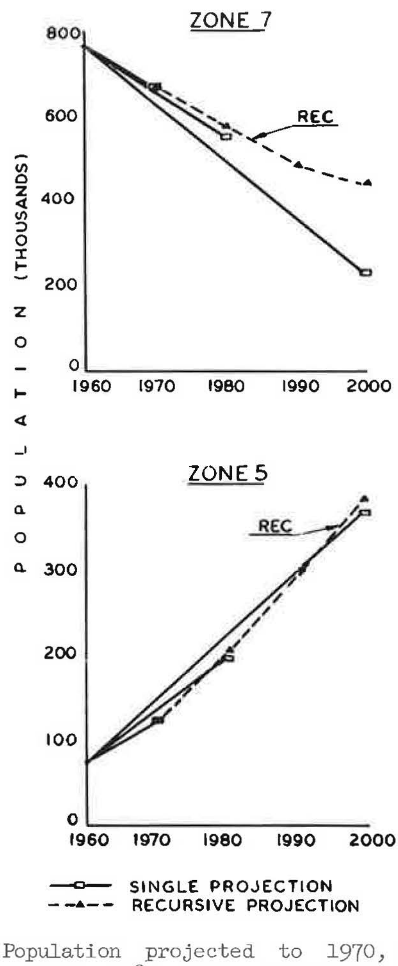

Figure 4. Population projected to 1970, 1980 and 2000 in single projections and to 1970, 1980, 1990 and 2000 recursively in 10-year intervals.

INVESTIGATIONS OF MODEL SENSITIVITY TO VARIATIONS IN FORECAST CONDITIONS

Several tests of the model were carried out for the purpose of investigating the effect on forecast values of: (a) changes in length of forecast period, (b) changes in specification of regional growth rates, (c) changes in zoning policies for suburban "bedroom" communities, and (d) changes in design policies of transportation facilities. These tests did not involve new model calibrations. Each of the tests and their findings are discussed in relation to one of the original 29 subregional model applications (I or II).

Changes in Length of Forecast Period

With any forecast model, errors generally increase as the length of the prediction period increases into the future. This model, as other models, forecasts subregional growths and declines, so that the further into the future one tries to forecast, the greater are these subregional growths (or declines) as a percentage of the original subregional activity levels. Hence, even if the percentage errors in the projected subregional growths remained constant, the percentage errors in the projected subregional values would increase.

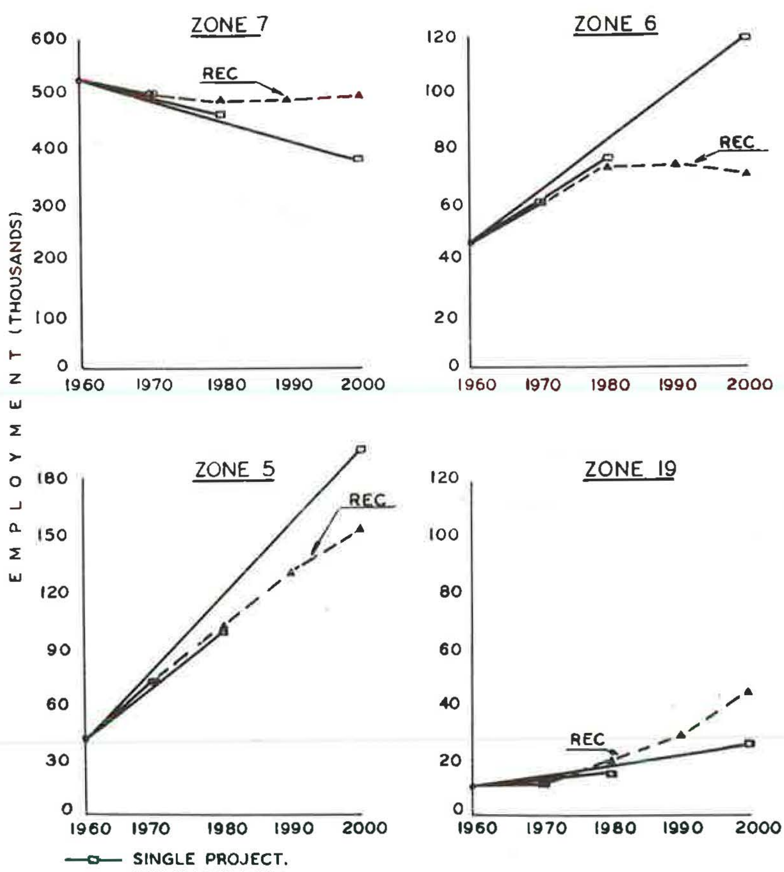

Figure 5. Employment projected to 1970, 1980 and 2000 in single projections and to 1970, 1980, 1990 and 2000 recursively in 10-year intervals.

Three single projections were made with Model Application I, i.e., from 1960 to 1970, from 1960 to 1980, and from 1960 to 2000. The results are demonstrated by Figure 4 for population and Figure 5 for employment. The three forecasts together demonstrate a near-linear change over time (not exactly linear due to compounding of growth). The definite linearity of projected subregional shares is achieved but not shown here.

In addition to the single (nonrecursive) tests, a recursive 10-year projection was conducted. (Recursive forecast means that the model is applied sequentially for relatively short forecasts with the results of each forecast providing input for the succeeding forecast.) At the end of each 10-year projection period, new accessibilities and densities were calculated and input into the model, based on the same 1960 transportation network but on the newly predicted subregional activity levels. The findings of this recursive test are presented in Figures 4 and 5, and the projection demonstrates now a curvilinear trend.

The recursive projection is anticipated to predict subregional growths and declines more accurately because changes in policy measures, the utilization of vacant land and accessibilities are input more frequently. Accordingly, the divergence of the recursive projection from a linear trend probably closely reflects future development rates and, hence, exhibits a generally lower forecast error than the single projections.

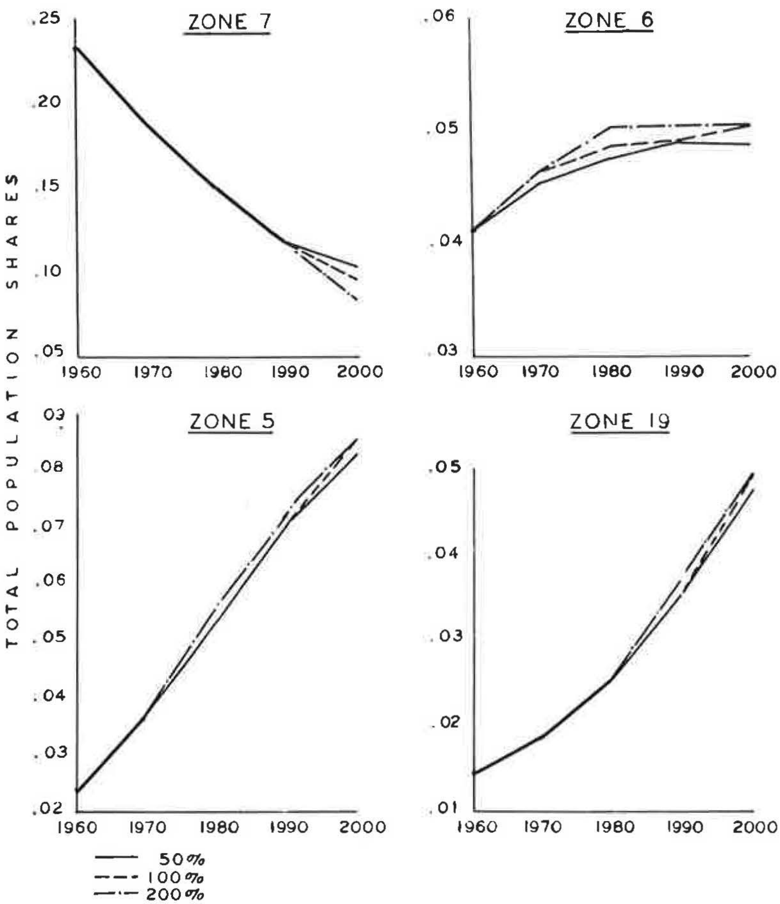

Figure 6. Population shares projected to 1970, 1980, 1990 and 2000 in recursive 10-year projections based on growth rates of 50, 100 and 200 percent of 1950-1960 growth.

Changes in Regional Growth Rates

Recursive forecasts to the year 2000 were conducted with Model Application I, setting the annual growth rates at 50, 100 and 200 percent of the average annual growth rates of each located activity experienced during the 1950-1960 period. (The same average annual growth rate was applied in the preceding forecast tests.)

Absolute subregional population and employment levels were found to increase in all cases as regional growth rates increased. However, subregional shares of regional growth were found to vary on a more selective basis. Subregional population shares for suburban and exurban subregions increased with increased estimated regional growth rates, but Boston (subregion 7) decreased slightly its share of increases in regional population growth. For employment shares, the pattern was reversed. Boston and inner ring subregions increased their share of regional employment as rates of regional growth increased, whereas the exurban subregions participated relatively less in an increased regional employment growth rate until the latter stages of the 40-year forecast interval.

These results for typical subregions are plotted in Figures 6 and 7. Subregion 7 (Boston) is typical of a core subregion. Subregions 5 and 6 are suburban subregions, the latter much older and more densely developed. Subregion 19 is typical of the exurban Boston subregions which only in the 1960's are beginning to undergo suburbanization. Their positions in the region may be seen in Figure 1.

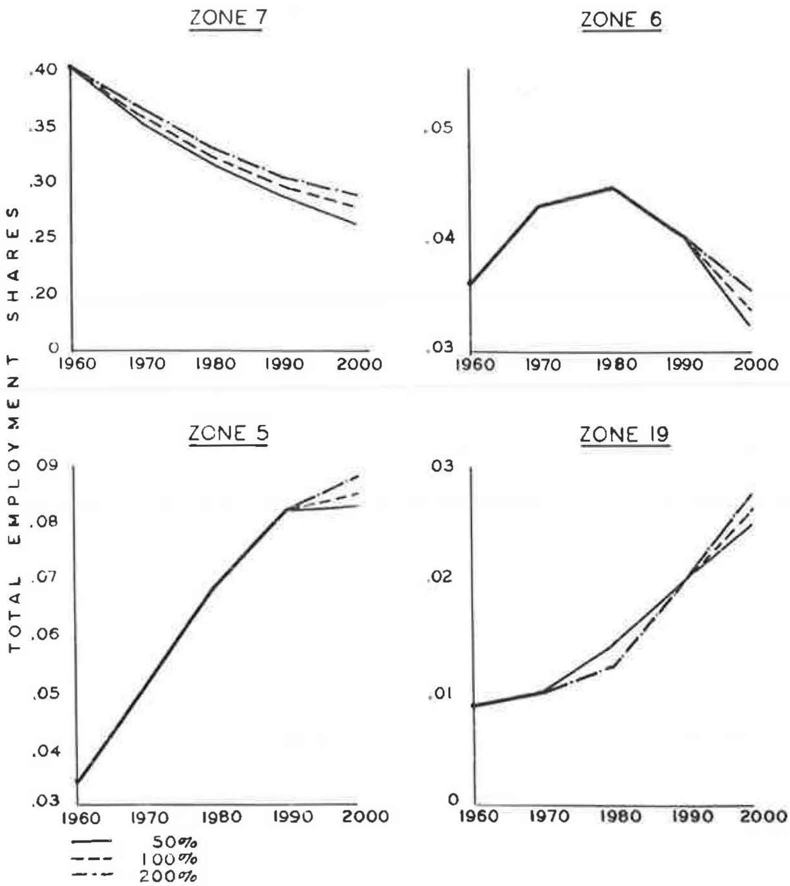

Figure 7. Employment shares projected to 1970, 1980, 1990 and 2000 in recursive 10-year projections based on growth rates of 50, 100 and 200 percent of 1950-1960 growth.

The results presented in Figures 4 through 7 can be interpreted only quantitatively at this stage, since they are intended to illustrate a test of the model's sensitivity to a change in a given forecast condition. They do not necessarily represent accurately future growth in the Boston region (which will be based on new policy decisions).

Changes in Suburban Zoning Policies

A 29-subregion projection from 1950 to 1960 was conducted with Model Application I, in which the 1960 standardized (allowable) population density, STNPLR, of one suburban subregion (Zone 4) was increased slightly and then greatly. This test was intended to determine the effect of such a zoning change on forecast values for the particular subregion and surrounding subregions.

Figures 8 and 9 show that forecast values of population and employment in subregion 4 increased as the STNPLR variable increased from 6. 3 to 8. 0 and lastly to 80. 0. The increases are very pronounced and are demonstrative of the model's sensitivity to the zoning variable. Close examination of the results revealed that subregions with larger original amounts of population and employment tended to lose larger amounts of these activities to subregion 4 than did those subregions with smaller original values.

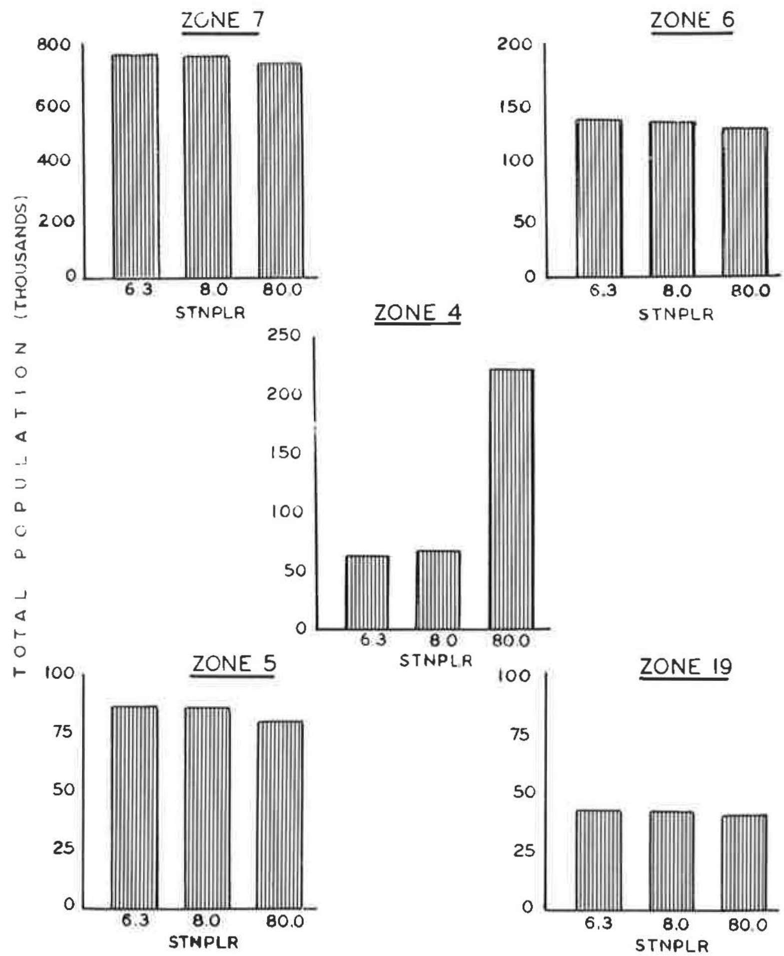

Figure 8. Growths or declines of population by changing STNPLR values of subregion 4.

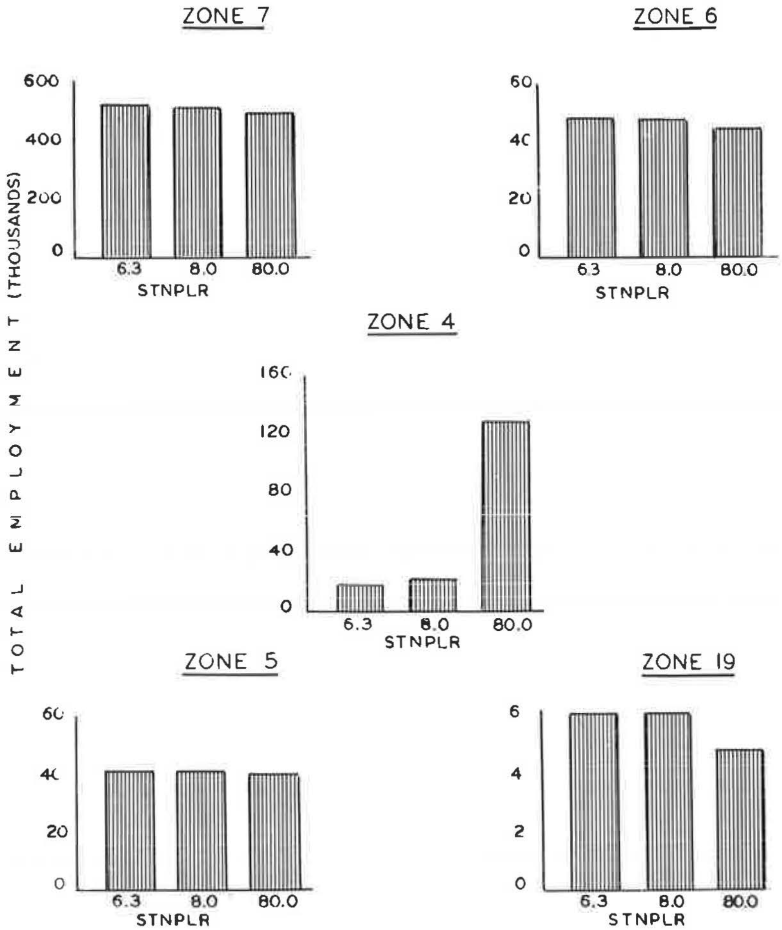

Figure 9. Growths or declines of employment by changing STNPLR values of subregion 4.

Changes in Design Policies of Transportation Facilities

As a final test of the sensitivity of the model, Model Application II, described previously, was used to simulate the effect on the locational patterns of population and employment in the Boston region for two different design policies of transportation facilities over the 1950-1960 decade. The first design policy simulated was exactly that which took place in the Boston region between 1950 and 1960 insofar as highway and mass transportation improvements or closures were concerned. The second simulated design policy was premised on no changes in the highway and mass transportation system between 1950 and 1960. The regional growth of population and employment was assumed to be the same for both design policies.

Figure 10 shows the major expressway segments built in the Boston region between 1950 and 1960. Major mass transportation improvements and closings during the decade are also shown. It should be noted that the transportation improvements consisted primarily of radial expressway sections, plus the major circumferential expressway, Rte. 128, which passed through a tier of suburban communities.

Figures 11 and 12 contain the 1960 subregional values of population and employment predicted by the model with the two simulated transportation policies. Examination of the results shown in these figures indicates that the policy of radial and circumferential transportation improvements result in the expected benefits of increased

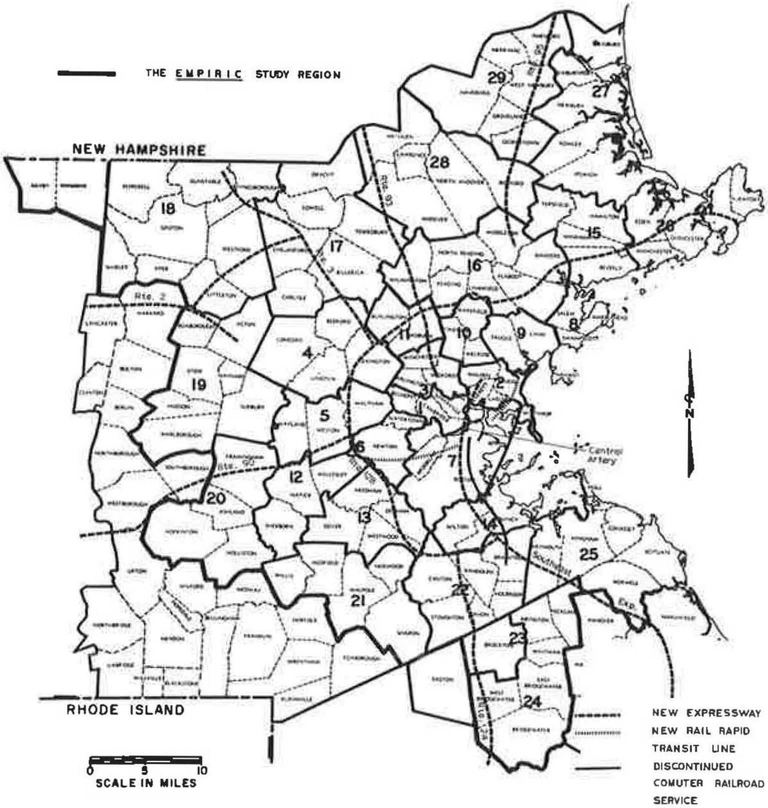

Figure 10. Major transportation facilities built or closed between 1950 and 1960, Boston metropolitan region.

population and employment in the third and fourth tier of suburban subregions. Also, it is interesting to note the increases in population, and employment in the older core cities of Boston, Cambridge and Somerville resulting from the policy of transportation improvements. This predicted redistribution of population and employment as a result of a transportation improvement is illustrative of the way in which a land-use model may be used to evaluate alternative design policies for public facilities.

APPLICATION OF EMPIRIC MODEL IN CONJUNCTION WITH TRAFFIC MODEL

The EMPIRIC land-use model may be applied in conjunction with a travel forecasting model in the following iterative manner:

1. Inventory would be made for the initial year (e.g., 1960 for the first forecasting period) of all travel flows, times and costs, and the level of each pertinent activity in each subregion. Estimates of regional growth factors for a 5-year period, for example, would be made for each activity to be predicted.
2. The land-use model (calibrated on the basis of past data) would be applied for a 5-year forecasting period starting with the initial values of activity levels in each subregion and using travel times and costs for the initial year and travel times and costs at the final year, based on the completion of new transportation facilities and the closure of old facilities. Values of other planned variables, such as utility coverage, would also be for the initial year and the final year.

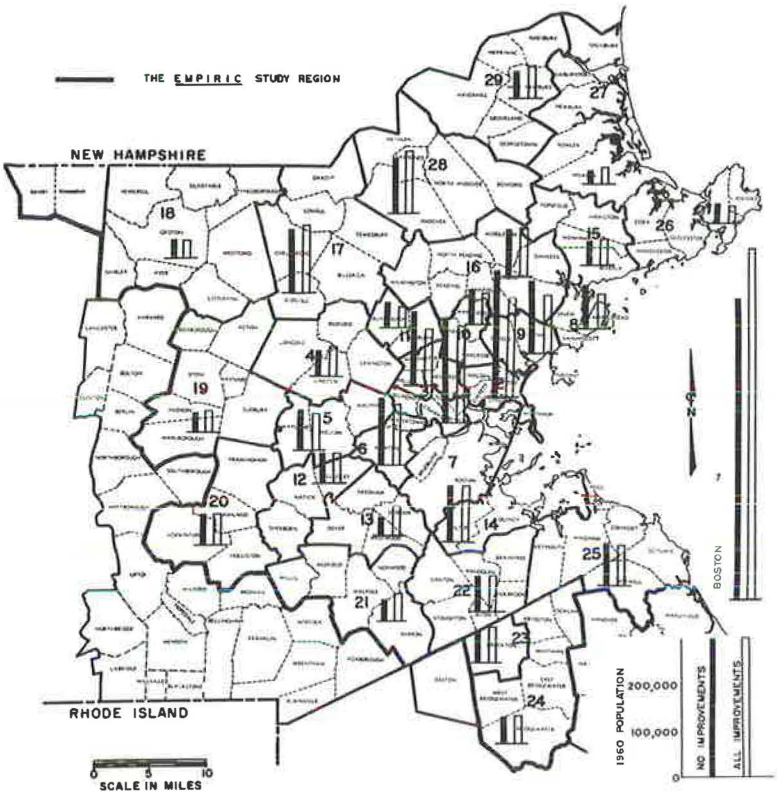

Figure 11. Results of two simulated transportation design policies using EMPIRIC land-use model (Application II): predicted 1960 population levels with no transportation improvements or closures between 1950 and 1960 vs predicted levels with all improvements and closures.

3. Based on the predicted land-use pattern of step 2 and the travel facilities scheduled for completion, the traffic model would be applied for the target year (every fifth year) to determine new traffic flows, travel times and costs.

4. The procedure outlined in steps 2 and 3 would be repeated if the travel times and costs found in step 3 differed substantially from values used in step 2.

5. The procedure outlined in steps 1, 2, 3, and 4 would be repeated for successive 5-year periods, using activity levels estimated by the land-use model at the end of each period as starting levels for forecasting in the next period.

This process would be repeated until the final target year had been reached. The sequence of forecasts of 5-year activity levels, travel flows, times and costs, etc., thus produced, would represent a systematic estimate of how the region would develop under the influence of regional growth rates and planning policies relating to transportation and utilities.

Steps 3 and 4 could be elaborated on if the flows and travel times produced initially were such as to indicate inadequacies in the proposed transportation system. More adequate transportation facilities could be proposed in this case and evaluated by the traffic model to provide a basis for further forecasts. Similarly, iterative application of the land-use model could be carried out in step 2 if the initial urban growth pattern for a particular period is found to be undesirable. In this case, the land-use model would be rerun using the same initial activity levels in each subregion but different proposed values of transportation and/or planned activities, chosen to correct, if possible, the undesirable qualities of the original growth pattern.

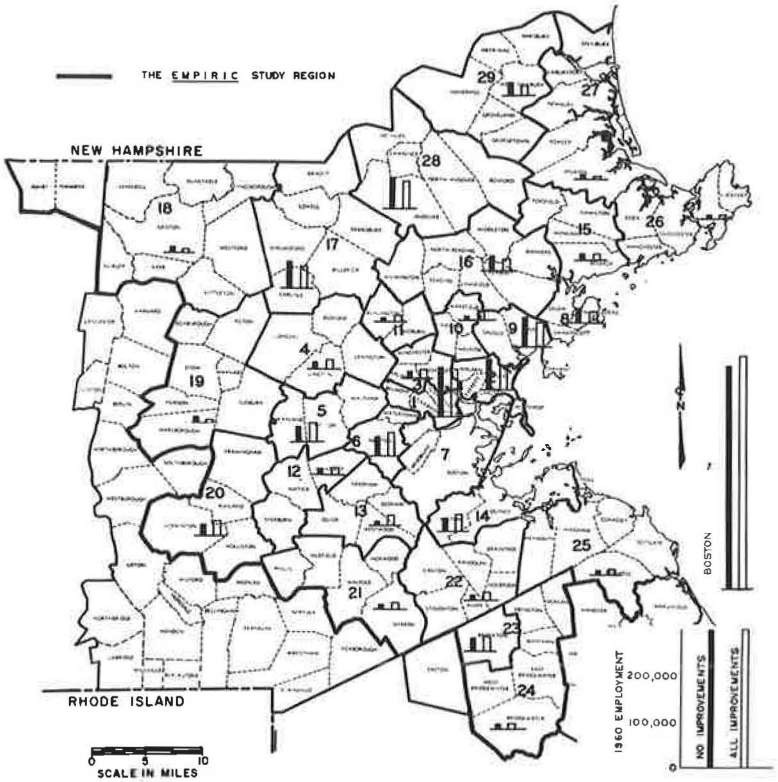

Figure 12. Results of two simulated transportation design policies using EMPIRIC land-use model (Application II): predicted 1960 employment levels with no transportation improvements or closures between 1950 and 1960 vs predicted levels with all improvements and closures.

In this manner, possible alternative staged plans would be evaluated in an effort to produce a master development plan for the region.

CONCLUSIONS

The results demonstrated by the prototype EMPIRIC model give rise to the conclusion that the model shows promise of bringing the planner the ability to simulate a chain of events in urban development, starting with variables he can control (such as the transportation system and open space regulations) and ending with a pattern of residential and industrial development. This process is amenable, efficient and desirable.

ACKNOWLEDGMENTS

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Evaluation of Intervening Opportunities Trip Distribution Model

CLYDE E. PYERS, Urban Planning Division, U. S. Bureau of Public Roads

Methods are presented for calibrating and testing the ability of the intervening opportunities model to simulate present travel patterns to forecast travel patterns for another point in time. Both the calibrating and forecast testing phase of the research, supplemented with necessary background information relating to each phase, as well as the detailed procedures utilized and results obtained (when compared with comprehensive home interview data) are reported. The basic source of data used in the calibration and simulation phase was the 1948 Washington area home interview O-D survey. The calibrated model was then applied to 1955 conditions and resulting trip distribution patterns were checked against the 1955 Washington area home interview survey data to test the forecasting ability of the model. Improved procedures and techniques for calibrating and testing the intervening opportunities trip distribution model are suggested.

•THE INTERVENING opportunities trip distribution model has been used to forecast future travel patterns in several of the larger transportation studies during the past few years. The theory of this model and the general procedures for applying it have been documented to some extent in the literature (1, 2, 3). The use of this model to forecast future travel patterns in several urban areas has also been reported (1, 4). However, there are little published data available to illustrate comprehensively the ability of the intervening opportunities model either to simulate existing travel patterns or forecast future patterns.

The author, together with other personnel from the Urban Planning Division of the U.S. Bureau of Public Roads, has been working on a project to analyze, test, and document the full transportation planning package as developed and programmed originally by the Chicago Area Transportation Study (CATS) (1, 2). The particular phase of the project treated here deals exclusively with the trip distribution portion of this package, herein called the intervening opportunities trip distribution model. This model has also been called the Schneider, Chicago, and the subtended volume trip distribution model. Procedures for applying this model are tested, as well as the accuracy of the model itself in simulating present travel patterns and forecasting future travel patterns in an urban area. In addition, this same project undertook the development of an IBM 7090/7094 computer program for implementing the analytical procedures required. The program was written to utilize input/output which would fit into the Bureau's battery of transportation planning programs.

To test the simulation and forecasting abilities of the model, adequate data on travel patterns for two time periods were required. The Washington, D.C., metropolitan area was chosen because complete and adequate home interview surveys for two separate time periods were available. These data were particularly valuable because similar research, testing other widely used trip distribution procedures, was already com-

Paper sponsored by Committee on Origin and Destination.

pleted (5). Similar research with the same data, providing the first side-by-side comparisons of relative accuracies and advantages of the different techniques, is reported elsewhere (6).

During the summer of 1948, a comprehensive origin-destination (O-D) survey was conducted of 5 percent of the dwelling units in the Washington metropolitan area (7). In 1955 a repeat O-D survey was conducted in the same area (8). Within the District of Columbia, occupants of 3 percent of the dwelling units were interviewed. Elsewhere in the area, occupants of 10 percent of the dwelling units were interviewed. Consequently, the Washington area provided an ideal situation for testing and evaluating the ability of the intervening opportunities model to simulate travel patterns for one period of time and also to forecast such patterns for a different period of time.

This paper describes research on methods for calibrating the intervening opportunities model for a large urban area and for testing the ability of this model to simulate present trip distribution patterns. In addition, it discusses investigations into the ability of this model to predict trip distribution patterns for another point in time. The calibrating and forecast testing phases of the research, supplemented with necessary background information relating to each phase, and the detailed procedures utilized and results obtained (when compared with comprehensive home interview data) are reported in this paper.

INTERVENING OPPORTUNITIES MODEL THEORY

The intervening opportunities trip distribution theory is based on the premise that in urban travel, total travel time from a point is minimized, subject to the condition that every destination has a stated probability of being acceptable if considered. The model states that the probability of a trip that originates in one zone finding a destination in another zone is proportional to the possible trip destinations in the other zone and to the number of trip destinations previously considered:

$$T_{ij} = O_i \left[e^{-LD} - e^{-L\left(D + D_j\right)} \right] \qquad (1)$$

where

- T_{ij} = trips originating in zone i and destined for zone j;
- O_i = trip origins in zone i;
- D = trip destinations considered before zone j;
- D_j = trip destinations in zone j;
- L = measure of probability that a random destination will satisfy needs of a particular trip (an empirically derived function describing rate of trip decay with increasing trip destinations and increasing length of trip); and
- e = base of natural logarithms (2.71828).

From this formula, it can be seen that four parameters must be known before T_{ij} can be computed. O_i and D_j are related to the use of land and the socioeconomic characteristics of each zone's traffic-generating population. D_j refers to the number of trips ending in a given zone and O_i refers to the number of trips originating in a given zone, regardless of the zone with which the other end of the trip is associated.

Spatial separation for the intervening opportunities model is measured, not in absolute travel time, time, cost, or distance, but in the number of intervening destinations or opportunities. These intervening destinations or opportunities were determined by time sequencing of possible destination zones from the zone of origin and accumulating the destinations in each of these zones by time sequence. This formula for calculating zone-to-zone movements, as used in previous operational transportation studies, is an integral part of a larger procedure that also adjusts the transportation network after calculating and assigning trips from each zone. The assumption which has always been made, that this does not significantly alter the ordering of zones or trips calculated between zones, has been verified in work reported by Soltman (9). Therefore, the use of the trip distribution model separately appears reasonable.

The probability factor L is empirically derived and describes the rate of trip decay with increasing trip destinations and increasing length of trip and, as such, gives the trip length distribution for a given network and a given set of trip ends.

Trip origins and destinations for each zone were obtained directly from the home interview O-D survey for both 1948 and 1955. Travel times between zones (skimmed trees) were originally calculated for use in previous research from data collected in the field on the type and extent of the transportation facilities available in the area in 1948 and 1955.

Initial values of L were determined empirically and then adjusted through an iterative process to bring the estimated trip length frequency as close as possible to the survey data.

STUDY AREA

The Washington, D. C., transportation study area is shown in Figure 1. As previously mentioned, comprehensive O-D studies were made in Washingtin in 1948 and 1955. All phases of these surveys (i.e., internal, external, truck and taxi) used procedures and sample sizes recommended in the U.S. Bureau of Public Roads Manual of Procedures for Home Interview Traffic Study (10). In 1948 data were collected on travel patterns only (7). Information on 1948 transportation facilities, however, was subsequently derived from secondary sources. In addition to 1955 travel data, information was available on the type, extent, and capacity of the transportation facilities in the area, as well as the use of land in the area, in terms of the type and intensity of use. The 1948 data were used to calibrate and test the base year intervening opportunities model, which was then used to forecast trip distribution patterns for 1955.

The cordon lines were located in approximately the same position in 1955 as in 1948. In some areas the 1955 cordon line was extended outward slightly to incorporate new development. Data for both 1948 and 1955 were assigned to 400 internal and 19 external zones. For summary and general analysis purposes, these 419 zones were combined into 47 districts or analysis areas which, in turn, were combined into 9 sectors. District and sector boundaries are shown in Figure 1.

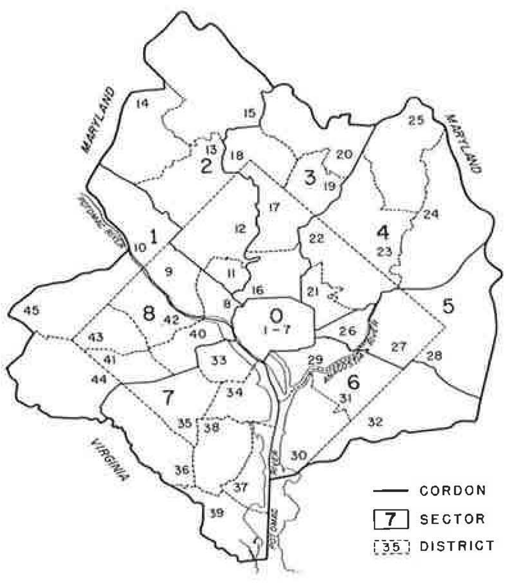

Figure 1. Study area, Washington, D. C., 1948 and 1955.

Probably the most significant change in the study area during the 7-year period was the decentralization of many activities of the urban population. Residential, employment, and shopping activities were all relatively less oriented to the central business district (CBD) in 1955 than in 1948 (11).

The total population increased 38 percent, to approximately 1.5 million during the 7-year interval; the number of internal person trips for all purposes increased slightly over 42 percent. The number of autos owned almost doubled, increasing 96 percent. This increase in auto ownership was reflected in the number of auto-driver trips which increased almost 90 percent. Mass transit trips showed a slight decrease in absolute numbers. Several significant improvements in the transportation system were made during the period between the two surveys, including the additions of the outlying portions of the Shirley Highway, the Spout Run Parkway, the Baltimore-Washington Parkway, and the South Capitol St., East Capitol St., and New York Avenue Bridges.

GENERAL STUDY PROCEDURES

In the use of any trip distribution model, many choices on the manner in which the model will be used are available to the analyst. These choices concern the universe of trips to be used (i.e., peak hour vs total daily trips, person trips vs auto-driver and mass transit trips, total trips in the study area vs trips made only by the residents of the study area, and purpose stratification) and the measure of spatial separation to be used (i.e., driving distance, time or cost vs travel distance, time or cost which includes a measure of terminal time in each zone to account for the congestion involved in parking, and peak hour vs nonpeak hour conditions).

This research project worked with the total daily person trips made by all residents of the area within the cordon line. Total daily trips were used because, in a city as large as Washington, it is desirable to have the total daily patterns rather than a single peak period. Only those trips made by the residents of the study area were used because, among other reasons, the trip length characteristics and the basic reasons for making trips of persons residing within the study area were different from those of persons residing outside but traveling to and from the study area. In addition, the desirability of keeping this research completely comparable to similar research on these same data using other trip distribution procedures was felt important enough to attempt to use person trips in place of auto-driver trips used previously with the intervening opportunities model.

The total travel demands were stratified and used in a number of ways for different research objectives to be discussed later. Both the stratification used previously with the intervening opportunities model and that used previously with other models were tested in this research project. The stratification used in Chicago and other previous applications of the intervening opportunities model is as follows:

Long residential—all home to work trips and trips from home outside the CBD to areas in the CBD for any other purpose;

Long nonresidential—all work to home trips and trips for any other purpose which originate in the CBD and are destined to homes outside the CBD; and

Short—all other trips not counted as long.

The second stratification used in this research has previously been used with the gravity model:

Home-based work—trips between a person's place of residence and his place of employment for the purpose of work;

Home-based shop—trips between a person's place of residence and a commercial establishment for the purpose of shopping;

Home-based social-recreation—trips between a person's place of residence and places of cultural, social, and recreational establishments for social and recreational purposes;

Home-based school—trips, by students, between place of residence and school for the purpose of attending classes;

Home-based miscellaneous—all other trips between a person's place of residence and some form of land use for personal business, medical, dental, and eat-meal purposes; and

Nonhome-based—all trips having neither origin nor destination at home, regardless of the basic trip purpose.

All information from both the 1948 and 1955 travel inventories had previously been verified, coded, and punched into detail trip cards. Trip cards from the home interview survey (No. 2 cards) in both 1948 and 1955 were edited for unacceptable characters and to insure that all pertinent information had been correctly punched. Data from the external cordon and from the truck and taxi surveys were not considered in this study.

The edited records, originally coded during the home interview survey as "change mode of travel" or "serve passenger" trips, were linked. The need for linking results from the standard home interview definition of a trip, where a single trip may be represented by two or more trip records (i.e., a trip involving change of mode). If each of these trip segments were analyzed separately, the relationships between the actual starting point, the ultimate destination, and the purpose of the trip would be lost. It would also be difficult to relate the type and intensity of land use. By linking trips, approximately 5 percent of the surveyed trip records and an estimated 3 percent of the person-minutes of travel were lost. In both 1948 and 1955 these reductions appeared to be geographically unbiased and, therefore, this linking process was judged to be acceptable.

The edited and linked records for each year, sorted by zone of origin, were then used in the trip table building program to obtain tables of zone-to-zone movements for each of the purpose stratifications outlined. The total number of trip origins and destinations by purpose stratification in each zone was obtained through the summary of trip ends program. These constitute two of the parameters required to calculate trip interchanges by the intervening opportunities model. The zone-to-zone movements were later used as test data in various analyses throughout the calibration of the models.

The travel time between zones used in this research consisted of the off-peak minimum path driving time between zones, obtained from field surveys measuring the geometrics and speed on links in the network, plus estimated terminal time at both ends of the zone-to-zone driving time. Terminal time at both ends of a trip transfer was added to driving time to allow for differences in parking and walking times resulting from congestion and parking conditions in these zones.

Terminal time in the analysis network has not been included in previous uses of this model, but findings of this research indicate that greater accuracy is obtained by its use.

With data from both the 1948 and 1955 surveys now available in the form of zone-to-zone movements by purpose, trip ends by purpose, and transportation networks for both years in terms of travel time between zones, the only other information still needed before calibration of the model was the frequency of trip occurrence by 1-min time intervals for each of the selected trip purpose categories. This was found by combining the travel time between zones with the appropriate zone-to-zone trip transfers. The results were later used in the model calibration procedures.

TABLE 1

DISTRIBUTION OF TOTAL PERSON TRAVEL BY PURPOSE OF TRIP WASHINGTON, D. C., 1948 AND 1955[a]

Trip Purpose	Person Trips				Person-Hours of Travel				Avg. Trip Length (min)[b]	
	1948		1955		1948		1955			
	No.[c]	Percent	No.[c]	Percent	No.[c]	Percent	No.[c]	Percent	1948	1955
Home-based:[d]										
Work	713	43.2	–	–	246	47.8	–	–	20.8	–
Shopping	156	9.5	–	–	41	8.0	–	–	15.6	–
Social-rec.	305	18.5	–	–	91	17.7	–	–	17.9	–
School	73	4.4	–	–	20	3.8	–	–	16.1	–
Miscellaneous	181	11.0	–	–	54	10.5	–	–	17.7	–
Nonhome-based	222	13.4	–	–	63	12.2	–	–	16.9	–
Total	1,650	100.0	–	–	515	100.0	–	–	–	–
Long residential	462	27.8	612	26.1	162	31.2	223	30.8	21.0	21.9
Long nonresidential	441	26.5	581	24.8	155	29.9	212	29.3	21.1	21.8
Short	761	45.7	1,149	49.1	202	38.9	289	39.9	15.9	15.1
Total	1,664	100.0	2,342	100.0	519	100.0	724	100.0	18.7	18.5

[a]Based on linked trip figures derived from 1948 and 1955 home interview study.
[b]Based on minimum path zone-to-zone travel time.
[c]In thousands.
[d]Data from 1955 study not included in this research.

When the data were fully assembled, the calibration phase of the research was begun. Several calibration procedures were attempted to determine relative accuracies and ease of application. The total trip universe was first stratified in the two different trip purpose groupings. The resultant trip ends for each of the trip purposes are given in Table 1 for 1948 and 1955.

An attempt was made to calibrate a six-purpose intervening opportunities model using the trip categories as defined and used in previous research in the Washington area with the gravity model (5). The procedure used in this calibration was to obtain a unique L value for each purpose which would result in an estimated mean trip length very closely matching the actual trip length for the appropriate purpose. This approach was evaluated not only from the standpoint of the trip length frequency curves but also for comparison of actual movements and determination of geographic bias.

The next approach used the three purposes as recommended by previous users of this model but with slightly different calibration procedures than previously used.[1] Each purpose was calibrated separately as outlined, with L values adjusted until each purpose model reproduced the average trip length for that particular purpose category of trips. Again the trip length frequency curves, as well as selected estimated movements, were examined.

The third approach utilized the same input trip ends in three categories as the second approach. The procedures used to calibrate this model also closely matched those as developed and used previously with the intervening opportunities model. The output by purpose was used only as information assisting in the calibration of a total purpose model. In adjusting the L values by trip category, no attempt was made to make this purpose estimated average trip length match that of this unique set of trips. Instead, each L was adjusted to bring not only the average trip length but also the trip length frequency curve of the total purpose model into agreement with the total purpose O-D information. Selected movements were examined with the output of the total purpose model using these procedures.

The best approach was selected and used to obtain a final calibrated model for the 1948 Washington, D. C., area. With this model, selected adjustments were made to the final 1948 L values to bring them into focus on 1955 conditions. This was done as nearly as possible as it would have to be done in an operational transportation study. All of the information which could be gleaned from the literature was used to make these adjustments. The actual trip end data from the 1955 survey were used in making these adjustments, as well as in the actual forecast runs of the model. The interest of this research was trip distribution procedures, not trip end estimating procedures; therefore, the ability to forecast trip ends perfectly was assumed.

Thus, the model was used to forecast travel patterns for the 1955 study area, using procedures evolved from the best 1948 calibration runs and input data consisting of these adjusted L values, trip origins and destinations from the 1955 survey, and travel times from the 1955 transportation system. The resulting travel patterns were rigorously tested by comparison to the actual data from the 1955 survey.

CALIBRATION OF 1948 INTERVENING OPPORTUNITIES MODEL

One problem involved in using the formula for the intervening opportunities model (Eq. 1) is the lack of a built-in process to insure that all the trips will be distributed. For a given set of trip destinations in a study area, any particular L value used in the formula will determine the number of trips sent from any zone. The percentage of trips that will actually be sent from a particular zone with a given L and number of trip destinations can be calculated by solving Eq. 1. By summing both sides for all destination zones j, we have

[1] The intervening opportunities trip distribution model has been used in transportation studies in Chicago, Pittsburgh, Upstate New York and other areas, with generally the same approach. Throughout this paper, mention of previous users of this model is meant to be a general reference to those previous studies unless specified otherwise.

$$\sum_{j=1}^{n} T_{ij} = O_i \sum_{j=1}^{n} \left[e^{-LD} - e^{-L\left(D + D_j\right)} \right] \quad (2)$$

Dividing by O_i yields the trips actually distributed from zone i, $\sum_{j=1}^{n} T_{ij}$, over those available to be sent, O_i, on the left side. Next, with expansion of the right side of the equation, $\sum_{j=1}^{n} \left[e^{-LD} - e^{-L\left(D + D_j\right)} \right]$, most of the terms cancel each other, leaving only $1 - e^{-L \sum_{j=1}^{n} D_j}$. The $\sum_{j=1}^{n} D_{ij}$ is nothing more than the total study area destinations which are known. Thus, by setting $100 \times \sum_{j=1}^{n} \frac{T_{ij}}{O_i}$ or the percent of trips sent at 98 or any desired level, the required L can be calculated.

However, an L value so calculated to assure sending the correct number of trips may not provide a satisfactory trip length frequency distribution, as determined from numerous runs using this model with varying L values. These runs indicated that the same ratio of trips actually sent over those available exist at the zone level as well as in the entire study area. If a particular zone was sending 70 percent of the trips available to it, then this percentage would be the same for every other zone and, therefore, for the entire study area. This is to say that the analysis outlined above for zone i can be applied for all zones. Furthermore, these same applications indicated that each receiving zone was also low by approximately the same amount. Thus, by adjusting each of the probability terms in the model $\left[e^{-LD} - e^{-L\left(D + D_j\right)} \right]$ by the same appropriate factor, the correct number of trips would be sent from each zone and, therefore, for the entire study area. This factor can be easily calculated and for ease of operation was applied to the O_i for each zone rather than individually to each of the $\left[e^{-LD} - e^{-L\left(D + D_j\right)} \right]$ terms, since the results would be the same. This adjustment has been added to the original procedures and incorporated into the U.S. Bureau of Public Roads program used throughout this research project. Its use in the BPR program is optional.

As noted previously, this project used only trips internal to the study area. Obviously, if more area is included in the analysis, more destinations will be added and less of a problem will exist in sending out all the trips. Previous uses of this model have employed the externally surveyed trips as well as measures of trip destinations for population centers somewhat removed from the immediate study area. Another objective of this research was to determine if procedures could be developed to work within a relatively closed study area.

With this revised program, the basic calibration of the 1948 model was undertaken. The first approach was to attempt to build six separate models using trip categories used previously with the gravity model and summarized in Table 1. Trip ends for these six purposes and the 1948 transportation system have already been discussed, and all that is needed to apply the model are L values.

The L values determine, for a given network and set of trip ends, the trip length distribution. Early uses of the intervening opportunities model required deriving the L factors empirically. Two such factors were required in most studies, one for the long trips and one for the short trips. The Pittsburgh Area Transportation Study developed an L value for each zone for both long and short trips (4).

Experience in several studies has allowed the development of procedures to obtain realistic first estimates of L factors. To obtain an estimated long L, two methods were used.

First Method (3)

$$\frac{\bar{r}_1}{\bar{r}_2} = \frac{\sqrt{L_2 \; P_2}}{\sqrt{L_1 \; P_1}} \tag{3}$$

where

$\bar{r}_1$, $\bar{r}_2$ = average trip length in miles for cases 1 and 2 where the first case is from a city where the model has already been calibrated;
L_1, L_2 = L values for cases 1 and 2 (L_1 already known); and
P_1, P_2 = trip ends per square mile.

Second Method (13)

$$\bar{r} = K\sqrt{\frac{1}{PL}} \tag{4}$$

where

$\bar{r}$ = average trip length in miles;
K = proportionality constant approximately equal to $\sqrt{2\pi}$;
P = density of study area expressed as trip ends per square mile; and
L = probability of trip termination described earlier.

In the applications reported here, the second method, with slightly revised input, was used to obtain the initial values of L for each of the six trip purposes. The first method requires data from a previously calibrated model for another city which was not available to us for the six-purpose model application. Also, it should be pointed out that in this case it was more desirable to work with the average trip length in minutes instead of miles. If miles were to be obtained, the output of the distribution program would require assignment to the transportation network to obtain average trip length in miles. Without this requirement, the distribution model calibration can be accomplished separately and assignments could await the development of sound zone-to-zone movements.

Information determined from the 1948 Washington, D.C., study results was inserted into the second equation using average trip length in minutes rather than miles and initial values of L calculated for each of the six purposes as follows:

Home-based work, 2.37×10^{-6};
Home-based shop, 19.22×10^{-6};
Home-based soc.-rec., 7.49×10^{-6};
Home-based school, 38.64×10^{-6};
Home-based other, 12.84×10^{-6}; and
Nonhome-based, 11.49×10^{-6}.

These L values were used with the appropriate trip ends and six models were built. The resulting output, in the form of average trip length and trip length frequency curves by purpose were compared to like information from the O-D survey (Table 1). Several runs were required for each purpose, adjusting L each time, before the average trip length of the estimated trips closely matched that from the survey. Table 2 summarizes selected information from the initial and final runs of this model for each purpose. The information in this table, when compared with similar informa-

TABLE 2

SUMMARY INFORMATION FROM INITIAL AND FINAL RUNS, SIX-PURPOSE INTERVENING OPPORTUNITIES MODEL, WASHINGTON, D. C., 1948

Trip Purpose	Person Trips (× 1,000)	Initial Run				Final Run			
		Person-Hours of Travel (× 1,000)	Avg. Trip Length[a] (min)	No. of Intras	L Value (× 10^{-6})	Person-Hours of Travel (× 1,000)	Avg. Trip Length (min)	No. of Intras	L Value (× 10^{-6})
Home-based:									
Work	713	251	21.1	3,378	2.37	246	20.7	3,801	2.85
Shopping	156	54	20.7	1,505	19.22	41	15.6	4,741	67.13
Social-rec.	305	107	21.0	2,998	7.49	91	17.8	5,829	16.16
School	73	24	19.5	815	38.64	19	16.1	1,805	93.65
Miscellaneous	181	62	20.7	1,492	12.84	53	17.6	3,103	21.50
Nonhome-based	222	69	18.6	5,287	11.49	62	16.8	8,641	15.76

[a]Based on minimum path zone-to-zone travel time.

tion from the O-D survey given in Table 1, indicates that the use of the six-purpose models allows the analyst to build a model which will duplicate the average trip length by purpose. However, the total number of intras (trips remaining in a zone) are underestimated by approximately 55 percent. By examining the trip length frequency curves plotted at 1-min travel time increments, it was apparent that satisfactory frequency curves could not be obtained with these procedures. Work and nonhome-based trip categories did fairly well. The work trip length frequency curve for the final model is shown plotted against the O-D data in Figure 2. However, when all purposes are combined, the total purpose trip length frequency indicates a very inadequate duplication of the O-D survey data. This can be seen by examining Figure 3.

Two other tests were made on the final work trip model to determine the accuracy of selected estimated movements. Figure 4 shows a comparison of the predicted movements against the O-D movements to the CBD for work trips and Table 3 gives a comparison of estimated to actual work trips crossing the Potomac and Anacostia Rivers. Both of these tests indicate that the model is simulating travel patterns fairly well; however, because of the inability to simulate the trip length frequency by 1-min increments satisfactorily for all purposes, the procedure using six separate purpose models, each with a unique L value, was deemed unsatisfactory.

The second approach used to calibrate the intervening opportunities model used similar reasoning and procedures as the first, but total trips were stratified according to the second group summarized in Table 1, namely, long residential, long nonresidential, and short. Using trip ends stratified into these trip categories and long and short L values of 3.11 × 10^{-6} and 5.60 × 10^{-6}, respectively, calculated using Eq. 4, the first estimate of travel patterns was obtained. Several runs were again made to obtain an L which, when applied, would give an average trip length closely matching that

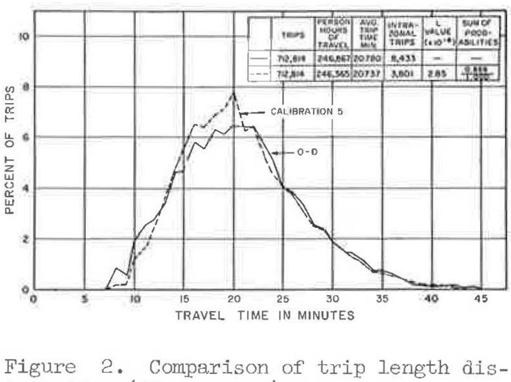

Figure 2. Comparison of trip length distribution (OD vs model), work trips, Washington, D. C., 1948.

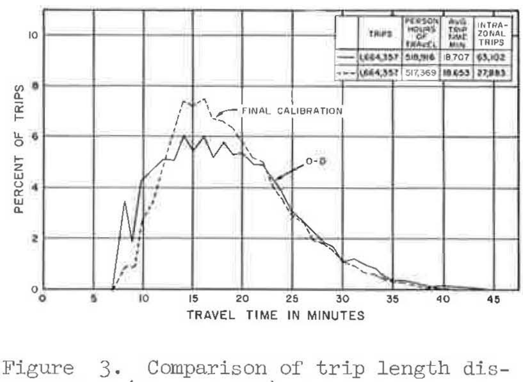

Figure 3. Comparison of trip length distribution (OD vs model), total trips, six-purpose model, Washington, D. C., 1948.

TABLE 3

COMPARISON OF TRIPS CROSSING POTOMAC AND ANACOSTIA RIVERS, HOME INTERVIEW SURVEY VS INTERVENING OPPORTUNITIES MODEL, WASHINGTON, D. C., 1948

Calibration	Trip Purpose	Potomac River						Anacostia River					
		Orig. in Va. (× 1,000)		Diff.[a] (%)	Orig. in Md. & D. C. (× 1,000)		Diff.[a] (%)	Orig. South of River (× 1,000)		Diff.[a] (%)	Orig. North of River (× 1,000)		Diff.[a] (%)
		Survey	Model		Survey	Model		Survey	Model		Survey	Model	
(a) Work Trip Model													
5	Home to work	70	90	+29	44	39	-12	83	90	+ 8	16	13	- 8
(b) Three-Purpose Model													
4	Long residential	52	63	+21	23	20	-12	57	61	+ 6	9	7	-24
	Long nonresidential	22	34	+55	50	54	+ 8	8	12	+49	54	43	-21
	Short	25	47	+91	25	18	-30	26	40	+53	29	15	-47
5	Long residential	52	57	+10	23	29	+27	57	59	+ 2	9	11	+25
	Long nonresidential	22	33	+49	50	61	+23	8	11	+36	54	57	+ 4
	Short	25	32	+30	25	23	- 7	26	28	+ 7	29	24	-18
(c)													
7	Total	98	114	+15	98	127	+29	92	92	0	92	105	+14
8	Total	98	103	+ 4	98	85	-13	92	95	+ 3	92	99	+ 8

[a]Computed before rounding.

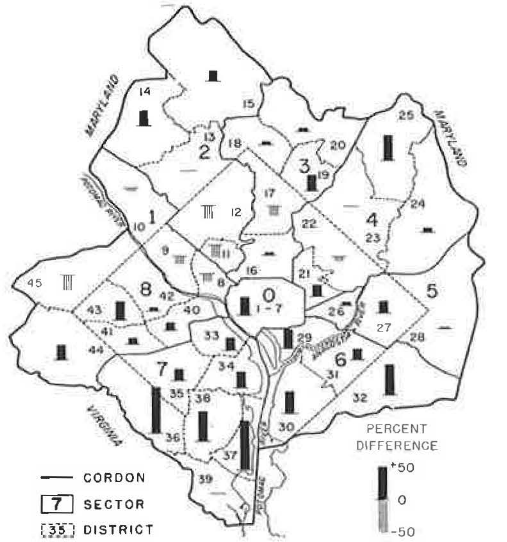

Figure 4. Comparison of work trips to zero sector, home-based work model, calibration 5, Washington, D. C., 1948.

from the appropriate trip category of the actual survey trips. Table 4 summarizes each of these runs. This desired objective was accomplished with two adjustments in L values for the long categories and three for the short trips. Selected information from these runs is shown on Figures 5 through 7, along with the initial and last estimate of trip length frequency. Again, it can be seen that the trip length frequency curves are not necessarily in close agreement with the O-D curve just because the average trip length is close. The curves for the long categories were in fairly close agreement, but the short category exhibited significant bias in some portions of the curve. As was the case with the six-purpose model, the intrazonal trips were considerably underestimated.

With the average trip length in agreement by purpose and, therefore, by total, but with known inadequacies in the number of intrazonal trips and the predicted trip length frequency curves, additional tests were made to examine more directly the trip movements as predicted by the model. Trips estimated by the model from each district to the CBD were examined and compared to the actual patterns. This comparison is shown on Figure 8. When compared to the O-D data, almost every district showed an overestimate of travel predicted by the model to this central part of the city; the average overestimate was 20 percent. Of course, with such a poor comparison within the CBD, other parts of the study area would necessarily have fewer trips ending than desired. A comparison of trips esti-

TABLE 4

SUMMARY INFORMATION FOR CALIBRATION OF THREE-PURPOSE INTERVENING OPPORTUNITIES MODEL, WASHINGTON, D. C., 1948

Trip Purpose	Run No.	Total Trips (× 1,000)	Person-Hours of Travel (× 1,000)	Avg. Trip Length[a] (min)	Intratrips	L Value ($\times 10^{-6}$)
Long residential	O-D	462	162	21.0	4,369	—
	1	462	165	21.4	1,780	3.11
	2	462	164	21.3	1,806	3.23
	3	462	162	21.0	2,042	3.88
	4	462	162	21.0	2,042	3.88
Long nonresidential	O-D	441	155	21.1	4,117	—
	1	441	154	21.0	1,646	3.11
	2	441	154	21.0	1,646	3.08
	3	441	155	21.1	1,618	2.96
	4	441	155	21.1	1,618	2.96
Short	O-D	761	202	15.9	54,616	—
	1	761	232	18.3	16,160	5.60
	2	761	217	17.1	20,983	7.38
	3	761	206	16.3	25,572	9.05
	4	761	203	16.0	27,494	9.75

[a]Based on minimum path zone-to-zone travel time.

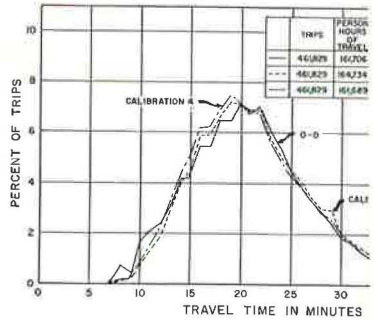

Figure 5. Comparison of trip
tribution (OD vs model), long
trips, Washington, D. C.,

mated to arrive at each zone i
the O-D survey. A statistical
are given for short trips in Ta
approximately the same for ea

To complete the analysis o
mated movements across the
known movements crossing th
dicate very strongly the same
does the previously discussed
by the overestimate of trips in
each river.

To document the accuracy o
process, both the estimated ar
district-to-district interchang
of this analysis by volume gro

After establishing the stron
trips received by zone, proced
be incorporated to insure that
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the river crossing bias.

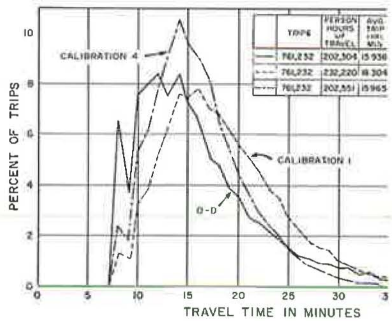

Figure 7. Comparison of trip
tribution (OD vs model) short t
ington, D. C., 1948.

An additional calibration run was made using the same input data as the one just discussed, but allowing the destinations to be adjusted by one iteration. This run was analyzed in much the same manner as the previous one to determine the effect of balancing the destinations. The results showed that the estimated total average trip length was increased to 18.924 min from 18.714 min. The trip length frequency curve was improved somewhat but still exhibited significantly different characteristics than the survey data. Of course, the trips sent and received by each zone were in approximate balance as designed.

Trips estimated by the model from each district to the CBD are compared in Figure 9 to the actual movements. This comparison shows a considerable improvement in these movements using the balanced trip destinations in the model. Table 3 indicates very little improvement in the total number of trips estimated to cross these two rivers. The assumption that the overestimate of river crossings would be substantially improved was, therefore, shown to be wrong.

Finally, the estimated zone-to-zone interchanges were compressed and compared statistically to the survey data (Table 6). When these results are compared with the results from calibration 4 (Table 6), the increased accuracy in the district-to-district movements brought about by balancing the destinations can be seen.

The procedures just discussed for calibrating the intervening opportunities model were rejected for much the same reasons as the first set of procedures. By attempting to develop a unique L value for each purpose of trip (long residential, long nonresidential and short) which will simulate the average trip length for the same group of survey trips, problems are encountered in other tests made on the model. The most basic problem is that even though the average trip lengths are in close agreement, the trip length frequencies do not exhibit close agreement.

Because of this problem, a third approach, very similar to that used in many previous applications of the intervening opportunities model, was tried. First, trip ends are stratified into long residential, long nonresidential and short categories. Next an L for short trips is estimated which will provide output giving approximately the correct number of intrazonal trips. Finally, one single L value for the long trips is chosen which, when applied to the two subcategories of long trip ends and combined with the short trips, will add up to a satisfactory duplication of the total purpose trip length frequency curve and average trip length.

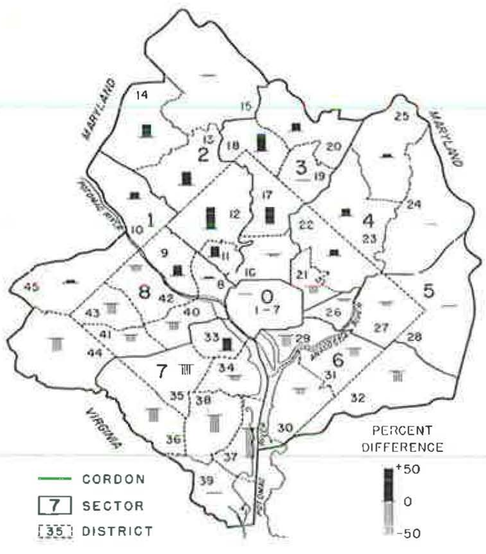

Figure 9. Comparison of total trips to zero sector, three-purpose model, calibration 5, balanced destinations, Washington, D. C., 1948.

With these procedures in mind, new L's were estimated by examining, first of all, the short L needed to send out the correct number of intrazonal trips. Next, an estimate of the person-hours of travel which such a short L would contribute was estimated by examining previous runs of the short trip category. This was subtracted from the total person-hours desired and a long L was estimated, again from previous runs which would combine to provide the desired total purpose hours of travel. These L values were estimated to be 17.0×10^{-6} for the short category and 0.5×10^{-6} for the long category.

With these revised L values and the trip ends broken down into long residential, long nonresidential and short, the model was run again. The total estimated intrazonal trips of 52,194 compare much more favorably with the survey intrazonal trips of 63,102 than do any previous runs. The total purpose estimated average trip length

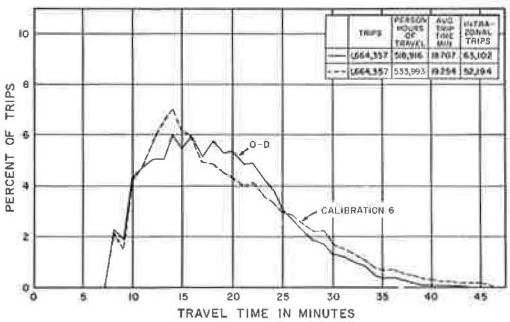

Figure 10. Comparison of trip length distribution (OD vs model), total trips, Washington, D. C., 1948.

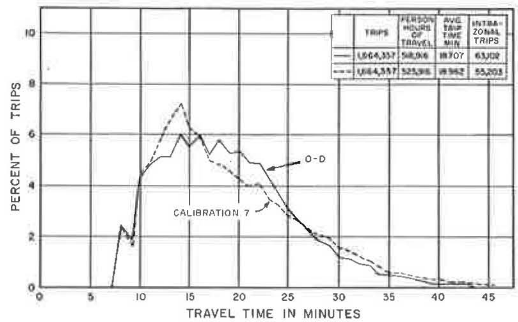

Figure 11. Comparison of trip length distribution (OD vs model), total trips, Washington, D. C., 1948.

of 19.254 min was slightly greater than the 18.707 min from the survey. The information showing estimated vs actual trips by trip length for the total purpose is shown in Figure 10.

This output was examined very closely and each L value was adjusted to bring the model results in terms of average trip length and the trip length frequency curve for total purpose trips into closer agreement with the desired objectives. Those revised L values are 18.0×10^{-6} for short trips and 1.0×10^{-6} for long trips.

The revised L values were used to obtain a new estimate of travel patterns for the study area. This time, 55,203 intrazonal trips were predicted as compared to the desired total of 63,102. The new average total purpose trip length of 18.962 min was also much closer to the desired 18.707 min from the survey.

Information showing trips estimated vs trips from the O-D survey by trip length is shown in Figure 11 for total trips. Some parts of this curve have been improved and other parts have decreased in accuracy when compared to the actual survey data.

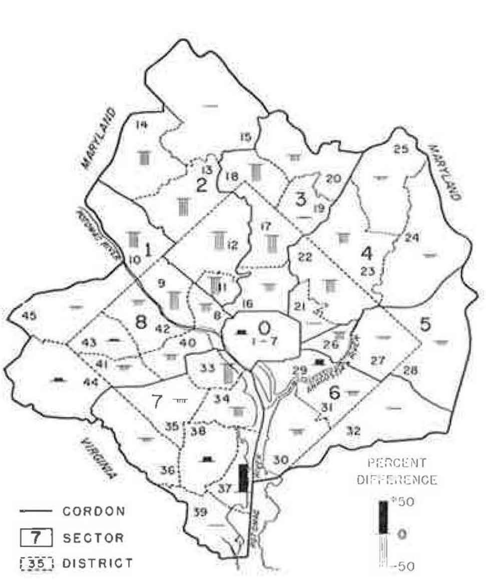

Figure 12. Comparison of total trips to zero sector, total purpose model, calibration 7, Washington, D. C., 1948.

A full set of tests was run on the output of this particular application of the model. Total purpose trips estimated from each district as compared with the O-D survey data to the CBD are shown in Figure 12. Although almost every district to CBD movement is underestimated, the results agree fairly well with actual data.

Table 3 indicates that problems still exist in predicting the correct number of trips crossing the Potomac River, but there is no problem with the Anacostia crossings.

As in previous runs of the model, the estimated zone-to-zone trip transfers were compressed to district-to-district tables and compared statistically to similar information from the O-D survey. The results are given in Table 7. Since the method being used to calibrate the model in this run was directed at satisfactory simulation of the total purpose travel patterns only, the comparison is for total purpose.

Examination of the various tests made on this output shows two problem areas. The first can be seen by comparing the

TABLE 7

FREQUENCY DISTRIBUTION AND ANALYSIS OF DIFFERENCES, TOTAL PURPOSE, DISTRICT MOVEMENTS, O-D VS INTERVENING OPPORTUNITIES MODEL, WASHINGTON, D. C., 1948

Volume Group	Frequency	O-D Mean Volume	Calibration 7			Calibration 8		
			Model Mean Volume	RMS Error		Model Mean Volume	RMS Error	
				Abs.	Percent		Abs.	Percent
0- 499	1,066	174.33	229.65	147.69	84.72	212.74	139.67	80.12
500- 999	257	711.55	755.66	275.02	38.65	750.72	323.94	45.53
1,000- 1,999	203	1,414.45	1,404.33	460.53	32.56	1,437.68	485.60	34.31
2,000- 2,999	78	2,574.65	2,267.94	761.77	29.59	2,403.04	792.21	30.77
3,000- 3,999	59	3,423.56	3,099.20	940.15	27.46	3,219.47	966.46	28.23
4,000- 4,999	29	4,425.83	4,495.03	1,320.88	29.84	4,812.66	1,261.42	28.50
5,000- 5,999	14	5,352.43	4,898.07	1,493.25	27.90	5,205.86	1,491.16	27.86
6,000- 7,999	9	6,541.44	7,317.89	2,718.33	41.56	7,042.11	1,986.34	30.36
8,000- 9,999	11	9,287.64	7,851.64	2,508.32	27.01	8,078.18	2,789.98	30.04
10,000-14,999	10	12,114.80	9,662.30	2,805.49	23.16	8,871.70	3,878.95	32.02
15,000-49,999	6	20,040.05	20,755.67	3,912.93	19.53	19,354.83	2,871.91	14.33

information on Figure 11 to that on Figure 10. Even though the use of a higher L value for the short trips in the latter run brought the intrazonal trips into closer agreement, it also had a detrimental effect on the trip length frequency curve by raising the peak so as to make the first portion of that curve worse. However, the increase of the long L values improved the curve in the range of 15 to 50 min. It is apparent that some compromise must be made between the number of intrazonal trips estimated and the trip length frequency. Because intrazonal trips vary by zone size, it appeared more reasonable to place greater emphasis on the trip length frequency.

In addition, to attempt to correct the bias in the estimated Potomac River crossings, a value of 5 min was added to all network links crossing this physical barrier to free travel. This procedure has also been found necessary in applying the gravity trip distribution model to the Washington area (5).

The results of these adjustments showed significant improvements in several key parameters of the model output. First, the total purpose trip length frequency curve showed improvement in the peak range of trip occurrence around 15 min brought about by reducing the L value for short trips. Next, the curve was improved in all times greater than 15 min resulting from the increased value of the long L. As was expected, that portion of the curve prior to 10 min was reduced in accuracy as the short L value was decreased. The average trip length of 19.419 min as predicted by the use of these L values compares quite favorably with the survey information of 19.297 min. Both the survey and model information reflects the use of the 5-min barrier. As expected, the intrazonal estimated trips were decreased to 41,834. This information is shown on Figure 13.

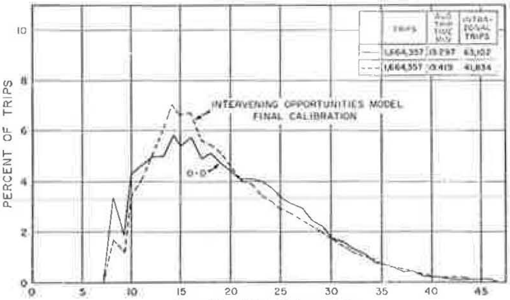

Figure 13. Comparison of trip length distribution (OD vs model), total trips, Washington, D. C., 1948.

Table 3 illustrates that with the use of the 5-min time barrier the problem of overestimating trips across the Potomac River is eliminated. Figure 14 shows a comparison of trips estimated from each district to the CBD to those known to make these movements from the O-D survey. This comparison indicates no strong geographical bias in model results.

Examination of the output from this run shows that the model is very close to the original goals of the calibration process. The average trip length for the estimated total trips is very close to that for the surveyed trips. Likewise, the trip length frequency curve of estimated total person

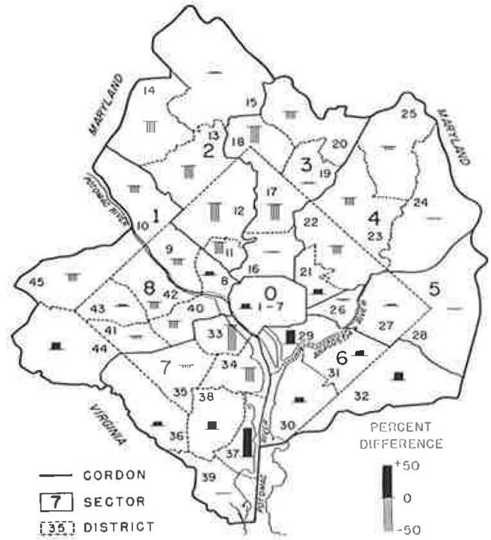

Figure 14. Comparison of total trips to zero sector, total purpose model, calibration 8, Washington, D. C., 1948.

trips is in closer agreement with the O-D survey data using this set of L values than with any previous runs of the model. Some thought was given to adjusting the L values again in an attempt to bring the model results closer. The peak of the travel occurrence could be reduced somewhat, but the number of intras would be further underestimated along with trips occurring from time 0 to 14 min in the trip length frequency curve. The use of the 13.0×10^{-6} and 2.5×10^{-6} L values gave results which come close to matching the 1948 travel patterns. Some compromise in accuracy must be made between the various parameters tested when using only two values of L.

By using a 5-min time barrier in the transportation network, a satisfactory estimate of trips crossing the two rivers was obtained.

The total purpose trip tables were compressed to district-to-district tables and compared statistically with the same information from the O-D survey. Results of this test are shown in Table 7 and indicate that the model was satisfactorily duplicating the survey data.

Out of the several calibration runs of the model, using the six-purpose and three-purpose trip ends and the three sets of calibration procedures, calibration 8 proved to be the best. This particular calibration has just been described. With this final model calibrated for 1948 conditions, necessary changes in the final L values could be made and the model applied to 1955 trip ends and transportation system to test the forecasting ability of the model.

FORECASTING 1955 TRAVEL PATTERNS

The next phase of the research was the forecasting of travel patterns for the 1955 Washington area. Trip ends were available for each zone for the three categories of trips. Likewise, the 1955 transportation network was available. The final 1948 L values required adjustment to fit the 1955 conditions. To do this, maximum use was made of published information on the procedure by previous users (1, 3, 4). It is well accepted that as the number of trips increase, L values should be reduced. Specifically, adjustments to obtain 1955 L values were made relying heavily on the procedures and reasoning used by CATS (1, p. 88).

The long L value for 1948 of 2.5×10^{-6} was adjusted by a factor of $1/1.4 \times 1/2$ to a value of 1.65×10^{-6} for 1955 conditions. This is the ratio of present trips to future trips multiplied by ½. Since there is an increase of 40 percent in the number of opportunities or destinations in the study area, it is apparent that the probability that any one destination will be acceptable to a particular origin will be reduced. The reduction in this case made in the 1948 L values to bring them into focus for the 1955 conditions was made following the CATS procedures (1).

The CATS final report suggests that the relationship of present short L value times present number of intrazonal trips equal to future short L value times future number of intrazonal trips can be used to calculate the future short L value. Thus, by knowing the future number of intrazonal trips, the future short L value may be obtained.

However, the number of intrazonal trips increased over 100 percent from 1948 to 1955 and, therefore, the recommended relationship of short L (1948) times volume of intrazonal trips (1948) equal to short L (1955) times volume of intrazonal trips (1955) did not appear reasonable, since this would reduce the 1955 L value for the short trips by over 50 percent.

The L value for short trips for 1955 was obtained by reducing the 1948 short L by 17 percent or half of the reduction for the long L value. This gave an answer of 10.80×10^{-6} for the 1955 short L value. This reduction was in about the same relationship to the reduction in the long L value as that made in Chicago (1).

These estimated 1955 L values, along with the appropriate 1955 trip ends and 1955 transportation system, revised to include the same 5-min time barrier on Potomac River crossings, were used in the model to forecast travel patterns for 1955.

The first information checked was the agreement of the trips received by zone as predicted by the model to those which were known to have been received by zone in the survey data and were coded as destinations in the first run. Again, as found in calibration 4, the CBD zones were all high in number of trips received. The total trips received by the CBD as estimated by the model was 51 percent too high. Therefore, the 1955 destinations were adjusted as outlined previously for the 1948 calibration 4 and the model was rerun using exactly the same input data with the adjusted destinations coded by zone.

The output for the total purpose trip length frequency is plotted with the actual trip length from the survey trips in Figure 15. The results show comparatively good agreement of the forecasted with the actual patterns when evaluated from a trip length frequency standpoint. The forecasted average trip length of 20.262 min is slightly over 1 min greater than the actual average trip length of 19.073 min from the surveyed travel patterns. Depending on the ability to forecast the average trip length accurately, either in time or distance, adjustment of the two L values might be in order if this forecast were being done in an operational study. The forecasting of such parameters is the subject of much interest and research at the present time. There did not appear to be sufficient evidence regarding trip length changes or trends to justify a correction in the forecast from the results obtained.

Trips estimated to the CBD were isolated and are compared to the actual movements in 1955 in Figure 16. The accuracy of these forecasts compares favorably with the same comparisons made with the final 1948 calibration run, shown in Figure 14.

As was done for 1948, the estimated and actual zone-to-zone movements were compressed to district-to-district movements and compared. This comparison was done by volume group and the results are given in Table 8. These results show, as would be expected, that the errors are slightly greater for the 1955 forecast comparisons than for the 1948 calibration comparison.

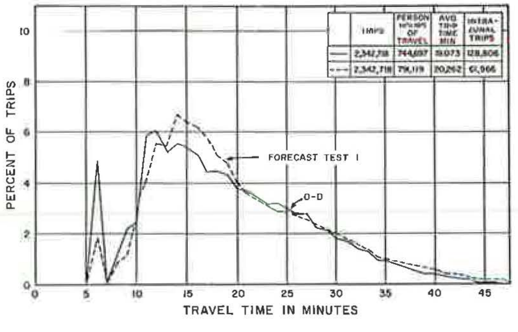

Figure 15. Comparison of trip length distribution (OD vs model), total trips, Washington, D. C., 1955.

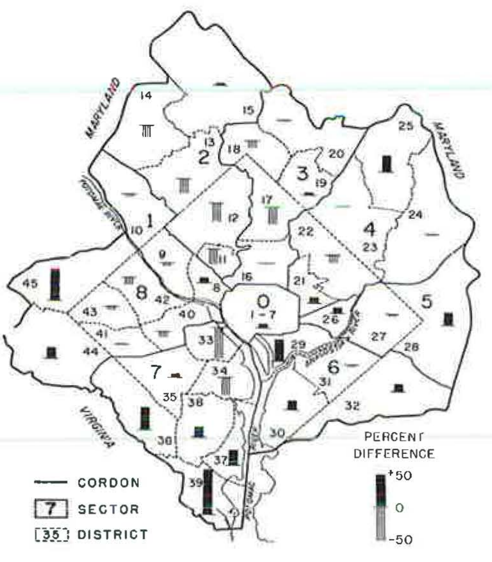

Figure 16. Comparison of total trips to zero sector, forecast 1, 5-min time barrier, Washington, D. C., 1955.

TABLE 8

FREQUENCY DISTRIBUTION AND ANALYSIS OF DIFFERENCE, TOTAL PURPOSE, DISTRICT MOVEMENTS, O-D VS INTERVENING OPPORTUNITIES MODEL, WASHINGTON, D. C., 1955

Volume Group	Frequency	Forecast 1[a]				Forecast 2[b]			
		Mean Volume		RMS Error		Mean Volume		RMS Error	
		Survey	Model	Abs.	Percent	Survey	Model	Abs.	Percent
0- 499	1,042	185.56	273.06	159.83	86.58	184.60	272.19	138.77	75.17
500- 999	356	732.78	842.01	340.78	46.50	732.78	844.19	346.35	47.27
1,000- 1,999	251	1,406.84	1,504.77	547.71	38.93	1,406.84	1,501.97	553.94	39.37
2,000- 2,999	126	2,416.34	2,669.71	887.72	36.74	2,416.34	2,670.18	888.75	36.78
3,000- 3,999	77	3,489.47	3,388.36	954.15	27.34	3,489.47	3,390.26	963.89	27.62
4,000- 4,999	43	4,429.81	4,409.60	1,429.92	32.28	4,429.81	4,418.65	1,424.46	32.16
5,000- 5,999	15	5,547.20	5,416.53	880.42	15.87	5,547.20	5,416.87	877.26	15.81
6,000- 7,999	17	6,742.06	5,581.53	2,298.20	34.09	6,742.06	5,588.88	2,297.78	34.08
8,000- 9,999	12	8,725.83	7,845.75	2,219.38	25.43	8,725.83	7,855.58	2,209.69	25.32
10,000-14,999	12	11,983.92	8,132.83	4,632.03	38.65	11,983.92	8,132.33	4,632.63	38.66
15,000-49,999	15	21,760.53	14,847.67	7,533.21	34.62	21,760.53	14,846.69	7,534.10	34.62

[a]Using 5-min barrier.
[b]Using 8-min barrier.

Finally, the river crossings as estimated by the model are compared to the actual crossings for 1955 in Table 9. Even with the use of the 5-min barrier on those links crossing the Potomac, the model overpredicted trip crossings by 22 percent.

Past research showed the need for the same type of barrier for the gravity model and, in addition, showed a quantity of barrier needed in 1955 different from that needed in 1948. The results indicated that the same might also be true with the intervening opportunities model. Using the same procedures as developed in earlier gravity model research, the required adjustment was made by assuming a direct relationship between congestion level for the 2 years and the required time barriers for each time period (5). The volume-to-capacity ratios for both periods were already known, as well as the time barriers required by the intervening opportunities model in 1948. Using this information, a revised time barrier of 8 min for 1955 was established. The transportation system input was updated to reflect the change and the model was run again with otherwise unchanged input data.

The predicted output for the total purpose trip length frequency based on an 8-min time penalty for river crossings is plotted with actual trip length in Figure 17. There is little change in the degree of agreement of these two curves from the previous run shown in Figure 15. The forecasted average trip length of 20.639 min compares with the actual average trip length of 19.388 min. Both the model and survey data include the effect of the 8-min time barrier.

Trips estimated to the CBD were isolated and are compared in Figure 18 to the actual movements in 1955. The improvement made by including the extra 3-min time barrier can be seen by comparing this figure with Figure 16.

Table 9 indicates that the use of the 8-min time barrier improved the ability of the model accurately to reflect trips crossing the Potomac River in 1955. However, the model results were still 16 percent high even with use of the 8-min barrier.

TABLE 9

COMPARISON OF TOTAL TRIPS CROSSING POTOMAC AND ANACOSTIA RIVERS, FORECAST VS HOME INTERVIEW SURVEY, WASHINGTON, D. C., 1955

Forecast	Potomac River						Anacostia River					
	Orig. in Va. (× 1,000)		Diff.[a] (%)	Orig. in Md. & D.C.		Diff.[a] (%)	Orig. South of River		Diff.[a] (%)	Orig. North of River		Diff.[a] (%)
	Survey	Model		Survey	Model		Survey	Model		Survey	Model	
1	123	153	+24.0	123	148	+20.2	144	163	+13.3	144	153	+6.3
2	123	149	+20.8	123	139	+12.6	144	163	+13.3	144	155	+8.1

[a]Computed before rounding.

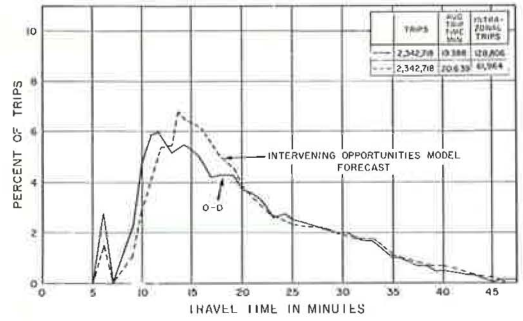

Figure 17. Comparison of trip length distribution (OD vs model), total trips, Washington, D. C., 1955.

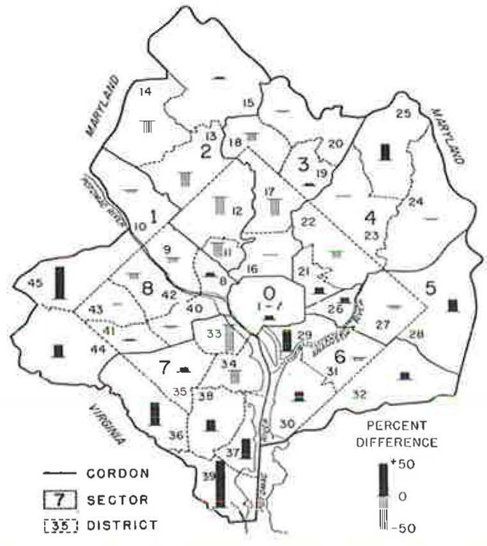

Figure 18. Comparison of total trips to zero sector, forecast 2, 8-min time barrier, Washington, D. C., 1955.

The estimated zone-to-zone movements were again compressed and compared to actual movements (Table 8). By using the 8-min time barrier, the comparisons of these movements have been improved only slightly. Although the various tests indicate that a small improvement has been introduced by the incorporation of the additional 3-min barrier, the value of such adjustment lies in the reduction of bias in the important river crossing prediction. One additional test was made using a time penalty of 10 min to determine if the overestimate of 16 percent for trips crossing the Potomac River could be reduced. There was a very small improvement, reducing the overestimate to 14 percent. From selected skim trees, it was determined that the inclusion of the 10-min barrier had re-sorted the zones by time sequence so that almost all the zones located on the same side of the river as any given origin zone would be considered in the model before any zone on the opposite side of the river. In other words, the improvement made in the model in calculations of trips crossing the river through the use of a time penalty had reached a cutoff point. Any further increase in the quantity of the penalty would have very little effect in these calculations.

The various tests outlined indicate that the intervening opportunities model can be used to forecast travel patterns. When the different procedures used in the forecasts are compared, it is evident that both trip origin and destination adjustments are as necessary in the forecasting stage of this model as in the calibration stage. Likewise, if time barriers are required in the calibration stage, they should be estimated for the forecast year by analysis of the tolerable level of congestion over these facilities for the design year and use of the present relationship between barriers and level of congestion. This area still requires substantial research to insure a more accurate forecasting procedure. The forecasted L values could be improved if total person hours of travel could be forecast accurately. Research presently under way should improve this ability considerably (12, 13). However, with the adjustments made in L values for 1955 conditions, with the knowledge of total number of future trips only, travel patterns were estimated to a reasonably accurate level.

SUMMARY AND CONCLUSIONS

This research provides comprehensive evaluations of the intervening opportunities model as a procedure for simulating present and forecasting future urban travel patterns. Data from the Washington, D.C., 1948 home interview survey were used to calibrate the basic intervening opportunities model and test this model for its ability to simulate current travel patterns. The 1955 O-D survey data were used in the analysis of forecasts over the 7-year period made by this model.

As part of this research, the original computer programming for this model was modified to make this theory of trip distribution available with input-output format which fits easily within other computer programs for transportation planning and analysis commonly in use throughout the country (14, 15). The basic program, with the exception of different input and output requirements, operates in the same manner as does the trip distribution portion of the total Chicago distribution and assignment package. The input and output of this program are discussed elsewhere. As research findings necessitated, two additional and optional features have been added to the basic program: (a) an adjustment which applies a uniform factor to all zonal origins to insure that all trips available are actually sent; and (b) an adjustment which operates in much the same manner, but at the opposite end of the trip. Zonal destinations are adjusted for an additional running of the program by examining the output of an initial pass of the program to insure that each zone receives approximately the correct number of trips.

In the calibration phase of this research, two methods of calibrating the model were tried. The first, using two different classifications of total trips, attempted to calibrate each purpose separately. The probability value (L) was adjusted until the average trip length for the estimated trips for that particular purpose was in close agreement with the actual average trip length for the same purpose. The two sets of trips for which these procedures were attempted were (a) home-based work, shop, school, social-recreation and other, and nonhome-based; and (b) long residential, long nonresidential, and short trips. The second classification of trips is that used in previous operational transportation studies utilizing the intervening opportunities model. Calibrating each purpose independently was not satisfactory for either set of trip categories tried.

The second method of calibration was accomplished using the long residential, long nonresidential, and short trip end categories but calibrating in a different manner. Each L value for a particular category of trips was adjusted based on the influence this category of trips plays on the total purpose trip distribution patterns, not to bring that category of trips into agreement with survey data.

A satisfactory duplication of 1948 travel patterns was obtained, using the second method of calibration, but with the following additional adjustments to the model. First, procedures had to be developed to insure that all trips were sent from each zone. Secondly, similar adjustments were found necessary to insure that each zone attracted approximately the correct number of trips. Of course, the need for such adjustments also exists with regard to other trip distribution models (5). Finally, a barrier to free travel in the form of a 5-min time barrier was necessary before the model would accurately distribute travel over the Potomac River.

The steps required to calibrate the intervening opportunities model should follow an orderly calibration procedure as just discussed. Sufficient testing of model results should be made to insure (a) that the correct number of trips are being sent; (b) that the average trip length and complete trip length frequency for total purpose trips are in close agreement with those from the O-D survey; (c) that trips received by each zone of the area are in close agreement to previously set zonal controls; and (d) that important movements such as river crossings or trips to large attractors, such as the CBD, do not reflect bias.

Such procedures were followed closely during the 1948 model calibration phase of this research, and the results clearly indicate that this model will provide an adequate duplication of travel patterns for the present period of time.

Several other observations should be made here. As stated earlier, the application of the intervening opportunities model reported here was the first to use a measure of terminal times in the analysis network. It is apparent that the overestimate of trips to the CBD would be even higher without the inclusion of the relative higher values of terminal times in the CBD.

The applications reported here used all person trips. In previous applications of this model, auto-driver equivalents have been used. There are apparently no unique problems in either approach and the decision on which to use depends primarily on considerations other than trip distribution, such as trip generation and modal split procedures.

There are also some questions raised when the model is examined closely regarding the extent of study area to be analyzed. The application reported here used only internal to internal trips. Other applications of this model have not only included the external surveyed trips but have also included some artificial measure of trip pull for population centers widely separated from the study area. By including the external trips, the need for adjustments to send all trips may be reduced or even eliminated. However, there is no indication that the use of internal trips only with the procedure to force all these trips to be sent introduced any bias in the estimated travel patterns.

Finally, the Chicago Area Transportation Study has recently developed procedures to apply a set of short L values in work being done by them in the Fox River Valley (16). These short L values are related to trip end density in the vicinity of the origin zone and the relationship used to forecast future short L values. The Upstate New York Transportation Studies have also been using a set of short L values and have applied them by ring instead of trip end density. Examination of the tests made in this paper indicate that the short category of trips are always the major problem. Both long residential and long nonresidential patterns are easily reproduced by the model. Future research and improvements in the applications of this model may well be in the area of a variable set of short L values.

Detailed tests of the forecasting ability of the intervening opportunities model were also made. From these tests several additional conclusions are evident. First of all, proper adjustments made to the present L values for the future year are critical in developing the model to the point where it can provide reliable future trip distribution patterns. The adjustments made in this research depended primarily on knowing only the total growth in trips. The use of the adjusted L values in this paper, based on this limited information, gave largely satisfactory results. However, the forecasting of L values would be strengthened enormously with additional knowledge of trends in trip length, either in time or distance, and with an increase in the ability to forecast more accurately the number of future intrazonal trips.

Finally, this research substantiated previous findings regarding the forecasting of time penalties required by physical barriers through the use of predicted tolerable congestion levels. The use of these penalty forecasting procedures did not completely eliminate error in river crossing prediction but did substantially improve them.

In conclusion, based on testing model forecasts over a 7-year period, the use of the intervening opportunities model to simulate and forecast urban travel will give satisfactory results if properly calibrated and tested. Even within the limited 7-year period, the total trips grew over 40 percent and several significant changes in the transportation system were made. The level of accuracy of the forecast year compares quite favorably with the levels of accuracy for the calibrated model measured against O-D survey data for the base year. Additional research into trip length trends and relationships should further strengthen the value of the intervening opportunities model.

ACKNOWLEDGMENTS

Much assistance has been given the study group during the last 2 years by individual members of several transportation studies, including the Chicago Area Transportation Study, Pittsburgh Area Transportation Study, Tri-State Transportation Committee, and the Upstate New York Transportation Studies. Without their help this research could not be reported.

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Discussion

ROBERT T. HOWE, Associate Professor of Civil Engineering, University of Cincinnati—The author is to be commended on his generally clear and detailed explanation of a rather complicated subject. This commentator must, however, raise several questions about the validity of the intervening opportunities model for predicting trip patterns.

In Eq. 1, L is defined as a "measure of probability that a random destination will satisfy the needs of a particular trip," and yet nowhere in the discussion is any apparent attempt made to make the summation of these L's be unity, or certainty. This commentator cannot understand the manipulations of this equation when the author says:

"Next, with expansion of the right side of the equation, $\sum_{j=1}^{n}\left[e^{-LD}-e^{-L\left(D + D_j\right)}\right]$,

most of the terms cancel each other, leaving only $1 - e^{-L}\sum_{j=1}^{n} D_j$."

$$\sum_{j=1}^{n}\left[e^{-LD}-e^{-L\left(D + D_j\right)}\right] = \sum_{j=1}^{n}\left[e^{-LD}-e^{-LD}\cdot e^{-LD_j}\right]$$

$$= \sum_{j=1}^{n} e^{-LD}\left[1 - e^{-LD_j}\right]$$

$$= e^{-LD}\left[1 - e^{-LD_1} - e^{-LD_2} - e^{-LD_3}\ldots\right]$$

$$\neq e^{-LD}\left[1 - e^{-L\left(D_1 + D_2 + D_3 \ldots\right)}\right] \qquad (6)$$

Early in Part E of the paper the author states that the model may not send enough trips out of a zone of origin or to a zone of destination, but when one uses a 5 percent or a 3 percent sample O-D survey as a source of information, he never really has correct information on such important statistics as how many workers really live in each zone or how many jobs are available in each zone. Would it not be well if an employment inventory were made at the same time that the dwelling unit inventory is made for the O-D survey?

Under his explanation of the method for determining preliminary values of "L," the author states "Also, it should be pointed out that in this case it was more desirable to work with the average trip length in minutes instead of miles. If miles were to be obtained, the output of the distribution program would require assignment. . . to obtain average trip length in miles." Presumably the time distances for calibration are obtained from the O-D data, but how does one arrive at future travel times, taking into account changes in the transportation system, if he has no idea of the actual trip lengths in miles? Earlier statements also seem to leave the measure of distance in some doubt: "Spatial separation for the intervening opportunities model is measured, not in absolute travel time, time, cost, or distance, but in the number of intervening destinations or opportunities," and "The probability factor L is empirically derived and describes the rate of trip decay with increasing trip destinations and increasing length of trip."

The terms long residential, long nonresidential, and short, as defined, seem to have little relationship to actual trip lengths; a 10-min shopping trip to the CBD would be "long," whereas a 20-min trip to a suburban center would be "short." The listing of L values given for each trip purpose indicates that the L factor for home-based shopping trips should be 19.22×10^{-6} without regard for length of trip, but Figure 5 shows L to be about 3.5 for "long residential trips" including, by definition, CBD-directed shopping trips, whereas Figure 7 shows L to be 5.60 and 9.75 for "short" trips including, by definition, all shopping trips not directed to the CBD. Table 2 indicates that the L value for home-based shopping trips was eventually increased to 67.13 through successive "adjustments." Later in the paper "short" is used to indicate intrazonal trips, but certainly not all non-work and non-CBD trips are really intrazonal.

Throughout the report emphasis seems to be placed on "adjusting" "L" values (a) to force the estimated mean travel time to equal the O-D observed mean travel time, and (b) to force corresponding travel time frequency distributions to match. It would seem to this commentator that more emphasis should be placed on reducing the over 30 percent RMS error indicated in Table 5 since the interzonal movements are the most important data.

Information given on forecasting 1955 travel patterns seems to cast further doubt on the process of selecting L values. Although it is stated that the Chicago method of developing projected L values was used as a guide, when the number of intrazonal trips in Washington was found to double between 1948 and 1955, the Chicago method was "modified." When the 1948 value of 5 min for river impedance did not produce satisfactory predictions of 1955 travel, the river impedance was raised to 8 min, and when this still yielded a 16-percent error a 10-min value was tried. What would one do if he did not have the "future" data available to adjust against?

In the final paragraph of Section F the author states:

> The various tests outlined indicate that the intervening opportunities model can be used to forecast travel patterns. When the different procedures used in the forecasts are compared, it is evident that both trip origin and destination adjustments are as necessary in the forecasting stage of this model as in the calibration stage. Likewise, if time barriers are required in the calibration stage, they should be estimated for the forecast year by analysis of the tolerable level of congestion over these facilities for the design year and use of the present relationship between barriers and level of congestion. This area still requires substantial research to insure a more accurate forecasting procedure. The forecasted L values could be improved if total person-hours of travel could be forecast accurately.

Since forecasting of any type involves dealing with many unknowns, it would seem to this commentator that any system of projecting trip patterns which requires accurate forecasts of total person hours of travel, in addition to the various essential land-use projections, plus estimates of future impedance, etc., can never be of great usefulness. What is really needed is a model which will simulate present and future travel patterns, without resort to the juggling of coefficients, exponents, etc., from city to city and from time to time. This commentator's electrostatic field model has given reasonable simulations of work trip desire lines in three cities (17, 18, 19) and of shopping trips in one (19), but no one has ever tested it as thoroughly as the author has now tested the intervening opportunities model. Since the latter has been found wanting, it is hoped that the field theory will soon be accorded an equally rigorous test.

References

17. Howe, R. T. A Theoretical Prediction of Work-Trip Patterns. Highway Research Board Bull. 253, pp. 155-165, 1960.
18. Howe, R. T. A Theoretical Prediction of Work Trips in the Minneapolis-St. Paul Area. Highway Research Board Bull. 347, pp. 156-181, 1962.
19. Howe, R. T. A Critical Analysis of an Origin-Destination Survey. Highway Research Record No. 41, pp. 79-98, 1963.

CLYDE E. PYERS, Closure—Professor Howe has allied himself with the entire field of urban transportation planners who look to the day when a model can be developed which will simulate present and future travel patterns without the need for adjustments from city to city and from time to time. If there is a possibility that such a model exists, it will surely be developed by those who have a good understanding of the strengths and weaknesses of the procedures in use today.

The purpose of the research reported in this paper is to improve the understanding of a widely used travel model, the intervening opportunities model, by giving a fairly detailed account of the application of this model over a period of time in a city showing significant growth. This would hopefully allow users to practice their art more efficiently and possibly would point the way to improvements in model technology. The fact that other models were also tested and comparisons were reported in a companion paper (6) made the results even more interesting.

Professor Howe has also raised certain questions in his discussion which should be answered. The first is related to the adjustment process which insures that all trip origins are actually sent. Apparently, the difficulty with the paper is related to the definition of D. The D being used has been defined as the destinations up to, but not including, zone j or, in effect, $\sum_{x=1}^{j-1} D_x$.

Treating this correctly, we have, from Eq. 1, for the zone first in time sequence from zone i:

$$T_{i1} = O_i \left[e^{-LD_0} - e^{-L(D_0 + D_1)} \right] \tag{7a}$$

for the zone second in time sequence from zone i:

$$T_{i2} = O_i \left[e^{-L(D_0 + D_1)} - e^{-L(D_0 + D_1 + D_2)} \right] \tag{7b}$$

for the zone third in time sequence from zone i:

$$T_{i3} = O_i \left[e^{-L(D_0 + D_1 + D_2)} - e^{-L(D_0 + D_1 + D_2 + D_3)} \right] \tag{7c}$$

and for the zone n th in time sequence from zone i:

$$T_{in} = O_i \left[e^{-L(D_0 + D_1 + \ldots + D_{n-1})} - e^{-L(D_0 + D_1 + D_2 + \ldots + D_n)} \right] \tag{7d}$$

With summation of both sides for all possible destination zones from 1 to n and with D_0 equal to zero, all but the first and last terms in the right side of the equation cancel out, yielding:

$$\sum_{j=1}^{n} T_{ij} = O_i \left[1 - e^{-L \sum_{j=1}^{n} D_j} \right] \tag{8a}$$

Dividing both sides by O_i yields:

$$\frac{\sum_{j=1}^{n} T_{ij}}{O_i} = 1 - e^{-L \sum_{j=1}^{n} D_j} \tag{8b}$$

Since the value of the right side of Eq. 8b is asymptotic and approaches a value of 1, the term $\frac{\sum_{j=1}^{n} T_{ij}}{O_i}$ may be set at 0.98, or any other desired level, and an L can be calculated which would send out this portion of the total trips.

As pointed out in the paper, an L value obtained in such a manner might not give a satisfactory trip length distribution. Thus, an L was sought which would give a satisfactory trip length distribution and each of the probability terms, i.e., $\left[e^{-LD} - e^{-L\left(D + D_j\right)}\right]$ was adjusted upward so that the summation of the probability terms would equal unity.

Professor Howe has questioned previously the adequacy of a 5- or 3-percent sample home interview survey to provide data on trips originating or designated to each zone (19). All transportation studies do check these data with other sources of information such as population, employment, and labor force by geographic location. Depending, of course, on such items as the definitions used, coverage, and methods of estimating, one source of information on labor force or employment may be better than others. But, of course, an information source designed to obtain data on employment and labor force by zone does not, by itself, provide answers on trips entering and leaving zones. The important point here is that certain adjustments were necessary to insure a balance between model inputs and outputs for both origins and destinations on a zonal level. This would have been true, regardless of the source of information for these input data.

In the research reported, time separation was used as a means of ranking destination zones from each origin zone. These times were derived from the transportation network. Future time separation is derived from the assumed future network, though in this case actual data were available and were used for the 1955 forecast network. The terms, long residential, long nonresidential, and short are clearly defined. As Professor Howe points out, any given short trip may be longer than one defined as long. Further examination of the actual data plotted on Figures 5 through 7 indicates definite patterns for the three categories of trips; it is seen that long trips have an average trip length some 40 percent greater than the short trips.

Information on several steps in the calibration process was included to provide as much insight on adjustments in L values as possible to future users of this procedure. Apparently, Professor Howe would use the application of a trial L value and subsequent model shortcomings as evidence that the theory is invalid.

A closer examination of the paper would have shown that Table 5, which Professor Howe cites, does not relate to interzonal movements at all. It is instead given to demonstrate the need for adjustments in the model so that each zone receives approximately the correct number of trips.

There are tables given statistically comparing interzonal movements, and examination of them indicates that each calibration step reduces the model error. Professor Howe seems to miss the entire point of model building when he criticizes adjustments to L to bring trip length into balance and suggests direct attempts to reduce the error in the interzonal movements. The intervening opportunities theory suggests that urban travel can be represented by a pair of decay rates acting on two different types of trips. If these decay rates (described by the L values) can be determined and applied to the appropriate trip ends, a matrix of zone-to-zone trip tables of acceptable accuracy can be calculated. This author feels that this was done in the subject research without any artificial zone-to-zone adjustment factors.

Again, the inclusion of several tests of forecasting ability with varying river barriers was done to provide some indication of the sensitivity and effect of the river crossing problem in the model. The 8-min barrier would have been used had this been an operational study, and the procedures used to estimate this value were fully referenced.

In any forecast of travel demand, a person-hours of travel check for reasonableness would seem elementary. It would also seem reasonable to adjust those forecasts to reproduce a sound estimate of person-hours of travel.

Coordinated Highway-Transit Interchange Stations

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The San Francisco Bay Area Rapid Transit project will consist of a 75-mile grade-separated regional rapid transit system, with schedule speeds of 45 to 50 mph and 33 rapid transit stations. Extensive planning and research have been conducted during the past 12 years on methods of attracting and accommodating the various access modes of travel to and from the stations. The objective of these studies was to provide the coordinated and integrated highway-transit interchange facilities necessary to the success of the system and to the alleviation of major corridor congestion.

An extensive postcard survey was conducted on the Bay Area Peninsula commute line of the Southern Pacific Company and additional data were provided by the Cleveland Transit System, with respect to access mode characteristics at outlying collector rapid transit stations. Other pertinent data have been evaluated and analyzed from other transit systems in America and abroad.

Station planning criteria and observations are presented in their several aspects. Access mode distributions, parking stall capacities, loading roadways, and facilities for walkers, feeder transit, taxis, kiss-riders, parkers, and bicycles are described and discussed. General aspects of highway-transit interchange station planning and design are reviewed. It is emphasized that system and station planning is a continuing process.

•CURRENT transportation planning interest is intensively focused on methods of coordinating, and providing interchange between, highways and public transit facilities in growing urban regions. These expanding needs are well understood by highway and transit planning officials. The objective is to optimize the utilization of each travel mode in its proper sphere and to minimize the critical peak period transportation capacity, investment, and operating costs required to serve major regional corridors and gateways properly.

Important provisions of the Federal-aid Highway Act of 1962, the Urban Mass Transportation Act of 1964, and the Federal Housing Acts of 1954 and 1961 require that urban planning assistance programs of the U.S. Bureau of Public Roads (BPR) and the Housing and Home Finance Agency (HHFA) give careful consideration to each mode of travel and emphasize the necessity for comprehensive, cooperative, and continuing transportation planning processes in all American urban regions. Before July 1, 1965, to be eligible for further Federal highway assistance, all American metropolitan areas of over 50,000 population must have such a recognized transportation planning process under way.

Since the initiation of planning and design studies for the San Francisco Bay Area Rapid Transit (BART) System in 1953, it has been recognized (1, 2) that a high degree

Paper sponsored by Committee on Origin and Destination.

of coordination and interchange will be essential between the growing street and highway facilities of the area and the rapid transit system. Present planning calls for over 23,000 parking stalls initially at 23 of the 33 rapid transit stations, careful coordination with feeder transit lines, and facilities for kiss-ride and taxi access to the stations. Figure 1 shows the three-county BART system which the voters approved for construction in November 1962.

On a rapid transit system, the stations themselves must be the foci to encourage the interchange of passengers with their automobiles and the street and highway facilities. During all of the past 12 years of planning for the BART system, and particularly during the past 6 years (3), this subject has been under intensive investigation. It is the purpose of this paper to discuss the research, planning, and proposed standards developed thus far in the program and to illustrate some interchange station concepts which are under consideration as BART enters the stage of final planning, design, and construction.

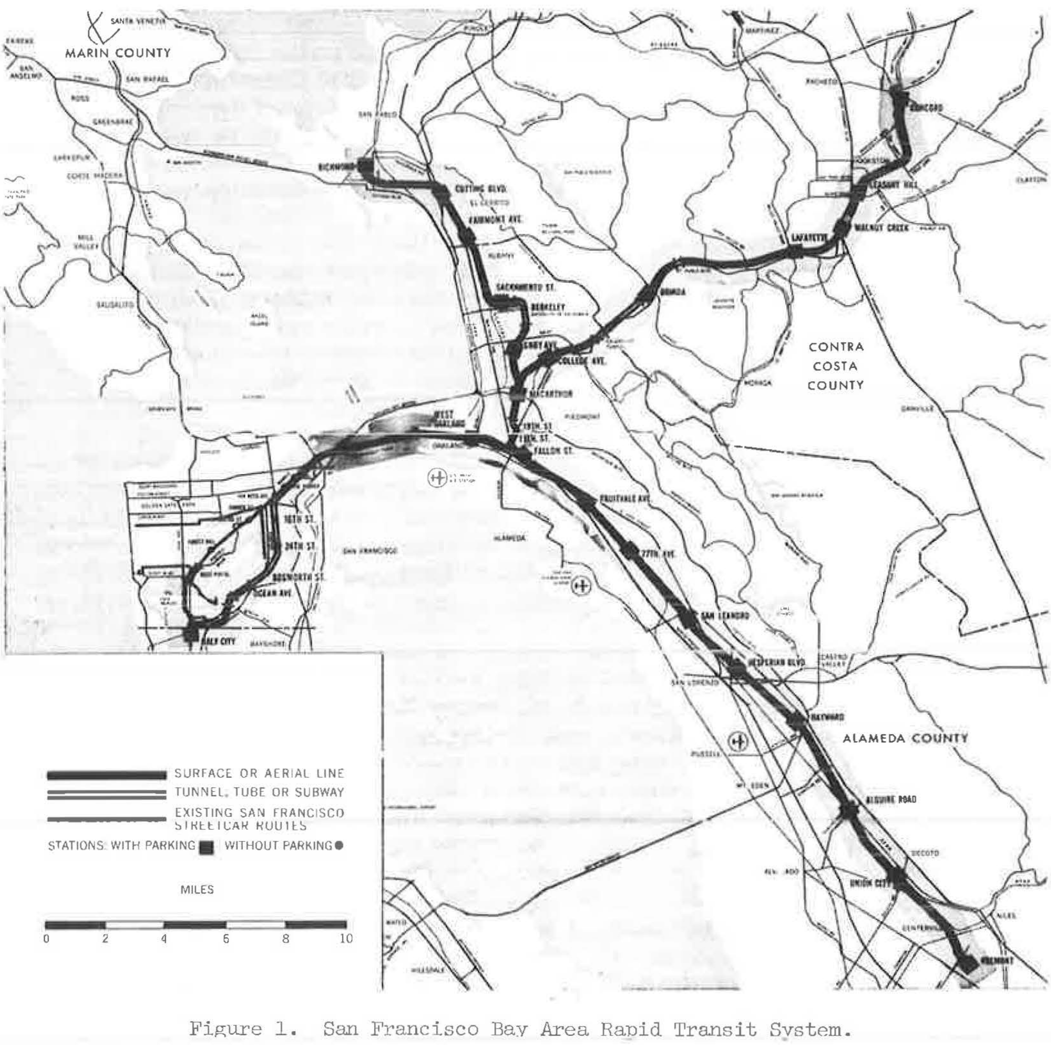

Figure 1. San Francisco Bay Area Rapid Transit System.

FIELD SURVEYS

To help determine the characteristics of Bay Area passengers arriving and leaving commuter stations, a 12,300-postcard survey was conducted on the Peninsula San Francisco-San Jose commute line of the Southern Pacific Co., which then carried approximately that number of riders in weekday round trips. Figures 2 and 3 illustrate the survey form distributed to all passengers on outbound S. P. trains from the San Francisco terminal on Tuesday, Jan. 19, 1960. Despite the length of the form, advance publicity and survey design enabled a 67 percent usable return to be obtained, which provided much valuable data on existing station access mode characteristics in the Bay Area. Tables 1 and 2 provide some of the results from this survey.

DEVELOPMENTS ELSEWHERE

During the past 7 years, the Cleveland Transit System (CTS) has conducted similar access characteristics studies at its outlying rapid transit stations, where 5,225 parking spaces are now provided (4). Through the courtesy of Donald C. Hyde, General Manager of CTS, acting as consultant to the BART project, pertinent CTS data were made available and used in BART system planning. Tables 3 through 6 present some of these data. A map of the CTS appears in Figure 4. Figures 5 and 6 illustrate the various external facilities at CTS' largest parking station, West Park, located at the present western terminal of the CTS rapid transit line.

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RAPID TRANSIT TRAVEL SURVEY

Parsons Brinckerhoff - Tudor - Bechtel
Room 1100
833 Market Street
San Francisco 3, California

YOUR HELP IS REQUESTED

Your San Francisco Bay Area Rapid Transit District is conducting engineering studies for the proposed regional rapid transit system. These studies are of great importance in planning the kind of rapid transit system you want.

You are being asked — as part of these studies — to give information concerning your trip via the S.P.R.R. today. Instead of delaying your trip by direct interviews, we ask only that you promptly:

1. **Fill out this questionnaire completely.**
2. **Fold along dotted lines shown.**
3. **Seal carefully along gummed edge.**
4. **Drop in any mail box.**

The questionnaire is self-addressed and postage paid.

Your cooperation is appreciated. Thank you.

Parsons Brinckerhoff - Tudor - Bechtel
General Engineering Consultants to the
San Francisco Bay Area Rapid Transit District

Nº 13757

Figure 2. Southern Pacific Co. commuter survey form: instructions side.

GUMMED EDGE. SEAL HERE

FOLD HERE

SAN FRANCISCO BAY AREA RAPID TRANSIT DISTRICT
POSTPAID MAIL QUESTIONNAIRE

of S.P. Commuters

It is important that YOU answer ALL questions below and RETURN this form promptly. Your answers will be of great help in improving traffic service in the Bay Area. This is YOUR PART in the rapid transit engineering studies.

1. At which station did you **board** the outbound S.P. train on which you received this questionnaire? (Check one.)
   ☐ Third & Townsend Depot (S.F.) ☐ Other: ________ (Specify)

2. At which station did you get off that train? ________ (Specify)

3. Where were you going to on that trip?
   ________ (Nearest Street Corner, or Address) ________ (City or Town)

4. How did you travel between the station where you got off train (Q. 2) and your ultimate destination (Q. 3)? (Check one.)
   ☐ Walked
   ☐ Feeder Bus
   ☐ **Passenger** } in an auto parked at or near Sta.
   ☐ **Driver** }
   ☐ Picked up at Sta. by auto not parked there
   ☐ Taxi (rode alone)
   ☐ Taxi (shared ride)
   ☐ Bicycle
   ☐ Other ________ (Specify)
   ☐ Combination of above ________ (Specify)

FOLD HERE

5. **IF YOU** were the **DRIVER of** an auto parked at or near the R.R. Station (Q. 4):—(Do not answer if **not driving** car away from station **on THIS** trip.)
   (a) **Where** was this auto parked? (Check one.)
   ☐ S.P. Station Lot ☐ At Curb
   ☐ Private Lot or Garage ☐ Other ________ (Specify)
   (b) How far was auto parked from station platform? (Check one.)
   ☐ Less than 200 ft. ☐ 1000-1300 ft. (quarter mile)
   ☐ 200-500 ft. ☐ ¼ to ½ mile
   ☐ 500-1000 ft. ☐ Over ½ mile
   (c) What is the size of this car? (Check one.)
   ☐ Standard-Size American ☐ "Small Foreign"
   ☐ American "Compact" ☐ Other ________ (Specify)

6. On your trip **inbound towards San Francisco** today, how did you travel **between** your starting point (origin) and the S.P. station **where** you **boarded train? (Check one.)**
   ☐ Walked
   ☐ Feeder Bus
   ☐ **Passenger** } **in an auto parked at or near Sta.**
   ☐ **Driver** }
   ☐ Dropped off at Sta. by auto **not** parked there
   ☐ Taxi (rode alone)
   ☐ Taxi (shared ride)
   ☐ Bicycle
   ☐ Other ________ (Specify)
   ☐ Combination of above ________ (Specify)
   ☐ Did not travel inbound today

7. On your inbound trip today, please give:
   (a) Station boarded train ________ (Write in)
   (b) Time train was due to leave ________ A.M. P.M. (Write in)
   (c) ☐ Did not travel inbound towards S.F. today.

FOLD HERE

8. For **these** same **S.P. trips today**, could you have **driven** or shared a ride in an auto, if you had **chosen** and **arranged** to do so? (**Check one.**)
   ☐ Yes ☐ **No; no** auto transportation could have been available.

9. What was the **purpose** of each of these trips today? (Check one in each line.)

		Work or Business	Home	Shop	Social or Recreation	Other
Inbound to S.F.	From	☐	☐	☐	☐	☐
	To	☐	☐	☐	☐	☐
Outbound from S.F.	From	☐	☐	☐	☐	☐
	To	☐	☐	☐	☐	☐

10. **Ordinarily, how many times a week do you make these same trips? (Check one in each line.)**

	Over 7	7	6	5	4	3	2	1	Under 1
Inbound to S.F.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Outbound from S.F.	☐	☐	☐	☐	☐	☐	☐	☐	☐

11. Brief comments and suggestions on the proposed regional rapid transit system: (optional answer) ________

Please fill out this questionnaire completely. Fold along dotted lines. Seal carefully along gummed edge. Drop in any mailbox. Your cooperation is appreciated. Thank you.

Figure 3. Southern Pacific Co. commuter survey form: questionnaire side.

TABLE 1

ACCESS MODES AT OUTLYING STATIONS, S.P. COMMUTER SURVEY[a]

Access Modes	Alighting, Outbound		Boarding, Inbound	
	No.	Percent	No.	Percent
Walked	1,997	15.5	2,272	17.6
Feeder bus	562	4.4	410	3.2
Passenger in parked auto	1,012	7.9	1,016	7.9
Driver of parked auto	5,019	39.2	5,224	40.2
"Kiss-ride" (picked up)	3,854	30.1	3,770	29.1
Taxi				
Alone	55	0.4	44	0.4
Share	26	0.2	22	0.2
Bicycle	74	0.6	79	0.6
Other	20	0.2	23	0.2
Combination of modes	193	1.5	76	0.6
Total	12,812	100.0	12,936	100.0

[a]Commuters outbound from San Francisco, Tuesday, Jan. 19, 1960, excluding only San Francisco terminal station.

TABLE 2

CHARACTERISTICS OF STATION PARKERS, S.P. COMMUTER SURVEY[a]

Characteristic	No.	Percent
Parked at:		
S.P. Co. lot	3,409	69
Private lot	342	7
Street curb	1,131	23
Other	58	1
Total	4,940	100
Parking distance from station platform:		
<200 ft	1,635	33
200-500 ft	1,938	40
500-1,000 ft	1,091	22
1,000-1,300 ft	207	4
1/4-1/2 mi	48	1
>1/2 mi	4	—
Total	4,923	100
Parked Auto Size:		
Standard American	4,271	89
American compact	126	3
Small foreign	383	8
Other	32	—
Total	4,812	100

[a]Commuters outbound from San Francisco, Tuesday, Jan. 19, 1960, excluding only San Francisco terminal station.

TABLE 3

CLEVELAND RAPID TRANSIT STATION INTERCHANGE FACILITIES, 1963

Station	No. Feeder Transit Lines	No. Parking Spaces	Kiss-Ride Loop
West Park	6[a]	2,000	Yes
Triskett	2[a]	1,200	Yes
W. 117th—Madison	4[a]	575	Yes
W. 98th—Detroit	3[a]	315	Yes
W. 65th—Madison	4	0	No
W. 25th—Lorain	14	0	No
Union Terminal (public square)		0	No
E. 55th St.	2	85	No
E. 79th St.	3	0	No
E. 105th—Quincy	2	0	No
University—Cedar	10[a]	0	No
Euclid—E. 120th	4	0	No
Superior	3[a]	150	Yes
Windermere	6[a]	900	Yes
Total	—	5,225	

[a]Off-street bus transfer facilities.

TABLE 4

CLEVELAND RAPID TRANSIT ACCESS MODES PERIODICITY

Time Period	Parking			Kiss-Ride			Feeder Transit[b]		Walking[c]	Total
	Autos	Psgrs.	Percent[a]	Autos	Psgrs.	Percent[a]	Psgrs.	Percent[a]	Psgrs.	Psgrs. to R. T.[d]
(a) West Park Station[e]										
6- 7 AM	209	247	37.6	72	76	11.6	332	50.6	1	656
7- 8 AM	807	924	35.2	397	453	17.2	1,226	46.6	27	2,630
8- 9 AM	325	412	32.8	174	183	14.5	638	50.7	25	1,258
9-10 AM	120	150	42.1	45	48	13.5	152	42.7	6	356
10-11 AM	101	116	35.5	40	52	15.9	158	48.3	1	327
11-12 AM	76	87	39.5	30	32	14.6	101	45.9	—	220
12- 1 PM	58	67	41.6	22	23	14.3	70	43.5	1	161
1- 2 PM	50	57	30.8	17	21	11.4	105	56.7	2	185
2- 3 PM	23	26	16.4	19	19	11.9	110	69.2	4	159
3- 4 PM	34	38	14.9	24	27	10.6	183	71.8	7	255
4- 5 PM	24	25	5.8	40	52	12.0	345	79.9	10	432
5- 6 PM	9	10	3.2	47	52	16.6	249	79.6	2	313
Total	1,836	2,159	31.1	927	1,038	14.9	3,669	52.8	86	6,952
(b) Triskett Station[f]										
6- 7 AM	86	99	41.8	16	16	6.7	112	47.3	10	237
7- 8 AM	516	652	49.3	153	171	12.9	493	37.3	6	1,322
8- 9 AM	305	358	52.3	89	100	14.6	222	32.4	5	685
9-10 AM	64	74	49.7	30	30	20.1	43	28.9	2	149
10-11 AM	70	85	60.3	24	26	18.4	28	19.9	2	141
11-12 AM	63	75	65.2	19	21	18.3	18	15.6	1	115
12- 1 PM	62	73	65.8	15	19	17.1	18	16.2	1	111
1- 2 PM	60	71	68.3	14	16	15.4	15	14.4	2	104
2- 3 PM	17	21	36.9	15	15	26.3	21	36.8	0	57
3- 4 PM	35	42	46.1	16	24	26.4	24	26.4	1	91
4- 5 PM	23	28	36.8	14	18	23.7	27	35.5	3	76
5- 6 PM	20	24	34.3	14	17	24.3	26	37.1	3	70
Total	1,321	1,602	50.7	419	473	15.0	1,047	33.2	36	3,158

[a] Of R.T. passengers via mode shown to total passengers to R.T.
[b] Latest available data (West Park 1963-1964, Triskett Feb.-March 1964) adjusted to turnstile reading of survey day.
[c] Walking passengers somewhat underreported, but not so much as to affect greatly the other modal percentages shown.
[d] Inbound turnstile count.
[e] Inbound toward CBD, Tuesday, March 24, 1964.
[f] Inbound toward CBD, Wednesday, March 25, 1964.

TABLE 5

DISTANCES OF TRIP ORIGINS TO FOUR WEST SIDE RAPID TRANSIT STATIONS[a]

Airline Dist. to Stations[b] (mi)	October 1959		March 1964	
	No. Parked Autos	Percent	No. Parked Autos	Percent
0.0- 0.5	126	5.00	123	3.95
0.6- 1.0	411	16.21	429	13.79
1.1- 1.5	402	15.89	447	14.38
1.6- 2.0	314	12.42	343	11.03
2.1- 3.0	249	9.87	272	8.74
3.1- 4.0	373	14.75	637	20.49
4.1- 5.0	80	3.15	82	2.63
5.1- 6.0	82	3.25	115	3.69
6.1- 7.0	407	16.04	523	16.80
7.1- 8.0	39	1.52	47	1.53
8.1- 9.0	20	0.76	50	1.57
9.1-10.0	23	0.92	36	1.15
>10.0	6	0.22	8	0.25
Total	2,532	100.00	3,112	100.00

[a]West Park, Triskett, W. 117th, and W. 98th (data expanded from average 75 percent sample).
[b]Avg. travel distance: Oct. 1959, 2.97 mi; March 1964, 3.22 mi.

TABLE 6

DISTANCES OF TRIP ORIGINS TO TWO WEST SIDE RAPID TRANSIT STATIONS, MARCH-APRIL 1958[a]

Airline Dist. to Stations (mi)	Parked Autos (%)			Kiss-Ride Autos (%)			Total Passengers[b]		
	W. 117th	W. 98th	Total	W. 117th	W. 98th	Total	W. 117th	W. 98th	Total
0-1	10.7	12.9	11.7	20.1	28.6	21.4	13.9	28.6	18.0
1-2	29.1	18.0	24.1	37.5	28.6	36.1	40.3	25.2	35.9
2-3	8.8	23.2	15.4	11.4	22.4	13.1	14.7	21.7	16.6
3-4	17.2	12.9	15.2	14.4	4.1	12.8	18.3	13.3	17.0
4-5	9.3	9.5	9.4	4.2	4.1	4.2	4.2	3.2	4.1
5-6	4.1	8.6	6.1	2.7	2.0	2.5	3.6	2.3	3.2
>6	20.8	14.9	18.1	9.7	10.2	9.9	5.0	5.7	5.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Avg. Travel Dist. (mi)	3.8	3.7	3.8	2.7	2.7	2.7	2.6	2.4	2.5

[a]Before opening of Triskett and West Park Stations; data from Gilman and Co. (5).
[b]Total boarding passengers at W. 117th and W. 98th Streets rapid transit stations.

Additional work on this subject has been conducted by the Delaware River Port Authority in connection with its Philadelphia-Kirkwood rapid transit line, now under construction. Table 7 indicates the amount and type of parking, kiss-ride, and other facilities presently proposed to be provided at stations along the Kirkwood line in New Jersey.

Significant progress in developing coordinated highway-transit interchange stations has been made in the past few years by several state highway departments in connection with express bus services on freeways and expressways, by the Metropolitan Transit Authority of Boston, the New York City Transit Authority, the rapid transit systems in Chicago and Toronto, several commuter railroads, and various cities (6), rapid transit systems, and state railroads in Europe (7).

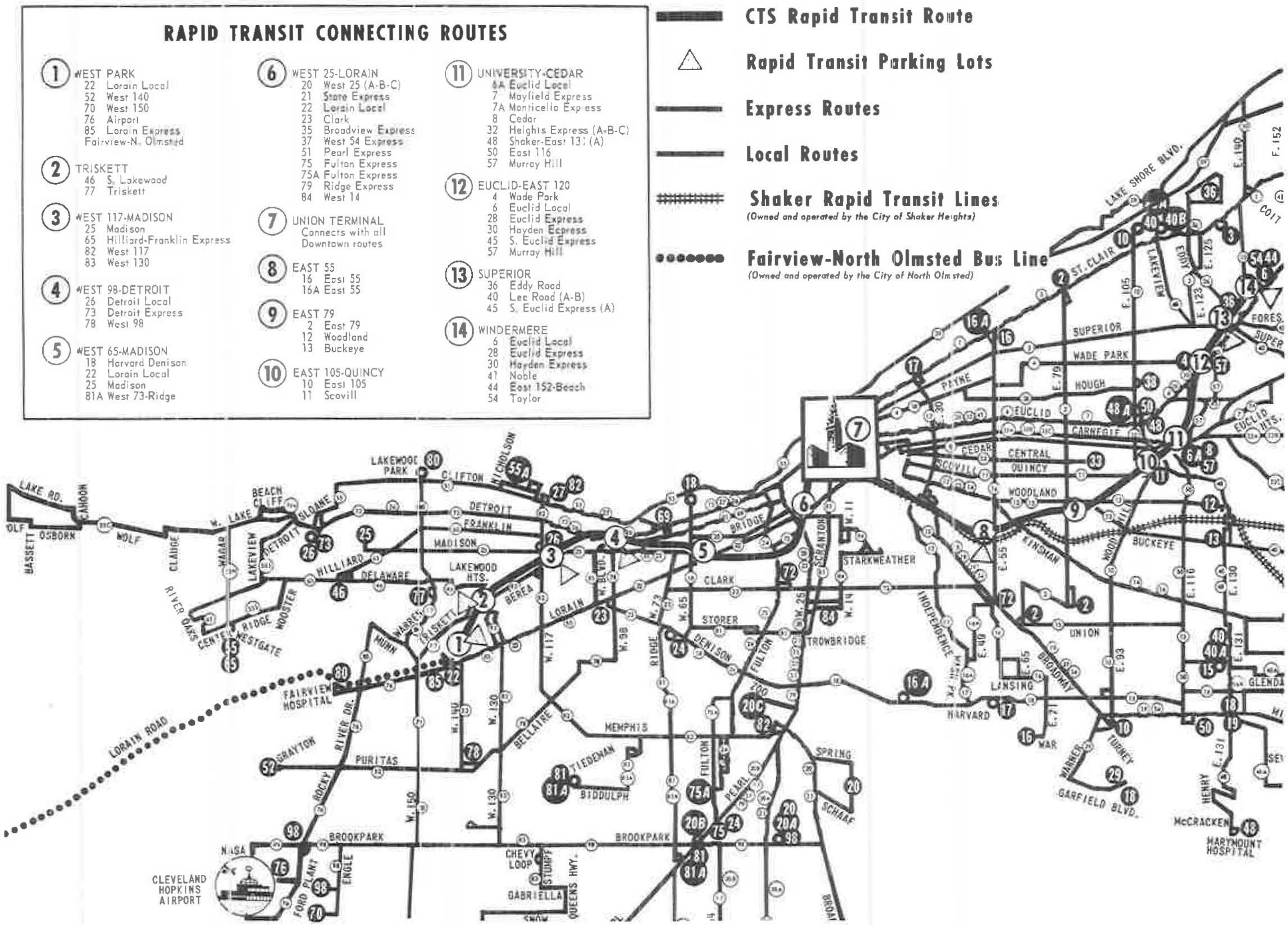

Figure 4. Cleveland Transit System routes, 1963.

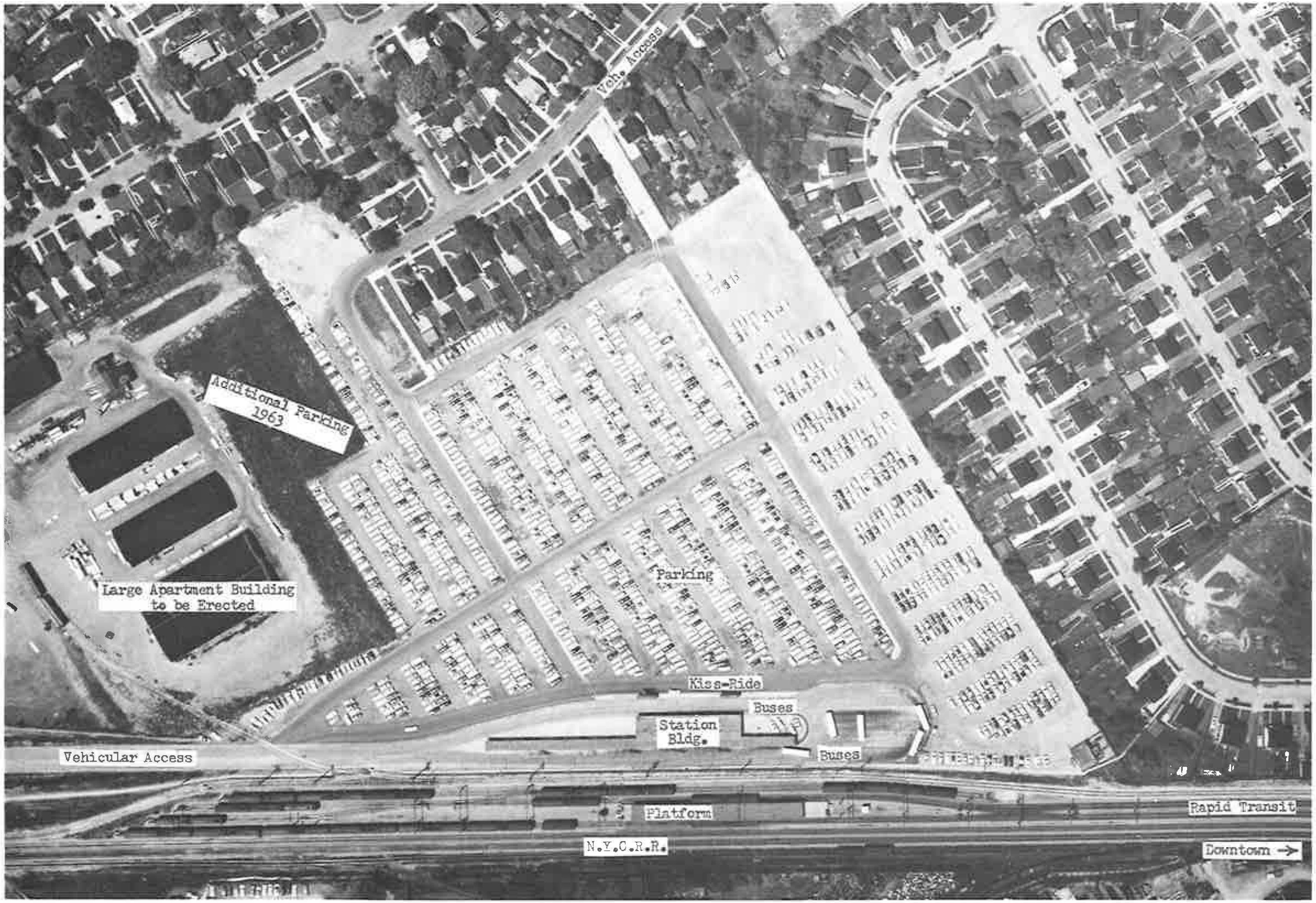

Figure 5. Station facilities, West Park Station, CTS, 1961.

Figure 6. Feeder bus and kiss-ride loading areas, West Park Station, Cleveland.

TABLE 7

PHILADELPHIA-KIRKWOOD PROPOSED RAPID TRANSIT STATION FACILITIES[a]

Station	Kiss-Ride Positions	Paid Parking Stalls	Free Parking Stalls	Total Spaces
Ferry Ave.	73	283	642	998
Collingswood	30	64	429	523
Westmont	23	217	540	780
Haddonfield	47[b]	187	687	921
Ashland	11	158	384	553[c]
Kirkwood	31	282	868	1,181[d]
Total	215	1,191	3,550	4,956

[a]Loading and unloading positions for feeder buses and taxis provided at all stations.
[b]35 15-min parking; 12 kiss-ride.
[c]Additional land to be purchased for 350 spaces to be provided in the future when traffic increases.
[d]Additional land to be purchased for 367 and 440 spaces to be provided in two stages when traffic increases.

The Demonstration Grant program, administered by the HHFA in accordance with the Housing Act of 1961, has also provided active assistance in this field. Of particular interest is an HHFA Demonstration Grant to the Tri-State Transportation Committee, in which a new station along a major Pennsylvania Railroad commute line was constructed at the outskirts of New Brunswick, N. J. The new station was opened on Oct. 24, 1963, and observation under the grant was to continue for an 18-month period.

The old station in the center of New Brunswick had been difficult to reach by automobile because of traffic congestion and insufficient parking facilities. The new station has a 300-car parking lot and is located about 1.5 miles from the center of New Brunswick. It is intended to demonstrate whether a station conveniently located outside a city's center and equipped with adequate parking facilities can attract enough commuters and other daytime passengers to be feasible.

HIGHWAY-TRANSIT INTERCHANGE STATION CRITERIA

Extensive BART studies have been and are being conducted on travel times, travel patterns, modal split, rapid transit patronage, fare levels and structure, gross revenue, operations planning, train schedules, operating expense, net revenue, rolling stock requirements, and parking facilities requirements.

Based on these studies, specific planning and research investigations for the BART stations, and data available from other existing and planned rapid transit systems, proposed planning criteria have been developed for highway-transit interchange facilities in this area. It should be emphasized that the planning process is continuous and subject to further development as the project proceeds through the stage of final design before construction.

ACCESS MODE DISTRIBUTIONS

Table 8 gives current estimated station access mode volumes for the BART stations on a 1975 annual average weekday. A careful evaluation of the potential characteristics of each of the 33 stations and their tributary areas was involved in these estimates. These characteristics included forecasts of future land uses, of the geography and quality of access routes and facilities, demography and economy, station site development considerations, and the ranking of the service functions attributable to each station. Also used in this preparation were the analyses and results of the rapid transit patronage studies and comparisons with the January 1960 S. P. postcard survey and the Cleveland data referred to previously. The station sector studies, described later, were important in refining the estimates.

PARKING CAPACITY

From the data of the foregoing studies and Table 8, the number of parking stalls required at each rapid transit station was estimated, taking into consideration several important factors. Initial estimates were prepared of potential stall demand by 1980 and 2000. The parking stall and area estimates were scaled to fit that part of the BART $792,000,000 general obligation bond resources budgeted for external station facilities. In scaling to this budget level, the distribution of numbers of stalls among the 23 stations selected by study for parking facilities was further evaluated and modified to account for several elements. Early trials of these distributions considered, successively, the potential demand estimates and relative demand variously modified by relative parking capital costs per square foot among the parking stations. Later trials added consideration of two other significant factors: (a) an evaluation of the relative magnitude of property acquisition problems likely to be encountered at the 23 parking stations; and (b) attraction to the system of the longest possible lengths of passenger trip, with the objective not only of increasing rapid transit revenues but also particularly of relieving major parallel highway facilities of the greatest possible amount of congesting vehicle-miles of automobile travel.

The latter objective involved emphasizing the outer, more regional stations of the system where auto and parking access is proportionately of much greater importance. It is to be noted, for example, that of all existing North American rapid transit systems, the largest station parking capacities are generally placed at or toward the outer ends of rapid transit routes. Where several outlying stations on one route will have parking, it is not always necessary to provide well-above-average amounts of parking at the route's terminal station. It is apparent that parking is not generally provided at central stations in downtown areas, principally because they are delivery rather

TABLE 8

ESTIMATED ACCESS MODE VOLUMES, SAN FRANCISCO BAY AREA RAPID TRANSIT STATIONS[a]

Station	Total Boarding and Alighting	Walk		Feeder Transit		Taxi		Kiss-Ride		Parked Auto		Total Auto	
		Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.
Daly City	14,800	9	1,330	50	7,400	1	150	14	2,070	26	3,850	40	5,920
Ocean Ave.	10,700	15	1,600	64	6,850	3	320	18	1,930	0	0	18	1,930
Bosworth	9,400	22	2,070	59	5,550	3	280	16	1,500	0	0	16	1,500
24th St.	15,800	41	6,480	47	7,430	2	310	10	1,580	0	0	10	1,580
16th St.	9,500	64	6,080	31	2,940	2	190	3	290	0	0	3	290
Civic Center	22,200	63	13,990	34	7,550	2	440	1	220	0	0	1	220
Powell St.	31,600	66	20,850	32	10,110	1	320	1	320	0	0	1	320
Montgomery St.	66,200	66	43,690	32	21,190	1	660	1	660	0	0	1	660
W. Oakland	8,900	28	2,490	51	4,540	1	90	5	440	15	1,340	20	1,780
12th St.	39,900	68	27,130	27	10,770	2	800	3	1,200	0	0	3	1,200
19th St.	39,600	73	28,910	23	9,110	1	390	3	1,190	0	0	3	1,190
MacArthur Blvd.	16,500	17	2,810	50	8,250	1	160	17	2,810	15	2,470	32	5,280
College Ave.	7,700	15	1,150	45	3,470	1	80	14	1,080	25	1,920	39	3,000
Orinda	4,700	5	240	15	700	2	90	28	1,320	50	2,350	78	3,670
Lafayette	6,500	8	520	14	910	2	130	26	1,690	50	3,250	76	4,940
Walnut Creek	6,100	9	550	15	920	2	120	24	1,460	50	3,050	74	4,510
Pleasant Hill	5,300	12	640	14	740	2	100	22	1,170	50	2,650	72	3,820
Concord	4,700	10	470	15	710	2	90	21	990	52	2,440	73	3,430
Richmond	8,100	10	810	41	3,320	2	160	16	1,300	31	2,510	47	3,810
Cutting Blvd.	10,900	5	550	35	3,810	1	110	19	2,070	40	4,360	59	6,430
Fairmont Ave.	5,700	10	570	40	2,280	1	60	18	1,030	31	1,760	49	2,790
Sacramento St.	8,700	10	870	45	3,910	1	90	16	1,390	28	2,440	44	3,830
Berkeley	24,000	47	11,280	34	8,160	4	960	15	3,600	0	0	15	3,600
Ashby Ave.	16,400	21	3,450	50	8,200	1	160	12	1,970	16	2,620	28	4,590
Oak St.	19,800	30	5,940	41	8,120	2	400	19	3,760	8	1,580	27	5,340
Fruitvale Ave.	30,600	11	3,360	58	17,750	1	310	22	6,730	8	2,450	30	9,180
73rd Ave.	23,000	10	2,300	55	12,650	1	230	22	5,060	12	2,760	34	7,820
San Leandro	16,900	16	2,700	42	7,100	1	170	21	3,550	20	3,380	41	6,930
Hesperian Blvd.	9,800	5	490	35	3,430	1	100	22	2,150	37	3,630	59	5,780
Hayward	10,100	12	1,210	34	3,440	3	300	17	1,720	34	3,430	51	5,150
Tennyson Rd.	3,400	10	340	24	820	1	30	23	780	42	1,430	65	2,210
Union City	4,200	7	290	14	590	2	80	28	1,180	49	2,060	77	3,240
Fremont	5,100	4	200	16	820	2	100	29	1,480	49	2,500	78	3,980
Total (Aug. 1965)	516,800	38	195,360	37	193,540	2	7,980	11	59,690	12	60,230	23	119,920

[a]24-hr 1975 annual average weekday; data subject to continuing reevaluation as project planning and development proceed.

TABLE 9

SAN FRANCISCO BAY AREA RAPID TRANSIT STATION PARKING STALLS, INITIAL PROGRAM[a]

Station	Total Stalls
Daly City	1,250
W. Oakland	600
MacArthur Blvd.	900
College Ave.	800
Orinda	950
Lafayette	1,150
Walnut Creek	1,350
Pleasant Hill	1,250
Concord	1,350
Richmond	1,050
Cutting Blvd.	1,450
Fairmont Ave.	950
Sacramento St.	1,050
Ashby Ave.	900
Oak St.	450
Fruitvale Ave.	850
73rd Ave.	1,050
San Leandro	1,150
Hesperian Blvd.	1,550
Hayward	1,250
Alquire Road	850[b]
Union City	850[b]
Fremont	850[b]
Total	23,850

[a]Preliminary, subject to continuing re-evaluation as project planning and development proceed.

[b]Of which initially 500 would be constructed and land would be provided for remaining 350.

than collector stations and because parking capital costs in these areas are relatively high.

These studies, together with preliminary location studies, indicated that between 23,000 and 24,000 parking stalls could initially be provided at the 23 parking stations, with capacities varying between 450 and 1,550 stalls at the individual stations.

During subsequent design, property acquisition, and actual construction, changes in the cost factors involved, in specific problems of community planning and acquiring land, and other elements may affect the number and distribution of stalls at individual stations. Table 9 shows the initial number of parking stalls presently planned for each station, subject to these qualifications.

TRANSPORTATION DESIGN

External Station Layouts

Figure 7 illustrates, and supplements the following discussion of, criteria proposed for external station layouts at the 23 stations where parking space is planned ("parking stations"). Figure 7 is based on a capacity of 1,200 stalls, the approximate average number of lot (single-level) stalls shown in the engineering plans referenced to the May 1962 BART Composite Report (8). Specific conditions encountered during subsequent design, property acquisition, and actual construction at each of these 23 parking stations may cause marked variations from this optimal layout. Figure 7, however, provides an important illustrative basis for the external station functions and criteria subsequently described (9, 10, 11).

At the 14 other stations of the system (10 for rapid transit and four for express streetcars) where parking is not provided because they are purely downtown delivery, internal urban, or express streetcar stations, the rapid transit route is usually in subway under city streets. There are not likely to be extensive external station facilities involved at these 14 stations, other than loading-unloading space for autos, taxis, and feeder transit vehicles, arranged in accordance with the street geometry, building development, and access needs in the immediate vicinity of each station. It is expected that this loading-unloading space will usually be included within the existing general street geometry, with possibly some curb setbacks and other relatively minor modifications.

Initial Considerations

The BART station structures will be approximately 700 ft long and 50 to 60 ft wide. The 700-ft length will provide for 10-car trains of about 70-ft long cars. Optimally, external parking and circulation facilities should be grouped around the long, narrow station (a) to provide the closest access to the train platforms for the most efficient

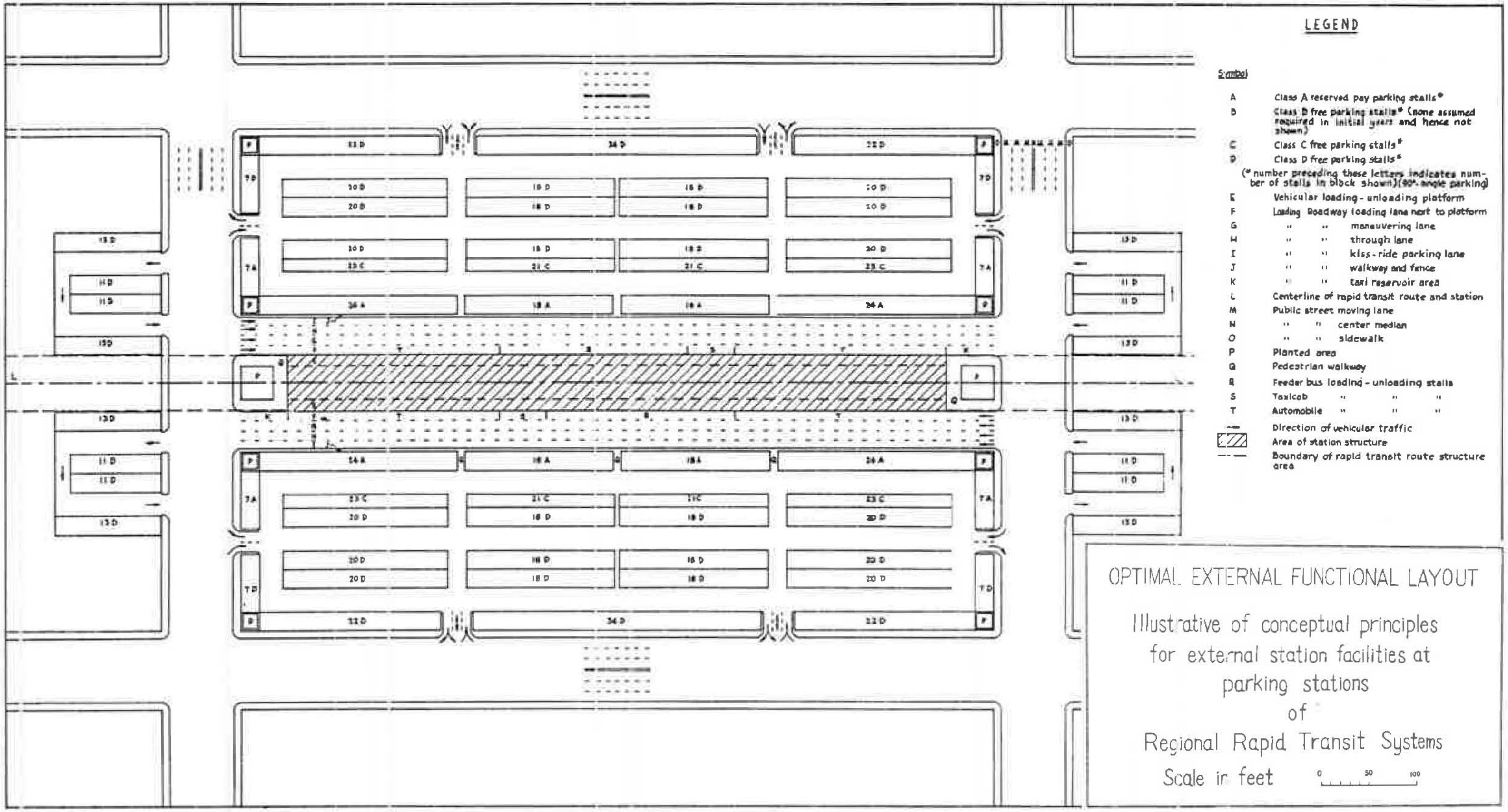
LEGEND
Symbol
A Class A reserved pay parking stalls*
B Class B free parking stalls* (none assumed required in initial years and hence not shown)
C Class C free parking stalls*
D Class D free parking stalls*
(* number preceding these letters indicates number of stalls in block shown)(90°-angle parking)
E Vehicular loading - unloading platform
F Loading Roadway loading lane next to platform
G " " maneuvering lane
H " " through lane
I " " kiss-ride parking lane
J " " walkway and fence
K " " taxi reservoir area
L Centerline of rapid transit route and station
M Public street moving lane
N " " center median
O " " sidewalk
P Planted area
Q Pedestrian walkway
R Feeder bus loading - unloading stalls
S Taxicab " " "
T Automobile " " "
Direction of vehicular traffic
Area of station structure
Boundary of rapid transit route structure area
OPTIMAL EXTERNAL FUNCTIONAL LAYOUT
Illustrative of conceptual principles for external station facilities at parking stations of Regional Rapid Transit Systems
Scale in feet
0 50 100

Figure 7.

access modes to encourage use of these modes, (b) to minimize walking distances between train platforms and all parking stalls, (c) to optimize the number of vehicular entrances from and exits to the street-highway network, and (d) to optimize automobile, taxi, and feeder transit loading, unloading, ingress, and egress (Fig. 7). From the station operation standpoint, the most efficient access modes are, in descending order, walk, feeder transit, bicycle, taxi, auto kiss-ride, miniature auto parked, small foreign auto parked, and standard American auto parked.

Loading Roadway

Because the stations are about 700 ft long, analysis indicates that a single loading roadway and vehicular loading-unloading platform of that length, along one side of a station, should be adequate to meet 1980 peak requirements for momentary loading and unloading of automobiles, taxis, and feeder transit buses. By the nominal year 2000, this single loading roadway and platform may still be adequate at most of the parking stations, but at others there should be a loading roadway and platform along both sides of each station. One 700-ft long loading-unloading platform provides space, for example, for three large transit buses, two taxis, and 11 automobiles at the platform curb.

As a general criterion, at most interchange stations, it is considered desirable, if found practicable at specific sites, to provide a vehicular loading roadway and loading-unloading platform along both long sides of each of the parking stations, in order to minimize peak vehicular concentrations entering and leaving the stations, even though the vehicular loading-unloading requirements themselves do not always indicate an absolute need for two such roadways. At a number of the stations, however, physical and site planning considerations will not make such double loading roadways practicable.

As shown in Figure 7, the vehicular loading-unloading platform should be 12 ft wide, the adjacent vehicle loading lane 10 ft wide, the maneuvering lane 11 ft wide, and the through lane 11 to 12 ft wide. There should be an 8.5-ft wide kiss-ride parking lane adjacent to the through lane and a 3-ft wide walkway and fence separating the parking lane from the main parking areas beyond. (The functions of these last two elements are described below.)

The loading, maneuvering, through, and parking lanes, and the walkway-fence strip, altogether make up approximately 43 to 45 feet of width and are termed the loading roadway. At aerial and subway stations the 12-ft wide loading-unloading platform is assumed to fall within the 50- to 60-ft width of the station structure itself, since the track level will be above or below the surface level where the vehicular loading-unloading platform is situated. At surface stations the width required for two train tracks with side platforms, fare collection equipment and fencing, and a vehicular loading-unloading platform on each side of the station, will approximate 96 ft.

Walking

Patrons walking to and from the 23 parking stations are, with few exceptions, not expected to be more than 20 percent of all patrons, and usually only 5 to 15 percent. Adequate pedestrian walkways should be provided from all areas of the station structure itself to various desirable points beyond the precincts of the external station facilities. These walkways should usually be at least 2 lanes or 60 in. wide. A pedestrian lane width of 27 in. is considered as a minimum, with 30 in. desirable. Walkways will be required as access to and possibly through station parking lots.

In most cases, special pedestrian undercrossings or overcrossings of adjacent streets and of the loading roadway(s) will not be justified, at least in the earlier years of operation. As patron walking volumes increase with the growth of residential, commercial, and industrial developments adjacent to the stations, more such separated crossings may later be required. Of particular concern will be the walking and parking patrons who must cross the loading roadway(s) to reach the station structures; here pedestrian conflicts with vehicular loading-unloading movements may be severe enough to warrant separated crossings, either later on or at the opening of service, depending on particular analysis of individual cases.

Bicycles

Patrons arriving and leaving by bicycle, motor bicycle, scooter, etc., are not expected initially to be a significant percentage of the total access volume. Consideration should, however, be given to their access movements and to the possible later provision of bike and other racks in a special storage area if this access mode were to develop to any degree.

Feeder Transit

At the 23 parking stations, all or virtually all feeder transit services will be provided by self-powered buses. In some cases, these buses will merely make curbside stops along streets at or near stations. In other cases, however, the buses will enter and leave via the loading roadway, and load and unload at the vehicular loading platform.

Analysis indicates that, until at least 1980, three or four bus platform stalls can be expected to meet the feeder bus loading requirements at most stations. A marked-off 200-ft center section of the 700-ft long loading platform, for example, would best accommodate three larger feeder transit buses for this purpose. By the nominal year 2000, more platform bus berths may be required at several of the parking stations; in those instances it would be desirable, if practicable, to distribute the feeder bus platform loading-unloading onto two vehicular loading platforms. Feeder bus layovers could be accommodated at these loading stalls, and at curbsides and other locations near the stations as desirable. By 1980 at these 23 stations, between 14 and 58 percent of total patron access volumes are expected to be by the feeder transit mode. The proportions of these which will board (a) at nearby curbside street bus stops, and (b) at the station access roadway loading platforms has been evaluated and will vary at each station.

Taxis

Patrons using taxicabs as their loading mode at the 23 parking stations are not expected usually to be more than 1 to 3 percent of total patronage. Until at least 1980 two taxi loading stalls, occupying a total of 50 ft of loading platform length, should adequately meet all requirements at these stations. In the nominal year 2000, four taxi loading stalls are indicated for most of these stations; again, it would be desirable, if practicable, to divide this requirement between two loading platforms located along each long side of the stations.

A small taxi reservoir area holding a maximum of four cabs would be desirable along the loading roadway at the end of the 700-ft long loading platform. A 4-cab reservoir would be about 100 ft long with the cabs in a single file; if in two files, about 1,000 sq ft of space would be required.

Kiss-Ride

Family members driving husbands and others to and from stations (with the automobiles involved not being parked there) are expected to account for about 5 to 30 percent of all patrons arriving and leaving the 23 parking stations. Patrons arriving at a station will be driven in via the loading roadway(s), discharged at the loading platform(s), and the automobiles involved will then be driven away from the station. Of the 700-ft length of loading platform, typically 200 ft would be taken up by three central bus loading stalls, 50 ft by two taxi loading stalls, and the remaining 450 ft would be available for about 11 kiss-ride automobile stalls. These latter stalls will be most intensively used in the weekday inbound morning peak periods, during which analysis indicates that by 1980 one loading roadway with its 11 kiss-ride platform unloading stalls would be sufficient. However, as indicated above, if practicable it would be highly desirable to de-concentrate these loading roadway vehicular peaks onto two, rather than just one, loading roadway at each station. By the nominal year 2000, two such loading roadways, along both long sides of each station structure, may be required at least at some of the 23 parking stations.

Patron egress by the kiss-ride mode requires additional external station facilities. In the minority of cases where the patron reaches the vehicular loading platform before the kiss-ride automobile appears, the vehicular arrival process is simply repeated and the patron is driven away to his home. Most family members picking up husbands and others at the stations to drive them home will, however, by prearrangement, arrive at the station before patrons alight from their trains. These kiss-ride automobiles must, therefore, be parked for a relatively short period until the patrons appear for the trip home. As shown in Figure 7, one lane of kiss-ride parking, accommodating about 30 stalls, is located along the side of the loading roadway opposite the loading platform and next to the through lane. Since the short-term waits of kiss-ride autos picking up patrons are concentrated in the weekday outbound evening peak periods, it would be wasteful of space and capital funds to provide much more than one file or lane of these stalls along each loading roadway; these stalls may be used conveniently for this purpose throughout the day. At all 23 parking stations in 2000 and at most of them in 1980, however, the estimated requirement for kiss-ride short-term parking stalls in the evening peaks is several times higher than the loading roadway stalls which can economically be provided for this purpose.

The remainder of this evening peak kiss-ride stall requirement could be met conveniently in another manner. By regular prearrangement, the family member driving the automobile to the station to pick up a kiss-ride patron could select a first and a second parking choice among alphabetically lettered small sections of the station parking area shown in Figure 7. The kiss-ride patron, knowing that his auto pickup would be parked in one of two adjacent lettered parking sections, walks to the first-choice section and finds his auto there or, if not there, locates it in the second section. Because, in each lettered small section, some automobiles parked there all day will already have been driven away by parker patrons early in the afternoon peak, the family member driving the pickup auto into this section, by regular prearrangement, would be able to find a vacant stall for her use for short-term parking while awaiting the kiss-ride patron. A special colored pennant attached to the auto aerial while waiting for the kiss-ride patron might aid his identification of his automobile. The family member waiting for the kiss-ride patron might also park in the aisle while awaiting a stall vacancy, if two-lane two-way aisles are provided. The transit system could assist the lettered-area selection process by providing prearrangement duplicate forms (one copy for the kiss-ride patron and the other for the driver) and recommending which lettered sections should be used to balance the demands for this type of short-term-waiting parking. In addition, some curbside space on streets adjacent to the stations may also be suitable for this kiss-ride vehicle waiting function.

Parking

General Layout. —Generally between 10 and 50 percent of all patrons at the 23 parking stations are expected to arrive and leave these stations as either drivers or passengers in automobiles parked at the stations. Figure 7 shows an optimum parking layout for a typical station requiring 1,200 lot stalls. It is to be noted that the parking stalls are distributed in an equidistant manner from all points along the edge of the 700-ft long by 60-ft wide station structure to minimize stall walking distances and peak vehicular concentrations at parking entrances and exits.

For most large parking lot sizes and shapes, 90-deg-angle parking, with stalls and aisles wide enough to permit convenient one-maneuver stall entry and exit, and generally two-lane two-way aisle movement, provides the most economical use of space, the most efficient arrangement of stalls, and the most efficient internal vehicular circulation (Fig. 7). Almost 100 percent of the Cleveland rapid transit system's 5,225 station parking stalls are right-angle (4), and this is common, although not exclusive, practice on other commuting systems.

Access Dispersion. —It is essential to disperse the entrance and exit of parking vehicles onto as many different streets and highways as possible in the vicinities of the stations to minimize peak vehicular congestion on these feeding streets and in the station parking facilities. At least one entrance lane and one exit lane should be provided for every 300 (and preferably every 250) station parking stalls. Where more than 2,000 parking stalls may be provided in the future in one facility, a rate of up to 500 stalls per entrance and per exit lane may have to be tolerated, provided the feeding streets-highways involved will then have reasonably high individual capacities. These entrance and exit lanes should be dispersed throughout the parking facility and not concentrated in just one or two places or onto just one street. At stations with more than 1,000 stalls, it will be important to disperse parking entrances and exits onto several feeding streets of relatively low individual capacity, directly onto at least one or two highways or streets of high capacity, or onto an adequate combination of the two.

These vehicular dispersal criteria are essential to avoid overtaxing the available capacity of one or more feeding streets adjacent to the station parking facilities, since these streets have more community traffic-moving functions than just those related to an individual rapid transit station. Similar comments were made previously with respect to the station loading roadways.

Comprehensive functional traffic engineering studies are being made at each station site to insure that all elements of station access and parking are in close harmony with then-present and future land use, traffic circulation, and planning in the general vicinity of each individual station. This work is being accomplished in close coordination with the interested local planners and engineers.

Classes. —It is proposed that the station parking area itself be divided for use by four classes of parker (A, B, C, and D) as shown in Figure 7. This proposal is subject, however, to further review and has not yet been adopted as a policy for the BART system. Class A parkers are those who are willing to pay about $0.25 a day for a reserved standard-size stall (8.75 by 20 ft, aisle width of 25 ft) located as close as possible to train platforms. About 15 to 25 percent of all stalls at each station may be of this type. The revenue from Class A parkers pays for the maintenance and operation of the entire parking facility.

Class B parkers are free parkers who drive miniature vehicles or go-carts which can be parked in a miniature-size stall (about 6.5 by 11 ft, aisle width of about 16 ft). They are given second preference in propinquity to train platforms (after Class A) because of the small spaces they occupy. For design purposes it is assumed that by 1980 there will not be enough miniature vehicles on the market to make this class of parker a significant enough customer to warrant special Class B stalls. Nevertheless, it is known that some manufacturers are experimenting with miniature cars of low capital cost for home-to-station commuting and for family "second cars" to be used in local neighborhood travel (school, shopping, and other local trips). It is estimated that these may represent 10 percent of all parkers by the nominal year 2000. Because of their economy in parking space usage, they should be given every encouragement.

Class C parkers are free parkers who drive small foreign cars which can be parked in a small-size stall (about 7.5 by 14 ft, aisle width of about 20 ft). They are given third preference in propinquity to train platforms (after Class B). Small foreign car usage has been growing and already represented 8 percent of all cars parked at Southern Pacific Peninsula commuter stations in 1960. It is estimated that at the rapid transit stations they may represent 15 percent in 1980 and 25 percent in 2000.

Class D parkers are free parkers who drive standard-size American cars which can be parked in a standard-size stall (8.75 by 20 ft, aisle width of 25 ft). In 1980 they are estimated to represent 85 percent and in 2000, 65 percent of all cars parked at the 23 parking stations. They will occupy the remainder of the parking area as shown in Figure 7.

Portions of Class D space may be set aside for short-term (3 to 5 hour) parking for off-peak users, particularly women shoppers.

Flexible Periodic Layout Readjustments. —It is apparent, from the changing circulation requirements and proportions of different classes of parkers, likely to occur in the future, that the parking stalls and aisles, as well as the entrances, exits, and access roadways, should be constructed and delineated so that they may be conveniently and flexibly readjusted to meet changing conditions. This criterion does not preclude the landscaping and other architectural treatments which are most necessary in all of the external station facilities to create a pleasing impression for rapid transit users and the general community involved. It is also to be observed that the aisle and stall dimensional requirements of each parking class tend to create modules which limit such readjustments and may tend in some cases to limit the effectiveness of small or miniature stalls and aisles.

Operation. —Parking revenue collection for Class A parkers should be separated from train fare collection because of the great expense of maintenance and capital cost of installation, as an alternative, additional system fare collection equipment out-of-doors at the several entrances and exits of all station parking facilities. Actuated gates and fee payment at parking entrances and exits are also expensive and relatively impractical for these applications. Parking meters are relatively expensive to maintain and operate under these conditions. Instead, a much simpler and more economical method of Class A parker revenue collection has been proposed for consideration. The station agent at each parking station and/or the system's several Customer Service Centers would issue, on proper payment and identification, window stickers for automobiles showing date of expiration of validity, station valid at, and class of parker. The parkers affix the stickers at a directed specific place inside a specific window of their automobiles.

On presentation of proper information, Class B, C, and D parkers would obtain free, from the same sources, stickers showing similar information. Roving checkers would periodically check the stickers on all parked vehicles for validity; repeating offenders would be towed away. The sticker identification system would be necessary at most, if not all, parking stations to insure that the parking stalls will be available to and used by bona fide rapid transit parker patrons. General parking demand near these stations might otherwise cause these stalls to be occupied by nonusers.

Rapid transit fares are dedicated for purposes other than the expenses of maintenance and operation of parking facilities. Therefore, revenues from Class A parkers should be sufficient to cover the expenses of the entire parking facilities, which include maintenance, cleaning, window-sticker checking and issuing, lighting, insurance, accounting, administration, and miscellaneous expenses.

Lot vs Multi-Deck. —At most of the 23 parking stations, present plans are that all stalls initially provided will be in lot-type facilities. It is possible that the point may be reached in certain cases, however, where it would be less expensive to construct initially some multi-deck rather than single-level lot parking facilities.

All station parking facilities will be developed to permit the future addition of multiple parking decks. The sizes and shapes of the initial parking facilities, and their stall-aisle modules, must permit the possible subsequent vertical expansion of parking capacity. A frequent advantage of multi-deck parking structures is the marked reduction in average walking distances between auto stall and train platform. It is also then possible to consolidate large parking capacities into multi-deck structures to avoid sprawling the entire capacity over huge single-level lots.

As a general guide, the following walking distance standards have been provided for parking stalls, expressed in terms of radius from the station structure: a desirable maximum of 300 ft and an absolute maximum of 500 to 600 ft. These radii are measured from along the edges of the 700- by 50- to 60-ft station structures. The boundaries indicated by these radii, in effect, form around the station a type of oval in which all of the parking stalls should be located if practicable.

TRANSIT AND TRAFFIC OPERATIONS

Feeder Transit Operations

As shown in Table 8, the vast majority of patrons will reach the outlying parking stations by modes other than walking because of the access distances involved. During the critical peak periods, the passenger occupancy ratio of one bus will be typically 30 times that of one automobile reaching the station. Preferential treatment should be given to feeder transit buses, therefore, in planning station layouts. All present transit operations in the Bay Area have been inventoried and reviewed in past studies to ascertain their potential value as transit feeders to the rapid transit stations. This review process will continue during future stages of the project.

There are important potential economies to the existing transit systems in the conduct of feeder services to BART, especially on routes where feeder patronage is attracted above minimum levels. Feeder trips typically will be short, usually less than 2.5 miles in length and seldom over 6 miles. The bus mileage and operating expense required to serve them, therefore, will be relatively lower than when (as is now the case) such passengers must be hauled by bus all the way to their destinations, often with transfers between buses.

Most feeder transit routes to BART stations will be less than 4 miles in length, and on such routes a feeder bus can be recycled so as to carry two to five peak direction loads during the same crest peak period. There are also important opportunities for balancing the peak directional feeder volumes with additional patronage gained in the reverse direction. At a number of the stations, for example, not only will patrons be boarding rapid transit to commute to work elsewhere, but also commuters will be arriving at these stations for work in the general vicinity.

A significant number of local routes can with few changes be adapted as BART feeders. The operating ratio (expenses to revenues) on many of such routes may be susceptible to marked improvement over present levels. Patronage on such routes could be substantially increased by BART feeder demands; passenger trips, fare revenues, and net revenues per bus-mile could well be improved. The logic and economy of feeder transit operations, where patronage levels are sufficient, point strongly in this direction.

Further potential economies are possible for each local transit system as a whole. At present, usually for $0.15 or $0.20 these local systems must haul their patrons for much longer average distances (at much slower speeds than BART) over the whole lengths of their patrons' trips. They must also provide numerous presently uneconomic feeder bus routes to feed their main trunk routes. For one $0.15 or $0.20 fare today, therefore, their transferring patrons ride on two or even three different buses. One bus gets this fare and the other one or two collect only paper (i.e., the transfer). Such local transferring trips today are typically from 3 to 6 miles in total length.

With BART in operation, the bus patrons who transfer to BART rather than going all the way locally by bus will have typical feeder bus trip lengths of only 1 to 3 miles—less than half their present typical total trip length by bus. Furthermore, their feeder trips will almost always involve one bus to the BART station, rather than two or three when transferring as at present. In addition, these passengers will ride through the most critical (service-determining) transit maximum-load points and along the most congested urban corridors on high-capacity rapid transit, which can carry loads more economically at three to four times surface transit speeds.

These are factors of profound importance to local transit systems in areas served by rapid transit. They are the principal reasons why the general manager of the Cleveland Transit System can state that the introduction in 1955-1958 of the 15-mile East-West rapid transit line has improved the operating economy of the whole CTS bus and rail system and has retarded periodic needs for systemwide fare increases.

Vehicular Traffic Operations in Station Vicinities

In rapid transit station facilities, certain other general traffic operational considerations are important. As in most traffic planning, efforts should be made to deconcentrate potentially critical areas or points of congestion and conflict. Left turns across opposing vehicle flows should be eliminated as much as possible and right turns emphasized where appropriate.

It is desirable to prepare special estimates of the arriving and departing volumes of station vehicular and person trips, by each mode of access, during the design-determining peak periods. For this purpose, the effective tributary patronage territory of each station should be determined and divided into relatively small zones sectored or oriented toward the station itself. Such sector studies, with their estimated peak volumes arriving and departing by each access mode, are being prepared for each of the rapid transit and express streetcar stations of the BART system. These studies are essential to developing proper internal and external station area layouts, access roadways, and connections to the adjacent street and highway system. The sector studies also are essential to determine the impact of station-generated vehicular and pedestrian traffic on the feeding streets and highways in the vicinity.

Although feeder transit operations can, as indicated above, be conducted economically in many cases, there will be portions of some tributary patronage areas where potential feeder transit volumes will be light. It will often be less expensive, therefore, from the standpoint of overall regional and local transit operations to provide at the stations adequate parking stall capacity and kiss-ride facilities to reduce the needs for feeder transit services in cases where they are, in fact, uneconomical. The Cleveland Transit System has found this principle to be most effective at outlying stations where feeder transit patronage may be relatively light. It is less expensive for CTS to provide parking stalls in such cases than the equivalent feeder bus service. Obviously, the provision of the even less land-consuming and less costly kiss-ride auto facilities compares in this respect even more favorably.

GENERAL PLANNING CONSIDERATIONS

Population Densities and Rapid Transit

It is often advanced that urban areas of relatively low population density do not justify grade-separated rapid transit. Rather than the average population densities in each urban region involved, a more significant test is the relation between measured peak traffic volume-pattern demands and the transportation capacities available to meet these demands separately for each of the major corridors of the urban region. Although the overall population densities of a region, or the part of it proposed to be served by a rapid transit line, may be relatively low, the principal test is the ability of the proposed rapid transit facility to attract enough major corridor traffic of sufficient length to minimize effectively the total transportation facilities and costs required to meet total peak corridor demands.

Table 5 shows the parking-passenger trips attracted to four westside Cleveland rapid transit stations from their tributary patronage territories, and the lengths of those trips between place of residence and the rapid transit interchange stations used. It is significant to note from Table 5 that in October 1959 the weighted average access length of these trips was 2.97 miles, and that by March 1964 this average distance had increased by 8.4 percent to 3.22 miles. In fact, 25.0 percent of these trips reached the stations from distances of greater than 5 miles in 1964. The present West-Side rapid transit line serves ten suburban communities with an average population density of only 1,378 persons per square mile or 2.1 persons per acre (12). This line is being extended farther westward into outlying areas of low density.

Table 6 shows similar Cleveland rapid transit data for each access mode in March-April 1958. Although the West-Side Cleveland rapid transit line was only opened late in 1955, and by March-April 1958 extended west only to the W. 117th St. Station with less than adequate initial interchange facilities, even by 1958 24.2 percent of parker trips and 8.4 percent of all trips to and from the W. 117th and W. 98th St. Stations involved access distances of greater than 5 miles.

It is apparent that, with properly designed highway-transit interchange stations, the effective tributary patronage territory of rapid transit systems offering fast, convenient service may feasibly extend at least 4 to 6 miles in outlying areas. Even 6-mile trips to rapid transit stations typically involve only 15 to 20 min of travel time. A 4-mile auto access trip might typically involve 10 to 15 min of travel time to the station. Large portions of such station tributary areas may have very low suburban or exurban population densities. The important points are the amount of passengers attracted to the stations themselves and aggregated through the critical transit maximum load points of the major corridors served, as well as the lengths of the heavy-volume portions of those corridors.

Adequate well-designed provision must be made for potential patrons who will drive to collector stations and park there, enabling them to proceed over the most congested portions of their routes via rapid transit. From the standpoint of station economy, patrons who reach the station by kiss-ride vehicles and feeder buses require much less station facilities, capital investment, and area than do patrons parking automobiles there. Therefore, in planning and design, every encouragement should be given to the nonparking access mode categories.

Station Spacing and Location

In addition to emphasizing the needs for high standards in the planning and design of coordinated highway-transit interchange stations, these data illustrate that such collector stations usually should not be spaced closer together than every 2 to 3 miles in the outlying tributary residential areas of high-speed regional systems. A variety of access travel modes are usually available to prospective rapid transit patrons whose homes, or even places of work, are beyond normal walking distance from the station (1,300 to 2,600 ft). Long station spacings of 2 to 4 miles in the tributary residential areas are essential to insure high schedule speeds (45 to 50 mph) along the BART system. It is estimated (Table 8) that generally much less than 20 percent of all passengers reaching the 23 principal BART residential collector stations in outlying areas will do so on foot. The "reach" of the station, with proper feeder transit, parking, and kiss-ride facilities, is, therefore, vastly extended beyond the limited walking range, to effective distances of 4, 6 and, in some cases, 10 miles.

Station location, closely tied as it is to the general subject of rapid transit route location, is also influenced by a hierarchy of other considerations which can appropriately be the focus of a separate paper. Important among these considerations are the forecast characteristics of each potential station site and its tributary or service area, as discussed previously. Of considerable importance is the ranking of the service functions assigned to each station under study. Such functions include those of residential passenger collection and those of passenger delivery within regional subcenters and centers. The proportions of the collection and delivery functions will vary between stations. The best collector stations are usually those which strongly emphasize or solely possess this function, to the deemphasis or exclusion of central delivery functions.

Therefore, in rapid transit route location, the aim is often to locate some stations between or away from regional subcenters or centers to optimize coordination with access streets and highways, provide adequate station interchange facilities with minimum congestion, and thus serve well residential tributary areas which are usually spread out in composition. Other stations along the same route will emphasize the delivery function to regional subcenters and centers and may or may not also function as residential collectors.

CONCLUDING OBSERVATIONS

In the total transportation planning process under way in urban regions, it is evident that private and public transportation must be coordinated effectively to minimize the aggregate investment in transportation facilities and costs of operation, as well as to minimize urban congestion and travel times.

People must first get to public transit stations and stops if they are to make use of these facilities and not always travel all of the way in automobiles. The attraction of potential passengers to transit stations and stops is, therefore, of paramount importance. Not only must the transit systems themselves be fast, economical, convenient, and comfortable; the interchange facilities required to attract patrons at stations and stops must also be abundant and well-designed. The transit stations, therefore, become critical elements of transition between highway and transit travel.

There are important areas for further research and development within this general subject. Additional studies are desirable with respect to the characteristics of tributary station territories, patronage volumes, feeder transit operations, vehicular traffic operations, modes of access, and volume periodicity. Unfortunately, to date, rapid transit stations with parking, feeder transit, and kiss-ride facilities available for such studies, are relatively limited in number. Until the new generation of rapid transit systems are in operation in the Bay Area, Philadelphia, and elsewhere, further research must be concentrated principally at the rapid transit and commuter railroad stations having such facilities in Cleveland, Boston, New York, Philadelphia, Chicago, and a few pioneering cities abroad.

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Effects of Alternate Loading Sequences on Results From Chicago Trip Distribution and Assignment Model

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Use of alternate loading sequences has little effect on areawide totals for travel estimates (as applied to Pittsburgh Area Transportation Survey data). However, when smaller units—zones, districts, rings, sectors, links, or specific movements—are considered, the differences can be large and can exert a definite influence on design and economic analyses.

•THE BASIC concepts of traffic assignment—the allocation of vehicle trips to routes in a transportation network—evolved in the early and middle 1940's. The early work in assignment consisted primarily of estimating the diversion of traffic from existing roads to new, improved, high-speed arterials or freeways. Travel time savings and distance savings were the primary bases for the estimates.

Later attempts at estimating traffic diversion used the travel time (or speed) ratio and travel distance ratio, and better results were obtained. In 1955 the Detroit Metropolitan Area Traffic Study developed a method of estimating diversion using both the speed and distance ratios, and this was used in assigning traffic to a network of freeways and arterials. However, only two routes could be considered for each interzonal movement: the most direct arterial and the most advantageous freeway route. Although this method was workable and produced meaningful and useful results, a more efficient method of assigning traffic to an urban network was needed.

In 1957 the breakthrough in network assignment occurred. Edward F. Moore presented a paper entitled "The Shortest Path Through a Maze" to the International Symposium on the Theory of Switching at Harvard University. At about the same time a paper by Dantzig was published. Of these, the paper by Moore is more widely used in transportation planning.

Also in 1957, the staff of the Chicago Area Transportation Study (CATS) was looking for a computer program to assign traffic to a large urban road network and contracted with the Armour Research Foundation (now the Illinois Institute of Technology Research Institute) for its development. Mertz (4) reports the progress thus:

> This investigation resulted in an electronic computer program for an intermediate size computer for finding the minimum time (or distance) paths through a network. The program is something of a laboratory novelty in that it is limited to 18 nodes (intersections) and is quite extravagant of memory storage. It provided the beginning, however, for further development.
>
> Mr. Morton Schneider and others on Dr. Carroll's staff further refined the method through many evolutions on an intermediate size computer to the point where they were able to accommodate enough nodes to encompass a small section

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> of the Chicago metropolitan area. These efforts were still in the research and development category. Dr. Carroll decided that the method was feasible but far greater computer storage capacity and computing speed was needed to do the job for the highway system for the whole Chicago area.
>
> At this point, a computer programming development was undertaken by the Chicago staff for the largest and fastest electronic computer then available in the country. . . . This resulted in an operational program to assign traffic to the existing arterial streets as well as the proposed freeways and expressways for the entire Chicago metropolitan area.

In 1958 CATS used an IBM 704 for the first traffic assignment to a metropolitan road network. Morton Schneider developed a trip distribution model known as the intervening opportunities model or the opportunity model. This was combined with the traffic assignment program and together they are known as the Chicago trip distribution and assignment model or, commonly, the Chicago (CATS) model. With some modifications, this model is used by the Pittsburgh Area Transportation Study (PATS).

The CATS assignment program utilizes an unusual capacity restraint feature. Capacity restraint is based on the premise that as the volume on a link increases, the time required to traverse that link increases. The CATS program applies the restraint after the trips from each zone have been assigned. In this way, travel times on links change throughout the assignment process, tending to prevent one roadway from being overloaded while a nearby parallel route is almost unused; in reality, this is how traffic behaves.

There are other capacity restraints in use today, but all of them use an iterative approach. After all trips have been (distributed and[1]) assigned, the restraint feature is applied and link travel times are changed according to the volumes on the links. Trips are then (redistributed and) reassigned, and the process is repeated until some criterion of change reaches an arbitrarily selected acceptable level.

With the CATS approach to capacity restraint, the order in which trips from the zones are loaded onto the network can have two important effects on the assignment process:

1. It can change minimum time path from A to B. If trips from a zone are assigned near the start of a loading sequence, the minimum time paths to other zones probably will not vary much from the initial (free) minimum paths; if trips from the same zone were loaded late in the loading sequence, the minimum paths could vary greatly from the initial ones.
2. This change in minimum time path can result in different zone-to-zone movements as calculated by the opportunity model. One of the factors influencing the magnitude of zone-to-zone movements is the ranking of destination zones by travel time from each origin zone. A separate ranking is made before trips from each origin zone are distributed. If the changes in interzonal travel times can change this ranking, they can also alter the calculated zone-to-zone movements.

Although the transportation studies currently using the Chicago model know that the assignment loading sequence can have these effects, they have never evaluated the changes which occur. It is generally agreed that the adverse effects can be minimized by the use of a random or selected loading sequence which does not load zones from any concentrated area consecutively; spatially concentrated loading can result in distortion of the natural trip distribution and assignment patterns.

The purpose of this study is to determine a measure of the magnitude of the effects of alternate loading seqeces on:

1. The total vehicle-miles of travel (VMT) in the network;
2. The volumes assigned to links in the network; and

[1] The Chicago model, and most other models, can use either predetermined trip interchanges or internally calculated interchanges.

3. The magnitude of the zone-to-zone interchanges as calculated by the intervening opportunities model.

ROAD NETWORK

The network used in this study is the PATS 410 network (Fig. 1). It consists of the basic 1958 network plus 99 miles of new freeways for which the Pennsylvania Department of Highways believes it has the finances to build by 1980 in the internal study area. It is not the network recommended by PATS in its final report; network 410 was used here primarily for convenience and, in addition, because it is the basic network used by PATS to provide the Pennsylvania Department of Highways with freeway design volumes.

TRIP INPUTS

The basic trip inputs were the forecast 1980 trip ends for each zone, i. e., 226 internal zones, 46 adjacent area zones, and 8 points-of-entry. These trips were stratified as long residential, long nonresidential, and short, as required by the format of the intervening opportunities model.

DISTRIBUTION MODEL

All interzonal trip transfers were calculated by the intervening opportunities model, using the formula:

$$V_{ij} = \sum_{L} V_i \left[e^{-LV} - e^{-L(V + V_j)} \right] \qquad (1)$$

where

V_{ij} = number of trips from zone i to zone j;
V_i = number of trip origins in zone i;
V = number of satisfactory trip destinations lying closer (on the basis of travel time) to zone i than does zone j;
V_j = number of satisfactory trip destinations in zone j;
L = probability of a trip of a certain type stopping at a random destination;
e^{-LV} = probability of getting to zone j and of not finding an acceptable destination closer than zone j;
$e^{-L(V + V_j)}$ = probability of going beyond zone j and of not finding an acceptable destination even after considering zone j; and
$e^{-LV} - e^{-L(V + V_j)}$ = probability of stopping in zone j.

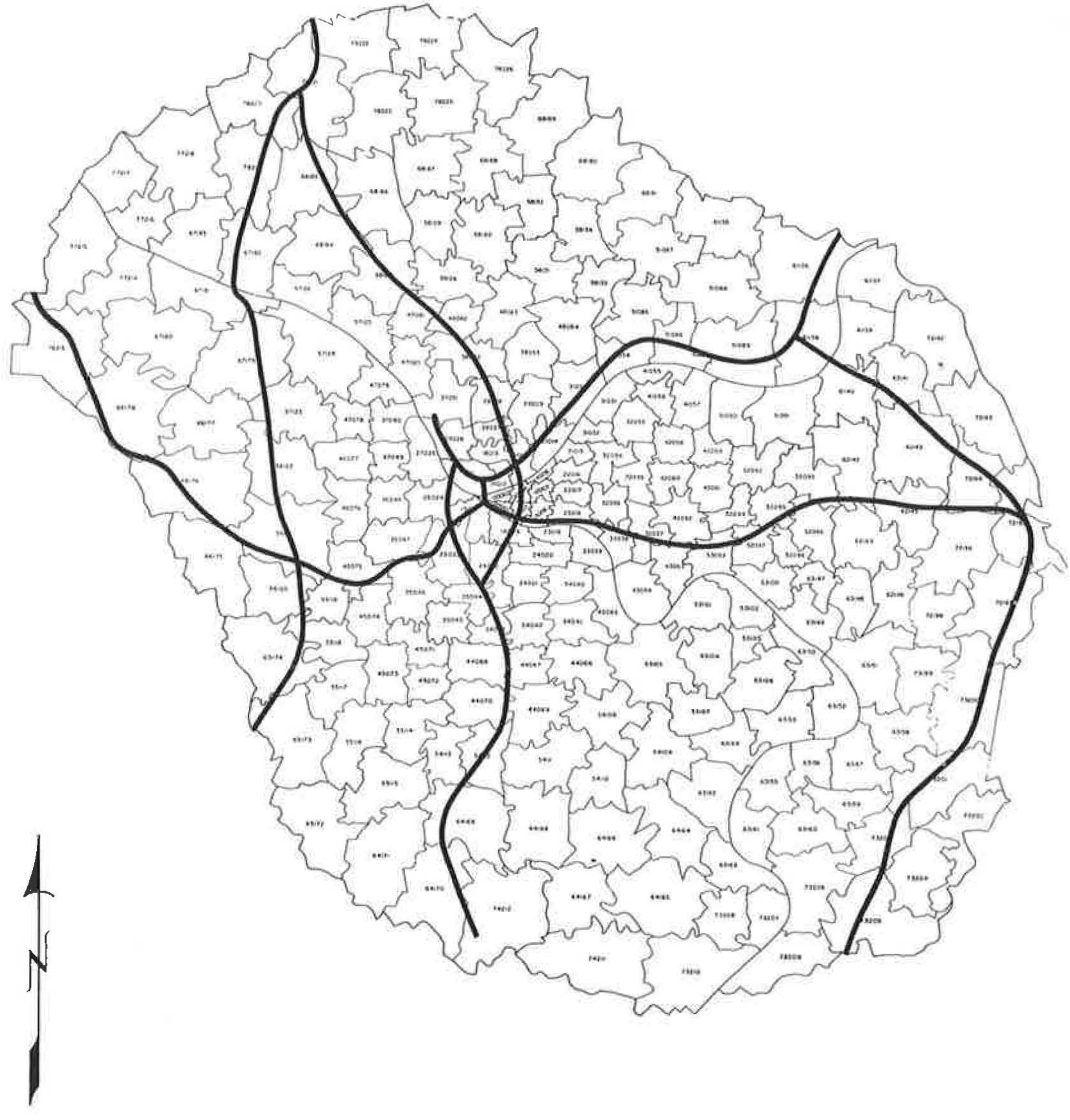
A separate calculation is made for the short, long residential, and the long nonresidential trips from each zone of origin.

There is one major difference between the CATS and PATS versions of the model: CATS uses one short L and one long L value for the entire study area; PATS uses separate long and short L values for each zone.

ASSIGNMENT PROCESS AND CAPACITY RESTRAINT

The trips are assigned to the roadway network in the following manner:

1. The network is provided as an input to the computer, complete with initial link travel times and 24-hour capacities.
2. The numbers of short, long residential, and long nonresidential trip ends in each zone are also inputs.



NOT TO SCALE

—— FREEWAY

Figure 1. PATS 410 network.

3. The computer seeks out the minimum time paths from the zone loaded first to all other zones and ranks these zones by travel time from the origin. The interchanges from this origin zone to all other zones are then calculated.

4. The calculated trip interchanges are then assigned to their respective proper minimum time paths according to the all-or-nothing method.

5. After all trips from the first zone have been assigned to the network, new link travel times are calculated to reflect the increased volume. The accumulated volume on each link is compared with the link's capacity, and the travel time is adjusted according to:

$$T_N = T_O \times 2^{V/C} \qquad (2)$$

where

T_N = new link travel time,
T_O = initial travel time (before any traffic assigned), and
V/C = volume-to-capacity ratio.

For computational purposes only, the V/C ratio has a limit of 2; thus, the maximum travel time on a link is four times its initial travel time ($T_N = T_O \times 2^2 = 4\,T_O$). Figure 2 shows this relationship. This curve was used because it was believed that a normal travel time vs volume/capacity curve would permit a majority of the trips to be assigned in an essentially unrestrained manner.

6. After steps 3 through 5 are completed for the first zone in the loading sequence, they are repeated for the second zone, the third zone, and so on until all trip interchanges have been calculated and assigned to the network.

LOADING SEQUENCE

This paper concerns itself with capacity restrained assignments only. In free (unrestrained) assignments the link travel times do not change from the initial values; hence, the loading sequence has no special significance or meaning.

Both CATS and PATS used "random" loading sequences with the Chicago model to eliminate bias and concentrated loading of trips. These were not random in a true mathematical sense. Rather, the sequences were handpicked or obtained on a sorter. It should be recognized that the use of a randomly generated loading sequence means only one thing: personal bias has been eliminated. There are almost 1.7×10^{565} possible loading sequences in the PATS area of 280 zones. Even considering only the 226 zones that send trips, there are still almost 1.8×10^{421} possible loading sequences.

For this study three loading sequences have been chosen for comparison. The first is the normal PATS sequence used in all official PATS assignments. It is developed from a reverse sort of the zone numbers. Zone 100 is loaded first, then 200, 010, 110, 210, . . . 179, 279, 089, 189, 099, 199. The scatter of this ordering is shown in Figure 3.

As a comparison, this sequence was completely reversed. Zone 199 is loaded first, then 099, 189, 089, 279, . . . 210, 110, 010, 200, 100.

The third sequence tested was the numerical sequence. As the name implies, zone 001 is loaded first, then 002, 003, 004, 005, . . . 278, 279, 280. This sequence loads trips originating in the CBD first, and then spirally works its way outward to the edges of the study area.

Although only zones 1 through 226 send trips, all 280 zones were used in setting up the sequence. It must be remembered that all network, trip, and L inputs were held constant during all three assignments; only the loading sequence was changed.

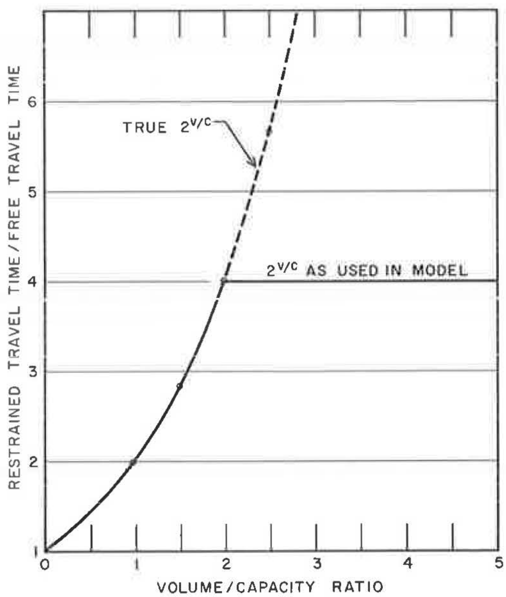


Figure 2. Travel time ratio vs volume/capacity.

VEHICLE-MILES OF TRAVEL

An important step in any transportation study is the calibration of the trip distribution and assignment models so that they reasonably simulate the total VMT (or some other parameter) in the study area. If there were any great differences in the total VMT between reasonable alternate loading sequences, it would be normal to question seriously the choice of loading sequence, and possibly even the validity of the model itself. Since, however, the variations in individual link travel would tend to be canceled out when aggregated, the total VMT would not be expected to vary much between loading sequences. Table 1, giving VMT data for the three loading sequences, confirms this.

The assignment of trips in the internal area by the reverse normal sequence produced 33,000 more VMT than did the normal sequence, a difference of only 0.20 percent. For the adjacent area the reverse sequence gave 31,000 fewer VMT than did the normal, a difference of -0.32 percent. Both of these are very close to the normal results, well within the accuracy of the data on which they are based. Summed for the

Figure 3. Loading sequence of internal zones—based on a 280-zone sequence (including adjacent area and points-of-entry).

TABLE 1

TOTAL VEHICLE-MILES OF TRAVEL: INTERNAL AND ADJACENT AREAS

Sequence	Internal VMT	Adjacent VMT	Total VMT
Normal	16,671,300	9,505,700	26,177,000
Reverse	16,704,300	9,474,700	26,179,000
Numerical	17,125,700	9,875,000	27,000,700

TABLE 2

VEHICLE-MILES OF TRAVEL BY RING: INTERNAL AND ADJACENT AREAS

Ring	VMT Normal	VMT Reverse	Diff. (%)	VMT Numerical	Diff. (%)
0	269,900	281,900	+4.4	262,700	-2.7
1	878,900	871,900	-0.8	797,900	-9.2
2	1,500,900	1,506,300	+0.4	1,389,400	-7.4
3	2,058,700	2,042,700	-0.8	1,957,800	-4.9
4	2,094,000	2,134,900	+2.0	2,049,600	-2.1
5	3,656,500	3,694,500	+1.0	3,813,000	+4.3
6	3,733,400	3,742,100	+0.2	4,061,100	+8.8
7	2,479,100	2,430,100	-2.0	2,794,300	+12.7
All internal[a]	16,671,300	16,704,300	+0.2	17,125,700	+2.7
8	4,891,400	4,837,900	-1.1	5,249,700	+7.3
9	4,614,400	4,636,800	+0.5	4,625,200	+0.2
All adjacent[a]	9,505,700	9,474,700	-0.3	9,875,000	+3.9
Total[a]	26,177,000	26,179,000	+0.008	27,000,700	+3.1

[a]Because of rounding, columns may not add to totals.

entire study area, the difference was only 2,000 VMT—0.008 percent—an unbelievably close correspondence.

The numerical sequence produced 454,400 more VMT than did the normal sequence in the internal area and 369,300 more VMT in the adjacent area. These represent differences of 2.7 and 3.9 percent, respectively. For the total study area the difference was 823,700 VMT, an increase of 3.1 percent. Although this is more variation than the reverse normal sequence produced, it is still within the accuracy of base data.

Table 2 shows the vehicle-miles of travel by ring obtained from each loading sequence for the internal and adjacent areas. Since all planning at PATS was done for the internal area, the differences observed in the adjacent area are not of prime importance. It suffices to say that for the adjacent area the reverse sequence produced 0.3 percent fewer VMT than did the normal sequence, whereas the numerical sequence gave 3.9 percent more VMT than did the normal sequence.

The comparisons for the internal rings (0 through 7) are interesting. Again the numerical sequence produced a greater overall difference in VMT than did the reverse normal sequence (2.7 percent vs 0.2 percent). The differences by ring when the reverse normal sequence was used showed no apparent pattern of increases and decreases. By contrast, the numerical sequence produced fewer VMT than did the normal sequence in rings 0 through 4 but more VMT in the other rings. The exact reason for this phenomenon is unknown; however, one possible explanation is worth considering. Trips from zones in ring 0 (the CBD) are sent first, zones in ring 1 (around the CBD) send their trips next, and so on, spirally outward, until all trips have been sent. When the trips from the innermost rings are assigned to the network, they result in increased travel times on the links of the network they use. Because of the mechanics of the model, all trips from a zone must be sent, but no zone must receive trips from all other zones. Therefore, the increased travel time on links in the inner rings made those zones less attractive as destinations and, in effect, diverted trips to other zones. The result is reduced VMT in the innermost rings. This is only an hypothesis, but it seems reasonable.

It is possible, also, to study the results by district, the area between two successive ring lines in a sector. Table 3 summarizes the effects of the alternate loading sequences on district vehicle-miles of travel. Figures 4 and 5 show the changes by district for the internal area only.

It is clear that there is an appreciable difference in the effects of the alternate loading sequences on the district vehicle-miles of travel. First, the use of the numerical sequence results in larger changes than does the reverse normal sequence. In the internal districts, the numerical sequence produced differences as large as 27.4 percent, almost twice as large as the maximum difference of 14.1 percent from the reverse normal sequence. The same is true for the adjacent area districts where the maximum differences are 14.9 percent for the numerical and 6.5 percent for the reverse normal sequence.

By comparing Figures 4 and 5, the effects of a numerical loading sequence are seen more clearly. Figure 4 shows that the districts with increased VMT from the reverse loading sequence were scattered over the study area in no apparent pattern. Figure 5 shows that the districts with increased VMT from the numerical loading sequence were concentrated around the outer portions of the study area. The reason for this has been discussed previously. There is no apparent reason for the area of decreased VMT on the western side of the study area.

Because of the amount of work and time involved in analyzing the vehicle-miles of travel by zone, a sample of 34 scattered internal zones (15 percent) was selected. These zones showed increases and decreases as large as 33 percent with both the reverse and the numerical loading sequences.

The most important conclusion from this part of the study is that the use of an alternate loading sequence has very little effect on the total vehicle-miles of travel in the study area. When smaller units of area—rings, sectors, districts, or zones—are considered, the effects of alternate loading sequences are much more pronounced. The smaller the area under consideration, the larger the difference in travel can be.

The next logical question is, "How do link volumes vary with loading sequence?"

TABLE 3

CHANGES IN VEHICLE-MILES OF TRAVEL BY DISTRICT

Area	Normal vs Reverse		Normal vs Numerical	
	Avg. Percent	Percent Range	Avg. Percent	Percent Range
Internal	+0.4	-14.1 to +10.5	-0.5	-27.4 to +19.8
Adjacent	-0.2	-4.4 to +6.5	+5.8	-5.5 to +14.9

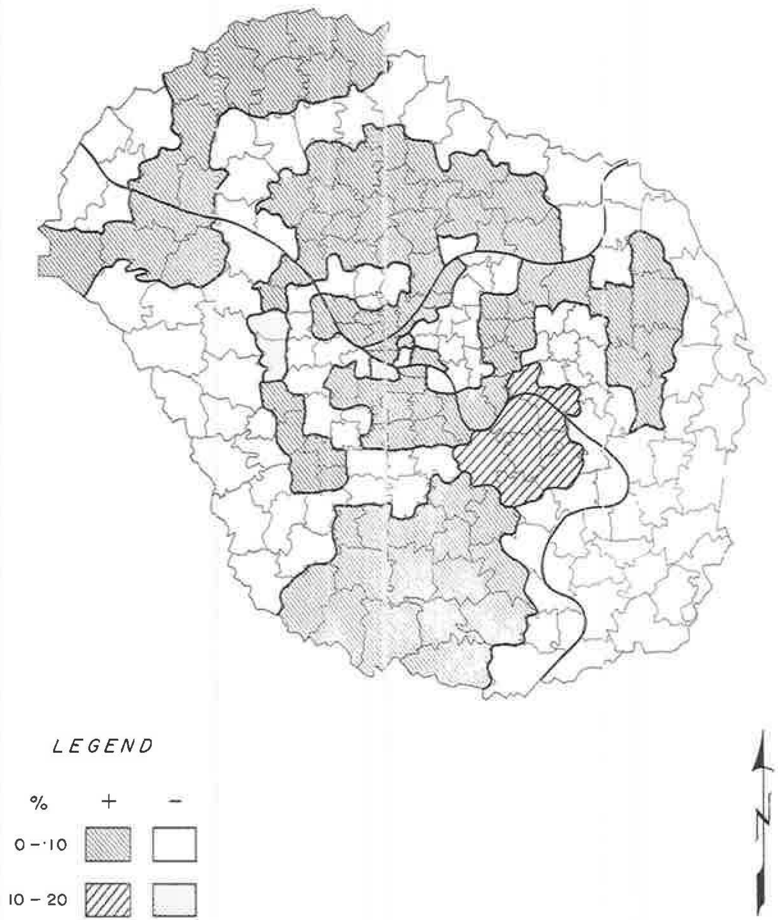


Figure 4. Vehicle-miles of travel by district: reverse vs normal sequence.

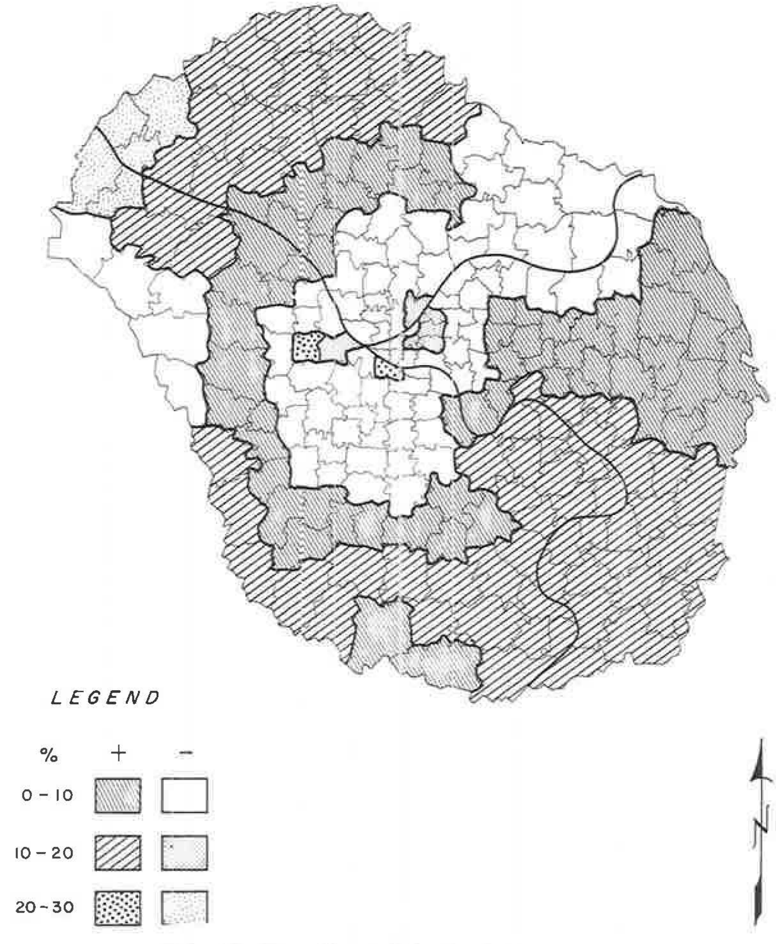


Figure 5. Vehicle-miles of travel by district: numerical vs normal sequence.

LINK VOLUMES

The 410 network used in this study has 3,041 links, including 2,136 arterials, 379 freeways, and 526 ramps. Table 4 shows the volume groupings used and the number of links in each volume class based on an assignment using the normal loading sequence. Because of the amount of time involved in the link-by-link analysis, only the results of the normal and reverse normal sequences have been compared.

In all studies of link volumes, comparisons are based on the normal sequence volumes. Thus, a difference of +10 percent means the alternate (reverse) sequence resulted in a 10 percent higher value than did the normal sequence.

It was believed that the root-mean-square (RMS) error of the link volumes would be a useful measure of the variations that occur. This is comparable with the standard deviation of a group of data around its mean (7). For each volume class the RMS error was found thus:

$$\text{RMS error} = \sqrt{\frac{\sum_{i=1}^{n}\left(V_{Ri} - V_{Ni}\right)^2}{n}} \tag{3}$$

where

V_{Ri} = link volume from reverse loading sequence,
V_{Ni} = link volume from normal loading sequence, and
n = number of links in a particular volume class.

All links were grouped by the normal sequence volume. Table 5 summarizes the calculations made. From this table, it is clear that the higher the volume assigned to a link, the less likely it is to fluctuate widely (on a percentage basis) when an alternate loading sequence is used. Figure 6 is a plot of the percent RMS error vs mean normal volume. The curve is handfitted to the data. The rapid decline in percent RMS error with increasing volume is very apparent. Links with volumes of less than 1,000 had an RMS error equal to 192 percent of the mean volume. As has been recognized by transportation planners, these low volumes are unreliable for many reasons, including the network configuration and loading node placement. These links seldom pose critical problems in planning work, but when such links are encountered, the planner must use his professional judgment and personal knowledge of the situation as guides.

Three links showed variations in excess of 1,000 percent. One was 1,277 percent, one 1,148 percent, and one 1,060 percent. The assigned volumes from the normal loading sequence were 480, 384, and 664, respectively. In each case the link was near, but not connected to, a loading node. It is believed that the differences were due primarily to changes in the distribution of trips from the nearby loading nodes. But this emphasizes a definite problem in constructing networks: loading nodes must be placed in such a way as to minimize their effects on the volumes assigned to major links near them. Two of these three links were expressway ramps—such vast dif-

TABLE 4

VOLUME GROUPINGS

Class	Normal Sequence Vol. (000)	No. Links
1[a]	0- 1	354
3	1- 3	305
4	3- 5	387
5	5-10	761
6	10-15	542
7	15-20	292
8	20-30	242
9	30-40	88
10	40-50	44
11	50-60	21
12	60-70	4
13	70-80	1

[a]Original classes 1 and 2 combined.

TABLE 5

LINK VOLUME DATA BY VOLUME CLASS: NORMAL VS REVERSE

Class	No. Links	Mean Normal Vol.[a]	Mean Reverse Vol.[b]	Diff. (%)	RMS Error	Percent RMS Error[c]
1	354	361	560	55.1	694	192.0
3	305	2,192	2,400	9.5	1,203	54.9
4	387	4,076	4,459	9.4	2,376	58.3
5	761	7,363	7,540	2.4	1,605	21.8
6	542	12,307	12,245	-0.5	2,424	19.7
7	292	17,270	17,063	-1.2	3,109	18.0
8	242	24,224	23,279	-3.9	3,755	15.5
9	88	33,748	33,377	-1.1	4,252	12.6
10	44	43,917	44,224	0.7	3,030	6.9
11	21	53,708	53,654	-0.1	2,041	3.8
12	4[d]	66,018	62,519	-5.3	—	—
13	1[d]	71,880	68,380	-4.9	—	—

[a]Mean volume of all links whose normal volume fell into a given class.
[b]Mean reverse sequence volume of all links whose normal volumes fell into a given class.
[c]Percent RMS error = RMS error/mean normal volume.
[d]Sample too small for statistical reliability.

ferences in volumes can be extremely important in the design of ramps and their terminals, and possibly in the design of the freeway itself.

The loading sequence underwent a most severe and drastic change when it was reversed. For this reason, the results of the link volume study are viewed most favorably.

From the foregoing link volume analyses, it can be concluded that in a restrained assignment using the Chicago model, the loading sequence exerts a definite influence on the volume assigned to each link in the network. Whether the volume on a particular link increases or decreases when the loading sequence changes is a function of loading sequence, location of the link with respect to other links, closeness to a loading node, etc. The change (plus or minus, and magnitude) cannot be predicted; generally speaking, the higher the assigned volume, the greater the faith that can be placed in it as a good estimate of that link's volume.

It is essential that the reader recognize that the network did not change during these assignment runs. If it had, more drastic changes in link volumes undoubtedly would have occurred. Because of the stability of freeway volumes during the changes in loading sequence, it is the author's belief that freeway volumes obtained from a restrained assignment can be used for design purposes under the following conditions:

1. No freeway, ramp, or major arterial link should connect directly to a loading node (zone centroid).
2. The arterial route system must be detailed enough to represent the major through routes and collector routes available to drivers in the area.
3. Perhaps most important, the volumes must be based on one freeway network (system). Major realignment of routes, or the addition or elimination of routes, can drastically influence the assigned volumes on all routes. Therefore, freeway volumes derived from an assignment using one network should never be used (except for comparison) with a different network.
4. All inputs to the model must have been carefully calculated and evaluated. If these are not reliable, why do an assignment?

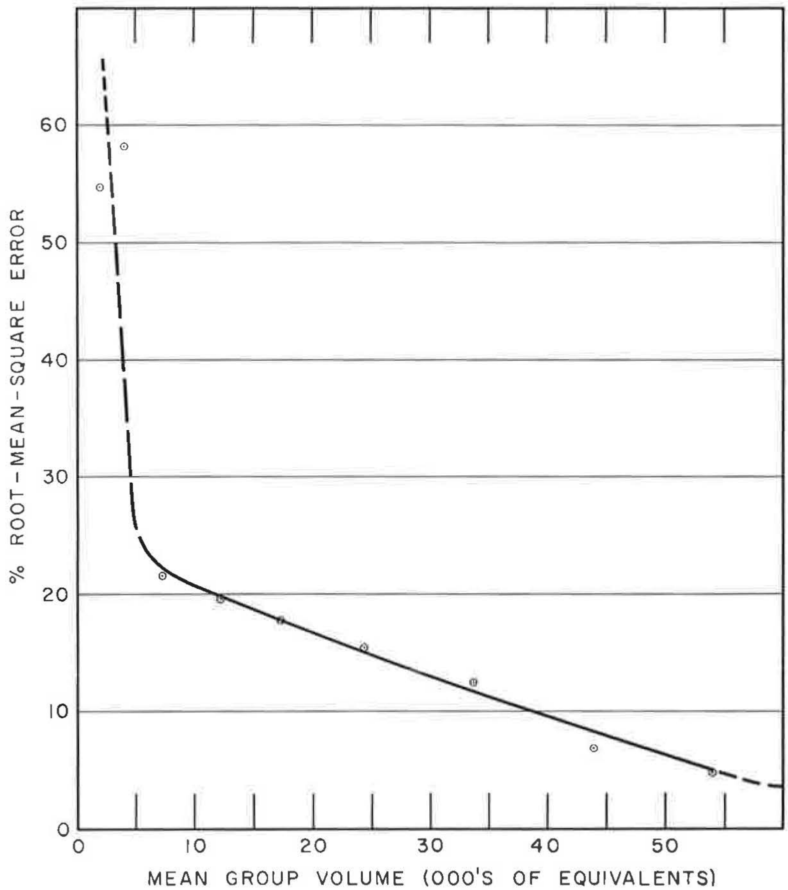


Figure 6. Percent RMS error vs mean group volume.

Some people argue that assignment volumes should not be used for design purposes. But what more reliable estimate of future freeway volumes is available?

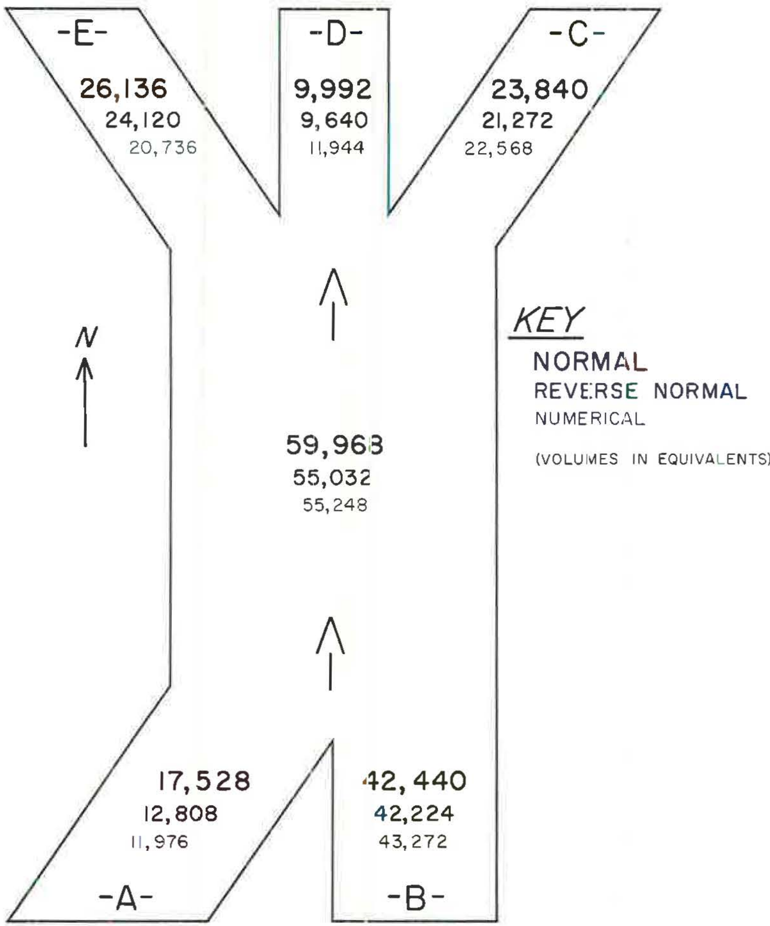
SELECTED LINK STUDY

It was decided to investigate in detail the effects of alternate loading sequences on the volume assigned to one key link in the network. The link selected was the Fort Pitt Bridge, a double-decked major connection on the Penn-Lincoln Parkway between the Golden Triangle and the southern and southwestern suburbs. (The Penn-Lincoln Parkway is actually a freeway according to the AASHO definition.)

The link volumes used in this study were obtained from the regular assignment outputs. The detailed data on individual interzonal movements were provided by the selected link subroutine developed for PATS by Morton Schneider. This subroutine gives the origin zone, destination zone, path time, and volume of each interzonal movement whose minimum time path utilizes the selected link (in this case, the Fort Pitt Bridge).

Figures 7 and 8, respectively, show the northbound and southbound volumes on each approach, on the bridge itself, and on each exit. The changes between normal and reverse normal sequences and between normal and numerical sequences are given in Table 6.

When the volumes from the normal and reverse sequences were compared, only one link (H) showed an increased volume (16.4 percent); all other link volumes decreased



NOT TO SCALE

Figure 7. Fort Pitt Bridge: northbound volumes.

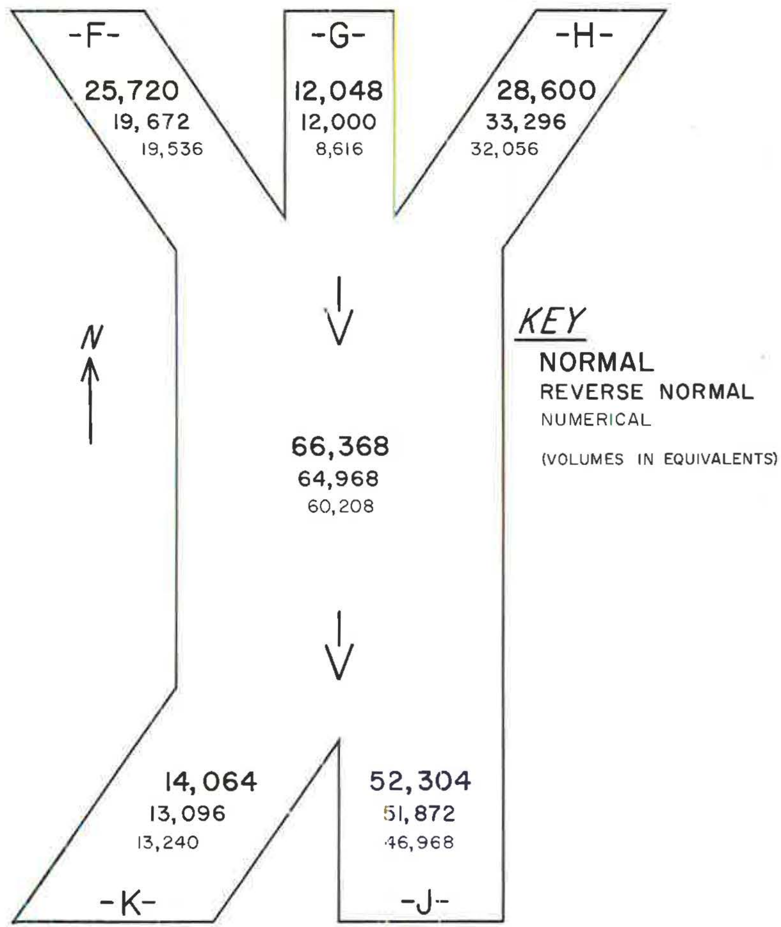


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Figure 8. Fort Pitt Bridge: southbound volumes.

TABLE 6

FORT PITT BRIDGE VOLUMES: NORMAL VS REVERSE AND NORMAL VS NUMERICAL

Direction	Link	Normal	Reverse	Normal vs Reverse		Numerical	Normal vs Numerical	
				Change	Percent		Change	Percent
Northbound	A	17,528	12,808	-4,720	-26.8	11,976	-5,552	-31.7
	B	42,440	42,224	- 216	- 0.5	43,272	+ 832	+ 2.0
	FPB	59,968	55,032	-4,936	- 8.2	55,248	-4,720	- 7.9
	C	23,840	21,272	-2,568	-10.8	22,568	-1,272	- 5.3
	D	9,992	9,640	- 352	- 3.5	11,944	+1,952	+19.5
	E	26,136	24,120	-2,016	- 7.7	20,736	-5,400	-20.7
Southbound	F	25,720	19,672	-6,048	-23.5	19,536	-6,184	-24.0
	G	12,048	12,000	- 48	- 0.4	8,616	-3,432	-28.5
	H	28,600	33,296	+4,696	+16.4	32,056	+3,456	+12.1
	FPB	66,368	64,968	-1,400	- 2.1	60,208	-6,160	- 9.3
	J	52,304	51,872	- 432	- 0.8	46,968	-5,336	-10.2
	K	14,064	13,096	- 968	- 6.9	13,240	- 824	- 5.9

between 0.4 and 26.8 percent. When the numerical sequence volumes were compared, three links (B, D, and H) had increased volumes (2, 19.5, and 12.1 percent); all other links had losses between 5.9 and 31.7 percent.

Of primary concern here are the normal vs reverse normal volume changes. (The numerical data are given for comparison only.) The Fort Pitt Bridge (FPB) itself showed small percentage changes in volume. These are not considered to be of great importance and would have at most minor influence on design. However, a few of the ramps (A, F, and H) showed large volume changes that could influence the design of the facility. This is one more indication of the danger of relying too heavily on assigned volumes for design purposes without first investigating the details of the network.

As a special part of the selected link study, an analysis was made of individual zone-to-zone movements using the Fort Pitt Bridge. A full deck of cards of zone-to-zone movements using the Fort Pitt Bridge was obtained as an output from each selected link assignment. The cards from the normal and reverse sequences were matched to find the number and volume of interzonal movements using the bridge on both assignments, as well as the number and volume of those movements using it with only one loading sequence. The same was done for the normal and numerical sequences (Table 7).

Table 7 shows a summary of interzonal movements assigned to the bridge. A matched movement is one whose minimum time path uses the Fort Pitt Bridge with both loading sequences. An unmatched movement is one using the bridge on only one sequence. For example, in the southbound normal vs reverse data, there were 2,831 interzonal movements whose minimum paths used the bridge with both loading sequences, 1,250 others used it with the normal sequence only, and another 1,313 used the bridge with the reverse sequence only. It is interesting that an average of 68 percent of the southbound movements and 75 percent of the northbound movements matched. There is no apparent reason for the differences in percent, but the results show that, despite a drastic loading sequence change (complete reversal), 68 to 75 percent of the same movements use the bridge. This is very important since it shows the basic stability of movements assigned to a link in a freeway system.

Table 7 also summarizes the two components of volumes assigned to the Fort Pitt Bridge. The matched volume represents the sum of all interzonal transfers whose minimum paths used the Fort Pitt Bridge on both the normal and reverse sequences. The unmatched volume represents those trips whose minimum time paths used the bridge on one assignment only. Comparing the southbound normal vs reverse data, the volumes that matched (49,592 and 49,280) represent the volumes of the 2,831 matched interzonal movements (Table 7). The difference between the matched volumes represents the net effect of changes in the calculated volume of each of the 2,831 move-

TABLE 7

ZONE-TO-ZONE MOVEMENTS AND VOLUMES USING FORT PITT BRIDGE

Direction	Assignment		Matched[a]	Unmatched	Total	Percent Matched
(a) Zone-to-Zone Movements						
Northbound	Normal	85	2,835	1,011	3,846	74
	Reverse	06	2,835	952	3,787	
	Normal	85	2,925	921	3,846	76
	Numerical	07	2,925	523	3,448	
Southbound	Normal	84	2,831	1,250	4,081	69
	Reverse	04	2,831	1,313	4,144	
	Normal	84	2,724	1,357	4,081	67
	Numerical	05	2,724	752	3,476	
(b) Volumes (vehicle equivalents)						
Northbound	Normal	85	47,680	12,288	59,968	80
	Reverse	06	46,384	8,648	55,032	84
	Normal	85	49,400	10,568	59,968	82
	Numerical	07	45,600	9,648	55,248	83
Southbound	Normal	84	49,592	16,776	66,368	75
	Reverse	04	49,280	15,688	64,968	76
	Normal	84	48,728	17,640	66,368	73
	Numerical	05	46,544	13,664	60,208	77

[a]Those interzonal movements or trips using Fort Pitt Bridge on both assignments of pair.

ments. In addition, there were 16,776 trips using the Fort Pitt Bridge only when the normal sequence was used; another 15,688 used it with the reverse sequence only.

Approximately 75 percent of the southbound volume and 82 percent of the northbound volume matched. (These same percentages were found for the normal-numerical analysis.) It is especially important to recognize that although the total directional volume assigned to the Fort Pitt Bridge with each loading sequence is about the same, a sizable portion of this volume is peculiar to each loading sequence. This means that there are about 16,000 southbound trips and 10,000 northbound trips whose presence is solely a function of loading sequence. Their distribution between the approaches to and exits from the bridge is a key factor in weaving area design, but determining this distribution was beyond the scope of this study. The previous numbers—16,000 and 10,000—may be misleading. They do not represent weaves, but the portion of the total volume that is a function of loading sequence. The actual volume of the weaves is, in all probability, much smaller.

VARIABILITY OF INTERZONAL TRIP DISTRIBUTION

As the basis for trip distribution, the intervening opportunities model uses the ranking of trip ends by travel time at the time of distribution. It was believed, therefore, that the use of an alternate loading sequence in a restrained assignment would change the volume of individual zone-to-zone movements. By use of the selected link subroutine, the volume of each interzonal movement using the Fort Pitt Bridge was obtained as an output from each assignment. Those matching—appearing on both assignments of a pair—were then compared. It would have been desirable to compare all possible zone-to-zone movements in the study area, but the amount of time and work involved was too great.

Table 8 gives the distribution of differences (normal volume minus reverse or numerical volume) for the northbound and southbound movements. The most important finding is that 80 to 85 percent of all movements corresponded exactly, and 97 percent of all movements were within 8 trips of the value from the normal distribution. Approximately 1 percent had differences greater than 16 trips. (It should be remembered

TABLE 8

CUMULATIVE TRIP DIFFERENCE DISTRIBUTION

Diff. (+)	Normal-Reverse			Normal-Numerical		
	No. Z-Z[a]	Cum. No.	Cum. Percent	No. Z-Z[a]	Cum. No.	Cum. Percent
			(a) Northbound			
0	2,215	2,215	78.1	2,413	2,413	82.5
8	531	2,746	96.9	431	2,844	97.2
16	52	2,798	98.7	44	2,888	98.7
24	11	2,809	99.1	16	2,904	99.3
32	10	2,819	99.4	4	2,908	99.4
40	3	2,822	99.5	6	2,914	99.6
48	4	2,826	99.7	4	2,918	99.8
56	4	2,830	99.8	—	—	—
64	1	2,831	99.9	1	2,919	99.8
72	—	—	—	—	—	—
80	—	—	—	3	2,922	99.9
88	1	2,832	99.9	—	—	—
112	1	2,833	99.9	—	—	—
144	—	—	—	1	2,923	99.9
192	1	2,834	99.9	1	2,924	99.9
264	1	2,835	100.0	—	—	—
312	—	—	—	1	2,925	100.0
			(b) Southbound			
0	2,348	2,348	82.9	2,316	2,316	85.0
8	434	2,782	98.3	362	2,678	98.3
16	26	2,806	99.1	15	2,693	98.8
24	6	2,812	99.3	11	2,704	99.2
32	6	2,818	99.5	3	2,707	99.3
40	2	2,820	99.6	3	2,710	99.4
48	3	2,823	99.7	1	2,711	99.5
56	2	2,825	99.8	5	2,716	99.7
64	—	—	—	2	2,718	99.7
72	—	—	—	—	—	—
80	2	2,827	99.9	—	—	—
88	—	—	—	1	2,719	99.8
96	1	2,828	99.9	—	—	—
104	1	2,829	99.9	1	2,720	99.8
120	—	—	—	1	2,721	99.9
168	—	—	—	1	2,722	99.9
184	1	2,830	99.9	1	2,723	99.9
192	1	2,831	100.0	—	—	—
232	—	—	—	1	2,724	99.9
392	—	—	—	1	2,725	100.0

[a]Zone-to-zone movements.

that all interzonal transfers were rounded to the octal digit.) This is a much better correspondence than was expected and means that the majority of interzonal trip transfers using the bridge are affected very little by variations in loading sequences. A few movements showed differences of more than 56 trips, but these constitute less than 0.2 percent of the total movements.

This indicates that 99 percent of the interzonal movements using the Fort Pitt Bridge are only very slightly affected by the use of alternate loading sequences when the trip distribution is determined by the intervening opportunities model. It is believed that a similar ratio would be found if all possible interzonal transfers were compared.

TABLE 9

COMPARISON OF INTERZONAL MOVEMENTS

Normal Vol.	Reverse Range[a]		Numerical Range[a]	
0	0- 8	(1,742/1,929)	0- 24	(1,756/1,790)
8	0- 48	(1,750/2,008)	0- 48	(1,731/1,969)
16	0- 56	(525/694)	0- 24	(580/751)
24	8-120	(252/367)	8- 80	(299/412)
32	16- 64	(107/177)	0- 72	(134/203)
40	8- 96	(65/124)	24- 56	(89/143)
48	24- 64	(40/79)	16-136	(45/83)
56	40- 80	(24/48)	32- 96	(27/56)
64	16- 96	(8/32)	48- 80	(15/39)
72	48-120	(12/38)	8-256	(12/40)
80	16-160	(7/30)	24-104	(10/31)
88	56-112	(4/13)	48-112	(6/14)
96	72-176	(4/16)	32-128	(2/15)
104	88-128	(5/15)	24-128	(4/15
112	80-144	(3/9)	104-216	(2/9)
120	16-168	(0/11)	88-168	(3/11)
128	112-152	(0/9)	112-144	(2/10)
136	120-152	(1/5)	120-144	(1/5)
144	112-192	(1/11)	152-208	(1/6)
152	120-152	(3/7)	104-160	(3/6)
160	144-176	(3/8)	136-184	(1/8)
168	160-184	(1/3)	88-192	(0/3)
176	144-200	(3/7)	176-232	(2/6)
184	144-208	(1/6)	16-192	(2/6)
192	192-240	(1/4)	168-232	(0/4)
200	152-232	(0/4)	176-200	(1/3)
208	96-200	(0/2)	64-208	(1/2)
224	232	(0/1)	232	(0/1)
280	272	(0/1)	264	(0/1)
304	112-248	(0/3)	72-336	(0/3)
320	264	(0/1)	280	(0/1)
328	240	(0/1)	248	(0/1)
392	128	(0/1)	80	(0/1)
464	272	(0/1)	344	(0/1)
480	480	(1/1)	88	(0/1)

[a](X/Y):

X = number of matching interzonal movements with a reverse (or numerical) volume equal to normal volume, and

Y = total number of matching interzonal movements with normal volume shown.

The volume of each zone-to-zone movement was studied using the Fort Pitt Bridge as compared with its volume from the normal loading sequence. The results of the analysis are given in Table 9. These data are based on a volume grouping of the matched zone-to-zone movements obtained with the normal loading sequence. For example, with a normal volume of 24, when the reverse sequence was used, the movements ranged between 8 and 120 equivalents. Similarly, the corresponding movements ranged between 8 and 80 equivalents when the numerical sequence was used.

The data show that the smaller a given interzonal movement is, the more likely it is that the volume of the movement will not be changed by the use of an alternate loading sequence. Whether or not this would hold true for even larger movements is a matter of speculation, but there is some indication that the trend would continue. The sample of movements greater than about 56 is too small to make a more positive statement.

In summary, the selected link study has shown that although a link's volume may remain almost unchanged when alternate loading sequences are used, the movements comprising that volume may not be the same ones. This is especially important where complex weaving maneuvers are encountered, as in multiple-approach and multiple-exit bridges and closely spaced interchanges.

CONCLUSIONS

What does all of this say about the effects of alternate loading sequences when used with the Chicago trip distribution and assignment model?

A brief review of the study is in order. Three assignments were run using different loading sequences: normal, reverse normal, and numerical. All other factors were held constant: trip inputs, the network, and the long and short L's. All results were compared with those from the normal loading sequence. Several conclusions may be drawn from these results.

1. The use of a reasonable alternate loading sequence has a very small effect on the total number of VMT in the study area. As expected, the reverse normal sequence gave a closer estimate (to the value from the normal sequence) than did the numerical sequence, but both were close to the base (normal) value.
2. When the amounts of travel as determined by alternate loading sequences for smaller units of area—rings, zones, sectors, or districts—are compared, the effects of alternate loading sequences are more pronounced; the smaller the unit of area, the greater the difference can be. Again, the reverse loading sequence gave results that corresponded more closely to those from the normal sequence than did the numerical sequence.
3. The volumes on individual links are subject to fluctuations when alternate loading sequences are used. The higher the volume assigned to a link, however, the less likely it is to change greatly when other loading sequences are used.
4. Because of the large fluctuations that can occur in link volumes when the loading sequence is changed, extreme care must be taken when using the assignment data for work with arterials. Perhaps corridor analysis should be used. However, freeway volumes are only slightly influenced by changes in loading sequences, and they can be used for design much more reliably. It should be remembered, though, that the volume on a freeway link is a function of the freeway network. That volume should be used only in conjunction with the whole network. Using a freeway link volume with a different network can lead to gross errors.
5. Although the volume of a given interzonal movement may vary from one loading sequence to another, it is estimated that in only 1 percent of the cases will this variation be more than 16 trips.

In setting up a network, there are two important points to be remembered. First, never connect a loading node directly to a ramp or freeway link; in fact, loading nodes should be offset from the arterial system by "local links." Second, when there is any doubt about the inclusion of a link in the network, put it in.

In summary, the use of alternate loading sequences has little effect on areawide totals for travel estimates. However, when smaller units—zones, districts, rings, sectors, links, or specific movements—are considered, the differences can be large and can influence both design and economic analyses.

SOME FURTHER THOUGHTS

Throughout this report the phrase "ideal loading sequence" has been avoided, and for good reason. What is an ideal loading sequence? Is it a mathematically random loading sequence? Probably not. Is it one that loads long trips first and short trips last? Or the reverse? Does it load CBD trips first? Does it produce the closest estimate of VMT, or the closest estimate of volumes on existing freeway links? Or does it load in increments?

For areawide totals, the use of reasonable alternate loading sequences has little effect on the results. But link volumes are susceptible to the influence of loading sequences. Should full confidence be placed in the assigned volume from one sequence? Would a better estimate of the future link volume be an average link volume, derived from two or more assignments using different loading sequences?

These are only a few of the questions that should be answered in future studies of the effects of loading sequences on assignment results.

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Social Status of Head of Household and Trip Generation from Home

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The social scientist has for a number of years made use of the concept social status in explaining differential patterns of behavior. He has, more often than not, used occupation or income to operationalize this concept for selectively grouping households into various social status classes. This paper explores in detail, using the home interview survey data gathered in 1961 by the Puget Sound Regional Transportation Study (PSRTS), the relationships of "social status" and trip production from the home. Comparisons and comments on similar research done in this area by Shuldiner and Stowers are included.

•RECENTLY researchers associated with comprehensive transportation and land-use studies have uncovered many relevant variables related to household trip generation which should facilitate the task of forecasting trip demand. Unfortunately, the problem of reliably forecasting variables related to trip-making, not to mention their interrelationships with time, can be awesome indeed to those concerned with developing a reliable forecast.

This ominous note, however, has been sounded in every age and at every developmental level of the sciences. The process of scientific research, being generated as it is from theory, has usually permitted the theoretical possibility of an act to precede its pragmatic application. This paper deals with only part of the problem—examining at a point in time variables associated with trip generation. Although the author is aware of the attendant difficulties of their pragmatic application, they are ignored.

STATEMENT OF PROBLEM

To make any forecast of future trip demand better than an educated guess bounded by personal experience, it is imperative as a first step to isolate the relevant variables. This requires determining their general applicability to different geographical areas before determining their variance over time.

Although comprehensive studies of urban travel are concerned with forecasting the movement of persons and goods, it is the former with which this paper is concerned and in a very real sense it is the antecedent of the latter. The household serves as the unit of this analysis, with particular emphasis being given to the relationship of the occupation of the head of the household and trip generation from the home when size of household and automobile ownership are controlled. The generality of these relationships is tested by using data from the Chicago Area Transportation Study (CATS) as reported by Stowers (1) and data from the Puget Sound Regional Transportation Study (PSRTS).

PREVIOUS RESEARCH FINDINGS

Shuldiner, in summarizing the findings of his research, reported that he analyzed the relationship between a number of household variables and neighborhood characteristics and the frequency of person trips associated with individual households. He found family size and vehicle ownership to have the greatest influence on trip genera-

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tion (2). Further on, Shuldiner notes, "The occupation of the head of the household is one of the major determinants of the level of living a family enjoys. As such, occupation should be associated with trip frequency, as well as with other household characteristics" (2, p. 49).

This suggestion by Shuldiner was further explored by Stowers working with Shuldiner at Northwestern University (1, Footnote 1). Stowers likewise found family size and car ownership the most important factors affecting trip-making, but their influence was significantly different among the various households classified by occupation of the head of household.

Michelson, in applying this line of research, found that occupation and family size were significant variables in predicting automobile ownership for small areas within metropolitan regions, particularly where other methods cannot be used because of lack of data (3).

To summarize, it is reasonable to assert that, taken together, these research findings have pointed out a direction to follow in trying to understand better the variables influencing person trip productions. The household is the generator of trip productions; the characteristics of its members determine the types and amounts of trips produced. Therefore, the researcher interested in improving the forecast procedures should pursue this line of research in the analyses of transportation data.

DATA USED IN THIS ANALYSIS

In 1961 PSRTS studied some 1,100 sq mi which comprise the major urban portion of four counties around Seattle and Tacoma, Washington. These counties include two Standard Metropolitan Statistical Areas (SMSA). The nearly 35,000 households sampled (factored to 474,032 households existing in 1961 for this area) were used, together with the Chicago Area Transportation Study data reported by Stowers, to derive the findings of this report.

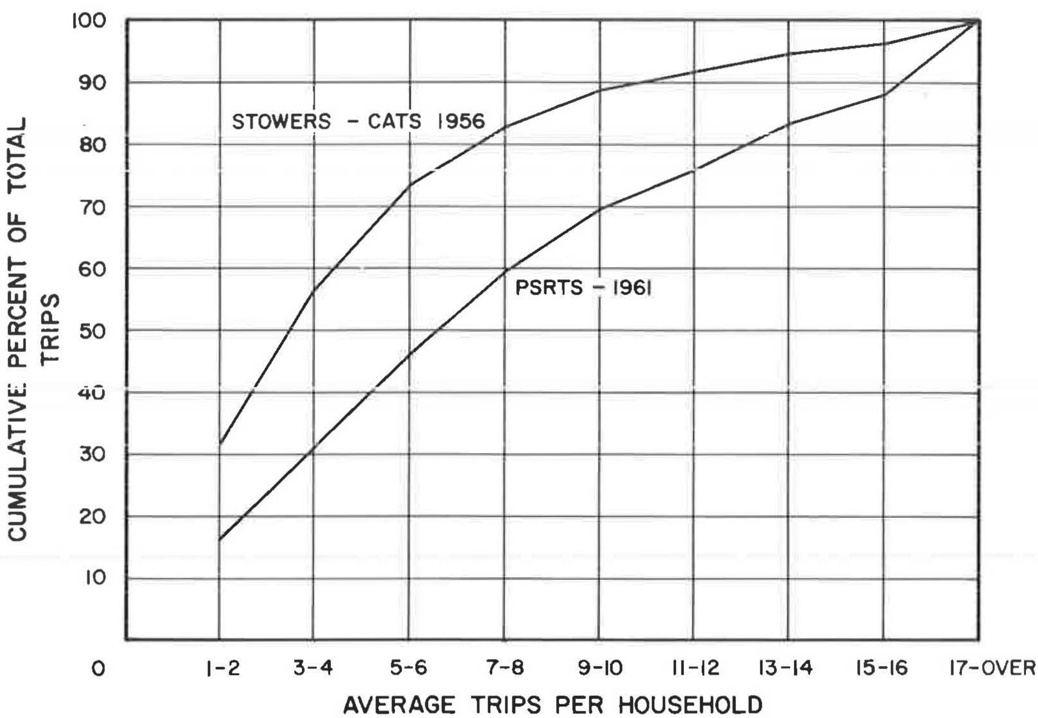

Figure 1. Cumulative percent by average trips per household for CATS and PSRTS data, all occupational groups.

The definitions for both the CATS and PSRTS data were comparable and patterned after the guidelines suggested by the U. S. Bureau of Public Roads: (a) trip information is for residents of the cordon area; (b) persons in household are for all persons, not just those 5 years of age and over; (c) occupation of the household is based on the occupation of the head of the household who makes trips, since the occupation of non-trip-makers was not coded; (d) miscellaneous occupational classifications, such as unemployed, housewife, student, or retired, are usually omitted from the analysis; and (e) the number of automobiles per household included those that are available for regular use by members of the household.

The accuracy checks of the characteristics of the household and selected trip information for PSRTS showed a rather remarkable agreement for the total cordon area when compared to independent source data (4).

COMPARISON OF TRIP GENERATION FOR HOUSEHOLDS BY OCCUPATION OF HEAD OF HOUSEHOLD

Figure 1 illustrates for all occupational groups the difference in the cumulative percent of the trip generation of the households analyzed by Stowers, using CATS 1956 data and PSRTS 1961 data. In general, the graph shows a consistently higher level of household trip generation for the PSRTS data. Seventy percent of all CATS household trips were made by households averaging fewer than six trips daily, compared to 45 percent of all PSRTS household trips for the same interval.

Many factors, such as automobile ownership, family size, and density of the area, can explain this difference, and to make a fair comparison of trip-making of the households classified by the occupation of the head of household, it will be necessary to control for these factors. In addition, the possibility exists that by occupational groups the relationship observed in Figure 1 does not hold for the two comparative areas; that is, PSRTS data by occupational group may, in fact, have a lower trip production rate. Some evidence of this can be found in Table 1.

TABLE 1

AVERAGE TRIPS PER HOUSEHOLD CLASSIFIED BY OCCUPATION OF HEAD OF HOUSEHOLD

Occupation	Avg. Trips per Household	
	Stowers' CATS Data, 1956	PSRTS Data, 1961
Professional	7.07	7.11
Manager	7.29	7.35
Clerical	4.90	5.40
Sales	7.40	6.59
Craftsman	5.70	7.13
Operative	5.04	6.76
Service	4.80	5.86
Laborer	4.61	5.74
Unemployed	4.47	6.43

The only group having a higher household generation rate for the CATS data than for the PSRTS data is the sales occupational group. Whether or not this is a real difference, or only indicative of some of the difficulties inherent in classification schemes, or simply insignificant statistically without regard to classification problems must await further research. (It should be pointed out that for the CATS occupation of head of household data, it was assumed that the trip-maker, person 01 of a household, was the head, whereas PSRTS specified that the head of household always be coded trip-maker 01 on the internal trip report.)

TABLE 2

TRIP PRODUCTION BY OCCUPATION AND SIZE OF FAMILY FOR ONE-CAR HOUSEHOLDS

Occupation of Head of Household	Trips per Household: CATS 1956 (Stowers)						PSRTS 1961					
	1 Person	2 Persons	3 Persons	4 Persons	5 Persons	≥6 Persons	1 Person	2 Persons	3 Persons	4 Persons	5 Persons	≥6 Persons
Professional	3.58	5.52	6.69	7.88	8.22	13.30	4.51	7.02	8.25	9.15	11.37	12.18
Manager	3.09	5.19	6.84	7.36	6.53	8.32	5.09	6.79	9.43	10.01	12.49	13.05
Sales	3.83	7.19	6.32	8.52	9.71	8.50	5.25	7.61	10.69	10.58	11.90	12.04
Craftsman	2.45	4.29	5.24	5.74	6.73	7.95	3.73	6.11	7.72	9.34	10.56	12.25
Operative	2.35	4.33	5.09	5.28	6.01	7.37	3.70	6.49	7.44	9.30	10.24	10.33
Clerical	3.23	4.57	5.40	6.61	6.91	8.19	3.87	6.94	8.30	9.60	11.17	12.90
Service	3.15	4.53	5.96	6.08	6.11	8.15	3.53	6.16	9.36	9.15	8.55	13.26
Laborer	2.09[a]	3.79	4.83	6.41	4.80	7.83	3.21	5.32	7.64	8.08	9.25	9.80

[a]Represents fewer than 10 observations.

As mentioned earlier, both Shuldiner and Stowers in their research found automobile ownership and family size the most important variables in explaining trip generation of the household. Table 2 compares CATS and PSRTS data for households owning one automobile by eight generalized occupational groups and by number of persons in the household. Data were available for comparing zero and two or more automobiles per household by family size, but in many instances the number of cell entries for the CATS data were statistically "thin." Nevertheless, the zero and two or more car families' patterns of relationship for the two studies were very similar. One-car families for both areas represent over 50 percent of the households and will serve to illustrate the relationship of trip production by occupational groups.

Table 2 gives only one case in which the trips per household are larger for the CATS data than for PSRTS data, i.e., for households classified as professional and having six or more members. Conversely, if we compare across the cell entries by each occupational group, only three cell entries of CATS data and three of PSRTS data fail to register an increase in trips per household with an increase in the number of persons in the household.

The answer to the question of which variable, family size or number of automobiles available for a household to use has more influence on household trip production was found by Shuldiner and Stowers to be automobiles available. Table 3 compares CATS and PSRTS trips per household by occupation and car ownership, using a typical household size of three persons. (In 1960 the average household size for SMSA's in the United States was slightly over three persons per occupied housing unit.)

In comparing Tables 2 and 3, it is readily evident that, although both family size and automobile ownership influence trip generation of the household, a change in the number of automobiles in a household has the greater impact on household trip-making. The greatest change in trip-making of households occurs between households owning no and one automobile and between households having one and two persons. This relationship is more clearly illustrated in Figure 2, using PSRTS data.

TABLE 3

TRIP PRODUCTION BY OCCUPATION AND CARS PER HOUSEHOLD FOR HOUSEHOLDS HAVING THREE PERSONS

Occupation of Head of Household	Trips per Household					
	CATS 1956 (Stowers)			PSRTS 1961		
	No Cars	1 Car	≥2 Cars	No Cars	1 Car	≥2 Cars
Professional	5.29[a]	6.69	9.50	7.70	8.25	11.69
Manager	3.71[a]	6.84	9.53	6.01	9.43	11.90
Sales	5.75[a]	6.32	8.06	5.40	10.69	13.60
Craftsman	3.76	5.24	7.70	3.77	7.72	9.82
Operative	3.53	5.09	8.95	3.62	7.44	10.08
Clerical	3.67	5.40	6.82	4.93	8.30	10.77
Service	3.80	5.96	6.10	5.17	9.36	10.64
Laborer	3.32	4.83	—[b]	3.93	7.64	9.57

[a]Represents fewer than 10 observations.
[b]No observations.

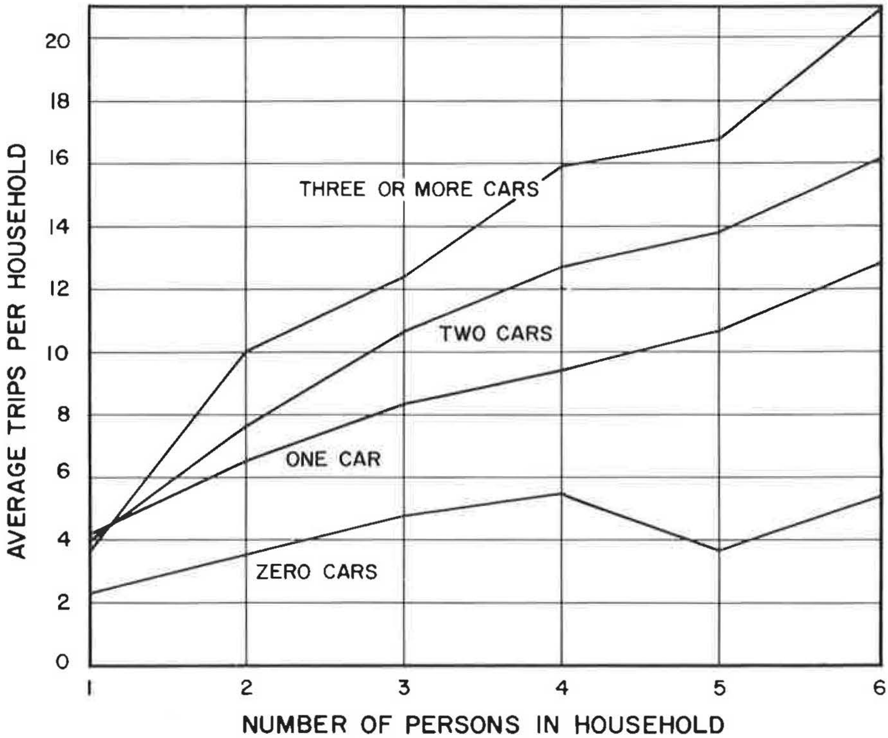

Figure 2. Average trips per household by persons in household and number of automobiles per household.

As pointed out by Stowers (1, Footnote 1), and as can be seen from examination of the preceding tables, the use of the generalized occupational groups shows little in the way of a consistent pattern with household trip production. The final sections of this paper report on trip production and the household using summary groupings of the generalized occupational classes.

CONCEPT OF SOCIAL STATUS

Shuldiner, Stowers, and Michelson are agreed that the concept of social or socioeconomic status of the household should be useful in distinguishing between households manifesting different trip generation rates. Indeed, they did find that occupation affected trip generation but was not as influential as size of family and automobile ownership.

The concept of social or socioeconomic status of a household refers to a generalized pattern or standard of living to which the members of a household strive. Many indices have been used to operationalize this concept at some point in time for a household. These indices range from such subjective methods as an individual ranking himself in a particular status or class, to the more objective criteria of educational attainment, wages or salary earned, and an individual's occupation. Implicit in the use of such a generalized or summary measure is that the categories or classes comprising the index are systematically related to other variables or behaviors not included in the formation of the index. This is to say, that if one can categorize persons or households as being of a particular class or status, one can also predict various patterns of behavior for individuals or households that are related to their class groups but are independent of the variables used to establish the class groupings. A society is the product of its institutions and institutions are, in turn, made up of organizations, composed of individuals especially trained to carry out the daily tasks necessary for the healthy functions of the organization. In a very real sense, the backbone of the "straw man" is joined together by occupational vertebrae.

OPERATIONAL DEFINITION OF SOCIAL STATUS

In this paper, occupation has been selected to operationalize the concept of social status. More specifically, the occupation of the head of household who made trips on the survey day is used. The head of household's description of his work activities was coded to a two-digit number based on the 1960 Alphabetical Index of Occupations and Industries, formulated by the U. S. Bureau of the Census. For the purpose of this report, only the generalized tens digit of the occupation code was used.

This general functional code of occupations was first described by Alba M. Edwards in the Journal of the American Statistical Association in 1917; in the same Journal in 1933, the code was revised and brought up to date, listing six general categories of socioeconomic rankings. Edwards' groupings and the ones used in this report, although different in ordering and grouping, contain basically the same general classes of:

1. Professional,
2. Managers,
3. Clerical,
4. Sales,
5. Craftsmen,
6. Operatives,
7. Service, and
8. Laborers.

Edwards combined occupations 3, 4, 7, and 8 into one class, and also listed separately unemployed and unknown.

Stowers noted in his thesis that, "Edwards considered these groupings to be a logical socioeconomic ranking of all occupations and presented them as such without offering any rigid sociological or economic justification for doing so" (1, p. 11). However, some objective evidence is available which permits grouping of the general occupational classes into socioeconomic categories. North and Hatt, using a national sample of public opinion after World War II, developed the North-Hatt scale of occupational status and prestige (5) based on the two-digit occupational classification used by the Bureau of the Census. The list given in Table 4 of generalized occupation groups ordered from the highest scaled to the lowest scaled are based on the work of North and Hatt.

The North-Hatt rating of occupational status and prestige is very similar to that advanced by Alba M. Edwards in 1933. The major difference is the ranking of government

TABLE 4

NORTH-HATT OCCUPATIONAL RATING OF STATUS AND PRESTIGE

No.	General Occupational Groups	Score
1	Government officials	90.9
2	Professional and semiprofessional workers	80.6
3	Proprietors, managers, and officials (except farm)	74.9
4	Clerical, sales, and kindred workers	68.2
5	Craftsmen, foremen, and kindred workers	68.0
6	Farmers and farm managers	61.3
7	Protective service workers	58.0
8	Operatives and kindred workers	52.8
9	Farm laborers	50.0
10	Service workers (except domestic and protective)	46.7
11	Laborers (except farm workers)	45.8

officials: first in the North-Hatt ranking and included in the second grouping in the Edwards ranking. For the purpose of this analysis, however, this difference is not significant since professional, manager, and government occupational groups are always grouped together into the same summary status of class grouping. A more serious difficulty, from the point of view of the relationship of social status and trip-making, is the grouping together in the North-Hatt scale of clerical and sales workers, particularly traveling salesmen. The North-Hatt ranking permitted score values ranging from 100 to 20 to be assigned to the 90 individual occupations representing the two-digit occupational classifications used by Bureau of the Census, but excluding the 90 series of retired, unemployed housewife, etc. Examination of the detailed two-digit status and prestige scores of occupations reported by North and Hatt reveals that "traveling salesmen" scored 68, whereas "clerks in a store" scored 58. Other research evidence has shown that in terms of similarity in selected behavioral patterns the clerical and kindred workers are different from sales workers but more similar in certain respects to the "so-called blue collar workers" and more particularly to the protective service workers, whereas craftsmen, foremen, and kindred workers are more like the "so-called white collar workers (6, 7).

TABLE 5

STATUS GROUPINGS USING GENERALIZED OCCUPATIONAL GROUPS

Occupation	Group I[a]	Group II[b]
Professional	W	H
Manager	W	H
Clerical	B	M
Sales	W	M
Craftsman	W	M
Operative	B	L
Service	B	L
Laborer	B	L

[a] W = white collar; B = blue collar.
[b] H = high; M = medium; L = low.

SOCIAL STATUS AND HOUSEHOLD TRIP GENERATION

The two summary groupings of occupational status used here are composed of (a) two occupational status classes traditionally referred to as the "white collar" and the "blue collar" groups, and (b) three occupational status classes called the high, medium, and low groups. Table 5 identifies the occupations included in the definition of these two summary groupings.

The operational use of the concept of status in transportation and land-use analysis is not new. Hansen in calibrating the gravity trip distribution model for Washington, D. C., used measures of white and blue collar workers in developing K factors (8). Others in the development of land-use models have tried to incorporate some status or prestige measures for distribution of population and residential land (9). However, to my knowledge, status measures have not been utilized directly in the forecasting of trip productions.

The general hypothesis of this analysis is that there is a direct relationship between trip generation from the home and social status; that is, as status increases trip generation from home will also increase. It was reasoned that a valid test of the hypothesis could be made only if the effect of automobile ownership and persons in the household were controlled, since previous research has shown the importance of these two variables in explaining trip production from the home.

No statistical tests are explicitly used to test the hypothesis for two reasons: (a) the author doubts that the basic assumption underlying the use of the available statistic (analysis of variance) could be met; and (b) the nature of the research is expository (10). However, the hypothesis can be accepted or rejected implicitly on the basis of the number of successes or failures observed in analyses of the two occupational status groupings.

Tables 6 and 7 summarize for the two measures of status the average trips per household by selected modes of travel. In general, the findings of these two tables are that trip-making of the household is directly related to the status classification of the household head. There are exceptions to the general relationship, particularly in the "transit bus passenger" mode of travel, where an inverse relationship exists between social status of household and transit bus passenger trip productions.

If one excludes transit bus passenger trips from this comparison, there are only four of the 144 cells in Tables 6 and 7 in which a horizontal, or between status, move does not result in a change in trip production in the direction hypothesized. By the same token, there are only eight of the 144 cells in which a vertical, or within status, move to a larger household size within an automobile per household class does not result in increasing the average trips per household. Of the 12 exceptions to the hypothesis in the within and between status cells, eleven of these occur in the no automobile per household class. (The peculiarity of the trip-making of households having no automobiles available for making trips has been noted by Keefer in his analysis of the "captive choice" transit ridership of the Pittsburg Area Transportation Study.)

INTERPRETATION AND APPLICATION OF FINDINGS

The inclusion of the social status variable with automobiles per household and family size of the household helps in understanding and explaining trip generation from the home, at least for a point in time. Whether or not this relationship is retained over time, not to mention the interrelationships or interdependence of the variables, are questions to be answered before any reliable predictive model utilizing these variables can be constructed.

Given the present state of the art, particularly in forecasting trips from the home for small areas, no relationship which can help one to accomplish this task should be overlooked. It is at the small area level of forecasting that the inclusions of the social status variable can be most helpful.

It is apparent from the analysis that households with like automobile ownership and family size have different trip production generation rates when examined by social status groups. For small areas within a community this fact can be significant, since research in community patterns of living has shown that families of a particular occupation tend to be separated spatially from families of other occupations in direct proportion to the distance between the occupations on the Edwards ranking by socio-economic status (11).

I conclude by pointing out two ways in which the inclusion of the social status variable could aid researchers confronted with analysis and forecasting of trip generation from the home. From census data, automobiles per household, number of persons per household, and occupation of the head of the household are available by small statistical areas. By application of generation rates based on the composition of the statistical area with regard to these variables, an independent forecast of trip generation from the

TABLE 6

TRIP-MAKING RELATIONSHIPS, STATUS CLASSES BASED ON WHITE AND BLUE COLLAR GROUPINGS

Autos In Household	Persons In Household	White Collar					Blue Collar				
			Trips per Household					Trips per Household			
		No. Households	Total Trips	Auto-Driver Trips	Auto-Truck Pass. Trips	Transit Bus Pass. Trips	No. Households	Total Trips	Auto-Driver Trips	Auto-Truck Pass. Trips	Transit Bus Pass. Trips
0	1-2	5,455	2.84	0.21	1.02	1.30	10,610	2.64	0.04	0.88	1.42
	3-4	1,067	5.76	0.41	2.48	2.26	1,999	4.82	0.31	2.15	1.93
	≥5	432	4.53[a]	0.40[a]	2.19[a]	1.70	715	4.66[a]	0.29[a]	2.34	1.53
	Total	6,954	3.39	0.25	1.32	1.47	13,324	3.07	.10	1.15	1.50
1	1-2	45,132	6.11	4.31	1.40	0.32	26,868	5.50	3.77	1.23	0.42
	3-4	42,090	9.05	5.41	2.93	0.39	20,114	8.57	5.13	2.73	0.43
	≥5	25,715	11.75	6.10	4.35	0.40	12,002	10.56	5.52	3.78	0.50
	Total	112,937	8.49	5.13	2.64	0.36	58,984	7.58	4.59	2.26	0.44
2	1-2	15,931	8.09	6.80	1.14	0.10	5,226	6.67	5.42	.98	0.22
	3-4	29,625	12.18	8.55	2.94	0.23	9,172	11.45	7.95	2.93	0.27
	≥5	22,198	15.02	9.02	4.68	0.26	6,342	14.11	8.15	4.68	0.36
	Total	67,754	12.15	8.29	3.09	0.21	20,740	11.06	7.37	2.97	0.29
≥3	1-2	454	10.08	8.70	1.20	0.08	151	8.87	8.25	.43	0.09
	3-4	3,894	14.85	11.70	2.76	0.18	1,452	12.68	9.78	2.45	0.20
	≥5	3,323	19.04	12.52	5.03	0.45	964	17.61	11.96	4.22	0.28
	Total	7,671	16.38	11.88	3.65	0.29	2,567	14.30	10.51	2.99	0.22
	Grand Total	195,316	9.89	6.32	2.79	0.35	95,615	7.88	4.73	2.28	0.55

[a]Exception to hypothesis.

TABLE 7

TRIP-MAKING RELATIONSHIPS, STATUS CLASSES BASED ON HIGH, MEDIUM, LOW OCCUPATIONAL GROUPINGS

Autos In Household	Persons In Household	High			Medium			Low		
		Total Households	Trips per Household		Total Households	Trips per Household		Total Households	Trips per Household	
			Total Trips	Auto-Driver Trips		Total Trips	Auto-Driver Trips		Total Trips	Auto-Driver Trips
0	1-2	2,965	2.85	0.14	6,904	2.75	0.12	6,196	2.59	0.06
	3-4	543	6.68	0.45	1,235	4.99	0.39	1,288	4.66	0.26
	≥5	185	4.81[a]	0.29	479	5.32[a]	0.62	483	3.82[a]	0.05
	Total	3,693	3.51	0.19	8,618	3.21	0.18	7,967	3.00	0.09
1	1-2	24,479	6.25	4.49	30,302	5.80	4.03	17,219	5.50	3.71
	3-4	21,893	9.10	5.48	25,516	8.97	5.31	14,795	8.47	5.09
	≥5	12,304	12.10	6.31	15,511	11.50	5.96	9,902	10.27	5.35
	Total	58,676	8.54	5.24	71,329	8.17	4.91	41,916	7.67	4.59
2	1-2	9,571	8.26	6.93	7,682	7.84	6.49	3,904	6.29	5.24
	3-4	17,257	12.27	8.60	14,319	12.09	8.50	7,221	11.23	7.79
	≥5	13,016	15.36	9.29	10,591	14.32	8.53	4,933	14.45[a]	8.22
	Total	39,844	12.31	8.42	32,592	11.81	8.03	16,058	11.02	7.30
	1-2	203	12.51	11.46	280	8.61	7.03	122	7.90	7.37
	3-4	2,298	15.56	12.18	1,890	14.10	11.13	1,158	11.94	9.28
	≥5	1,842	19.40	13.09	1,631	18.26	11.60	814	18.07	12.43
≥3	Total	4,343	17.05	12.53	3,801	15.48	11.03	2,094	14.09	10.40
	Grand Total	106,556	10.12	6.55	116,340	9.06	5.63	68,035	8.11	4.88

[a]Exception to hypothesis.

home can be developed to compare against and check the reasonableness of the results of the particular procedure used for the actual forecast, for example, regression analysis or land-use generation rates. In addition, by using census data to estimate trip productions (lacking a full-scale origin and destination survey), small area comprehensive community planning could benefit, particularly in the development of more realistic circulation plans.

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Relationships of Traffic and Floor Space Use in Central Business District

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In 1960, Harper and Edwards developed linear regression models for seven cities relating traffic flow to the central business district to floor space use. This is an extension in which models are developed for cities over a wide population range and for trips made for different purposes. Significant models were developed for total traffic and for work, shopping, and business trips. Social and recreation trips to the CBD were not found to be significantly related to floor space use. The research showed that traffic flow to the CBD is most closely related to the following classifications of floor space use: retail sales, service, office, and public. No significant relationships were found between traffic and manufacturing, wholesaling, and semi-public floor space use.

By using common floor space groupings of retail and service-office, it is shown that regression coefficients for these variables are significantly related to city population. However, important differences in the models were noted for cities of similar size, suggesting that more research is needed to identify and quantify other sources of variation in the regression coefficients.

It is also shown that regression coefficients in linear models relating CBD traffic flow and floor space use are influenced by the size and number of origin-destination zones. The use of smaller zones tends to produce better stratification of the data and results in more reliable models.

•THE PAST century has witnessed dramatic shifts in the growing population of the United States. In 1850, only 15 percent of the population lived in urban areas. By the turn of the century, this percentage had risen to 40 percent, and today two out of three Americans live in urban areas. By the year 2000, it is estimated that the population of the United States will exceed 300 million. Well over three-fourths of the expected increase can be expected to occur in metropolitan areas.

Urban traffic congestion, always serious, has become increasingly severe as cities have grown and matured. Efforts by traffic engineers to deal with traffic congestion have largely been of a stop-gap nature, and more symptomatic than corrective. Although the regulation of curb parking, provision of one-way streets, signalization of intersections, and the like have significantly decreased traffic delays and increased capacity, the problem of serious urban congestion remains.

Elimination of this problem is aggravated by the fact that urban transportation facilities are expensive and difficult to change. Once a transportation facility is provided, little can be done to change it radically for 20, 30, or more years.

Historically and to the present time, the central business district (CBD) has been the focal point for the city's population and has experienced the most serious traffic con-

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gestion and delays. The need for reliable predictions of traffic flow to the CBD is becoming increasingly apparent. If predictions of future traffic flow to the central city are to be made with confidence, more must be learned of its basic nature and causes. The development of such basic data is a primary purpose of this study.

City planners and others have suggested for some time that traffic attracted to a city's CBD is closely related to the type and intensity of use of the buildings in that center. If this hypothesis is true, it implies that CBD traffic forecasts should be made by considering anticipated changes in CBD floor space use. Development of mathematical models relating CBD traffic to floor space use would not only provide an additional check on traffic predictions but would also provide for consistent and coordinated planning for traffic and land use in the CBD.

A 1960 study of Harper and Edwards (1, 2) showed that the number of people attracted to CBD zones was closely related to floor space use within these zones. The authors of this study developed linear regression models for seven cities relating total person destinations to three classifications of floor space use.

The intent of the present study was to extend the work of Harper and Edwards by developing multiple regression models for cities of a wide population range and for trips made for various purposes.

METHOD OF STUDY

Using the Harper-Edwards study as a starting point, CBD floor space inventories and origin-destination (O-D) traffic studies were obtained for the cities of Pittsburgh, Pa.; Atlanta, Ga.; Chattanooga, Tenn.; Charlotte, N.C.; and Gainesville, Ga. Choice of these particular cities was dictated primarily by the availability of suitable traffic and floor space data. For each of these cities, floor space data were assembled and tabulated by O-D zones. Multiple regression models were developed relating traffic flow to CBD zones to floor space use within these zones. Various classifications of floor space use were related to total trips and to trips made for the following purposes: shopping, work, personal business, social, and recreation. In these models, traffic was regarded as the dependent variable and various classes of floor space use as independent variables. In effect, this assumes that changes in average traffic volumes attracted to a CBD zone are caused or explained by changes in the magnitude of one or more classifications of floor space use.

NOMENCLATURE

Y_t = average 24-hour person destinations to CBD zone.
Y_w = average 24-hour person destinations to CBD zone for work.
Y_s = average 24-hour person destinations to CBD zone for shopping.
Y_b = average 24-hour person destinations to CBD zone for business.
Y_{cr} = average 24-hour person destinations to CBD zone for social and recreation purposes.
Y_m = average 24-hour person destinations to CBD zone for miscellaneous purposes.
X_s = area of floor space within zone used for retail sales.
X_r = area of floor space within zone used for services.
X_o = area of floor space within zone used for offices.
X_p = area of floor space within zone used for public purposes.
X_1 = area of floor space within zone used for retail sales, Harper-Edwards model.
X_2 = area of floor space within zone used for service-office purposes, Harper-Edwards model.
X_3 = area of floor space within zone used for manufacturing-warehousing purposes, Harper-Edwards model.

RESULTS

In this study, more than 100 regression equations were developed relating traffic flow to the CBD to floor space use within the CBD. Statistical data for 42 of these models were given in a recent thesis (3). Twelve typical models are described in the succeeding paragraphs.

Total Traffic Models

The research indicated that total trips to the CBD are most closely related to retail sales, office, and public floor space use. Typical models for total 24-hour person destinations to CBD zones are as follows:

$$\text{Gainesville:}\quad Y_t = 8.98X_s + 21.12X_o + 63.26X_p + 216 \quad (1)$$

$$\text{Atlanta:}\quad Y_t = 9.58X_s + 7.52X_o - 1137 \quad (2)$$

$$\text{Pittsburgh:}\quad Y_t = 12.14X_s + 6.25X_r - 76 \quad (3)$$

Statistical data for these equations, as well as a zone-by-zone comparison of computed and observed traffic, are given in Tables 1, 2, and 3. In each of these total traffic models, the coefficient of multiple correlation exceeded 0.90, and all three models were significant at the 0.1 percent level.

In the Gainesville equation, traffic was most closely correlated with office floor space use, whereas retail sales floor space was the most significant variable in the Atlanta and Pittsburgh models.

TABLE 1

TOTAL DESTINATIONS RELATED TO SALES, OFFICE, PUBLIC FLOOR SPACE USE—GAINESVILLE, GA.[a]

O-D Zone	Total Person Destinations	
	Computed	Observed
01-006	2,035	2,845
01-010	2,020	2,169
01-003	4,516	4,316
01-001	4,949	4,873
01-011	1,152	1,265
01-004	856	500
05-009	356	178
01-002	412	526
01-007	418	667
01-009	560	393
01-005	415	640
01-008	1,019	552

[a]Regression equation = Eq. 1; F ratio = 90.82; standard error, S (Y_t) = 398; correlation coefficient, R = 0.9778; r^2 = 0.956; statistical data for regression coefficients:

Factor	Sales, b_s	Office, b_o	Public, b_p
Level of significance (%)	1	0.1	1
Partial correlation coefficient	0.827	0.907	0.822
Standard error	2.162	3.476	15.516

Of particular interest in Eq. 1 is the remarkably high regression coefficient for public floor space use which is more than seven times that of sales floor space and almost triple that of office floor space. This suggests that Gainesville's public floor space exerts a much stronger relative attraction to traffic than do retail sales and office floor space. In this is reflected the important civic and governmental functions served by Gainesville as the county seat of Hall County. These coefficients may also show that sales space is not intensively used in Gainesville and that overcrowding may prevail in public spaces.

Effect of City Population on Total Traffic Models

To provide a basis for comparing the results of their analysis of different cities, Harper and Edwards (2) related person destination to the CBD to three common floor space groups: retail (X_1), service-office (X_2), and manufacturing-warehousing (X_3). Typical floor space classifications included in these groups are given in Table 4. The model proposed by Harper and Edwards was of the form:

$$Y_t = b_1X_1 + b_2X_2 + b_3X_3 + K \quad (4)$$

TABLE 2

TOTAL PERSON DESTINATIONS RELATED TO RETAIL, OFFICE FLOOR SPACE USE—ATLANTA, GA.[a]

O-D Zone	Total Person Destinations	
	Computed	Observed
144	3,642	4,378
146	6,412	5,582
148	9,885	9,168
150	4,391	4,614
152	7,437	3,911
155	2,005	2,639
156	9,118	9,433
157	5,981	5,911
158	1,463	2,903
161	16,255	18,046

[a]Regression equation = Eq. 2; F ratio = 71.80, standard error, $S(Y_t)$ = 1,691; correlation coefficient, R = 0.9466; r^2 = 0.896; statistical data for regression coefficients:

Factor	Retail, b_s	Office, b_o
Level of significance (%)	0.1	5
Partial correlation coefficient	0.946	0.782
Standard error	1.245	2.265

TABLE 3

TOTAL PERSON DESTINATIONS RELATED TO RETAIL, SERVICE FLOOR SPACE USE—PITTSBURGH, PA.[a]

O-D Block[b]	Total Person Destinations	
	Computed	Observed
33-64	7,345	7,300
42-48	1,197	1,280
43-69	7,629	9,285
48-63	8,951	6,275
57-54	3,435	1,829
64-49	4,058	2,288
71-64	11,450	9,723
73-45	15,127	19,508
75-75	1,994	1,457
59-73	645	1,423

[a]Regression equation = Eq. 3; F ratio = 153.89; standard error, $S(Y_t)$ = 1,365; correlation coefficient, R = 0.9060; r^2 = 0.821; statistical data for regression coefficients:

Factor	Retail, b_s	Office, b_r
Level of significance (%)	0.1	0.1
Partial correlation coefficient	0.883	0.719
Standard error	0.862	0.807

[b]Model developed from data from 59 blocks, 10 of which are shown.

Models of this type were developed for Gainesville, Charlotte, and Chattanooga, providing a measure of the influence of city size on the total traffic model. These models, along with those developed by Harper and Edwards are given in Table 5.

TABLE 4

TYPICAL FLOOR SPACE CLASSIFICATIONS INCLUDED IN GROUPS USED BY HARPER AND EDWARDS

Retail (X_1)	Service-Office (X_2)	Manufacturing-Warehousing (X_3)
Retail	Business service	Manufacturing
Retail business	Consumer service	Wholesale with stocks
Core retail	Office buildings	Warehouses
Intensive retail	Public offices	Light industry
Extensive retail	Bank and miscellaneous	Heavy industry
Open business	Institutions	Industrial
	Wholesale without stocks	Wholesaling
	Utilities	
	Hotels	
	Terminals	
	Parking garages	
	Quasi-public	
	Eating places	
	Amusement	
	Recreation	

TABLE 5

MODELS FOR TEN CITIES RELATING TOTAL PERSON DESTINATIONS TO CBD TO RETAIL, SERVICE-OFFICE, AND MANUFACTURING-WAREHOUSING FLOOR SPACE USE

City	Population	Model
Gainesville	16,787	$Y_t = 10.95X_1 + 15.96X_2 - 3.30X_3 + 284$
Charlotte	202,000	$Y_t = 10.84X_1 + 13.83X_2 + 1.61X_3 + 1095$
Chattanooga	283,170	$Y_t = 8.49X_1 + 7.63X_2 - 2.92X_3 - 1168$
Tacoma	275,876	$Y_t = 7.71X_1 + 2.49X_2 - 17.70X_3 + 3590$
Vancouver	600,000	$Y_t = 14.32X_1 + 10.53X_2 + 3.67X_3 + 1560$
Dallas	614,799	$Y_t = 16.19X_1 + 3.55X_2 + 12.65X_3 - 8570$
Seattle	732,992	$Y_t = 13.68X_1 + 4.38X_2 + 0.15X_3 - 200$
Baltimore	1,337,373	$Y_t = 12.87X_1 + 4.52X_2 + 1.34X_3 - 1080$
Detroit	3,016,197	$Y_t = 13.92X_1 + 4.61X_2 + 1.72X_3 - 2280$
Philadelphia	3,671,048	$Y_t = 14.60X_1 + 5.86X_2 + 1.28X_3 - 3470$

A study of the models in Table 5 revealed that the manufacturing-warehousing floor space variable is not closely related to traffic destinations. Of the ten manufacturing-warehousing coefficients shown, only two are significant, even at the 20 percent level. In short, manufacturing-warehousing floor space in the CBD does not have a significant effect on the regression model. With this in mind, models were developed relating only retail and service-office floor space to total person trips attracted to the CBD. These models are given in Table 6.

The omission of the manufacturing-warehousing variable did not appear to have a harmful effect on the predictive value of the models. In fact, the simpler three-dimensional model in several cases appeared to be superior to the Harper-Edwards model. A comparison of the standard errors and correlation coefficients of the models with and without the manufacturing-warehousing variable is given in Table 7.

Utilizing the regression coefficients in the three-dimensional models given in Table 6, relationships were developed between population and the retail and service-office coefficients:

$$b_1 = 0.00150\,(\text{population, thousands}) + 9.72 \qquad (5)$$

$$b_2 = 22.61 - 2.33\,\ln(\text{population, thousands}) \qquad (6)$$

Plots of these functions are shown in Figures 1 and 2.

TABLE 6

MODELS FOR TEN CITIES RELATING TOTAL PERSON DESTINATIONS TO CBD TO RETAIL AND SERVICE-OFFICE FLOOR SPACE USE

City	Population	Model
Gainesville	16,787	$Y_t = 10.96X_1 + 16.48X_2 + 171$
Charlotte	202,000	$Y_t = 9.89X_1 + 15.68X_2 + 1404$
Chattanooga	283,170	$Y_t = 8.89X_1 + 7.31X_2 - 1388$
Tacoma	275,876	$Y_t = 6.20X_1 + 7.22X_2 - 1049$
Vancouver	600,000	$Y_t = 15.38X_1 + 9.76X_2 + 3898$
Dallas	614,799	$Y_t = 6.89X_1 + 4.86X_2 + 1475$
Seattle	732,922	$Y_t = 13.66X_1 + 4.35X_2 - 129$
Baltimore	1,337,373	$Y_t = 12.81X_1 + 4.52X_2 - 75$
Detroit	3,016,197	$Y_t = 13.50X_1 + 4.78X_2 - 380$
Philadelphia	3,671,048	$Y_t = 15.08X_1 + 5.93X_2 - 2584$

TABLE 7

STANDARD ERRORS AND CORRELATION COEFFICIENTS OF HARPER-EDWARDS MODELS VS MODELS WITHOUT MANUFACTURING-WAREHOUSING COEFFICIENT

City	Standard Error		Correlation Coefficient	
	With X_3	Without X_3	With X_3	Without X_3
Gainesville	870	833	0.889	0.885
Charlotte	801	729	0.999	0.997
Chattanooga	1,133	1,063	0.996	0.995
Tacoma	80	743	0.998	0.992
Vancouver	3,920	4,251	0.982	0.975
Dallas	4,420	5,367	0.959	0.927
Seattle	1,590	1,512	0.983	0.982
Baltimore	5,630	5,198	0.817	0.821
Detroit	2,890	3,071	0.998	0.998
Philadelphia	5,490	5,570	0.980	0.979

Correlation coefficients for Eqs. 5 and 6 were, respectively, 0.57 and 0.79. Both models were significant at the 0.1 percent level.

The regression coefficient of 0.00150 in Eq. 5 is significant at the 10 percent level, whereas the regression coefficient of 2.33 in Eq. 6 is significant at the 1 percent level. Thus, it can be asserted with confidence that the service-office coefficients given in Table 6 decrease with logarithmic increases in city population. It can be similarly stated, but with less confidence, that the retail regression coefficients increase with increases in population.

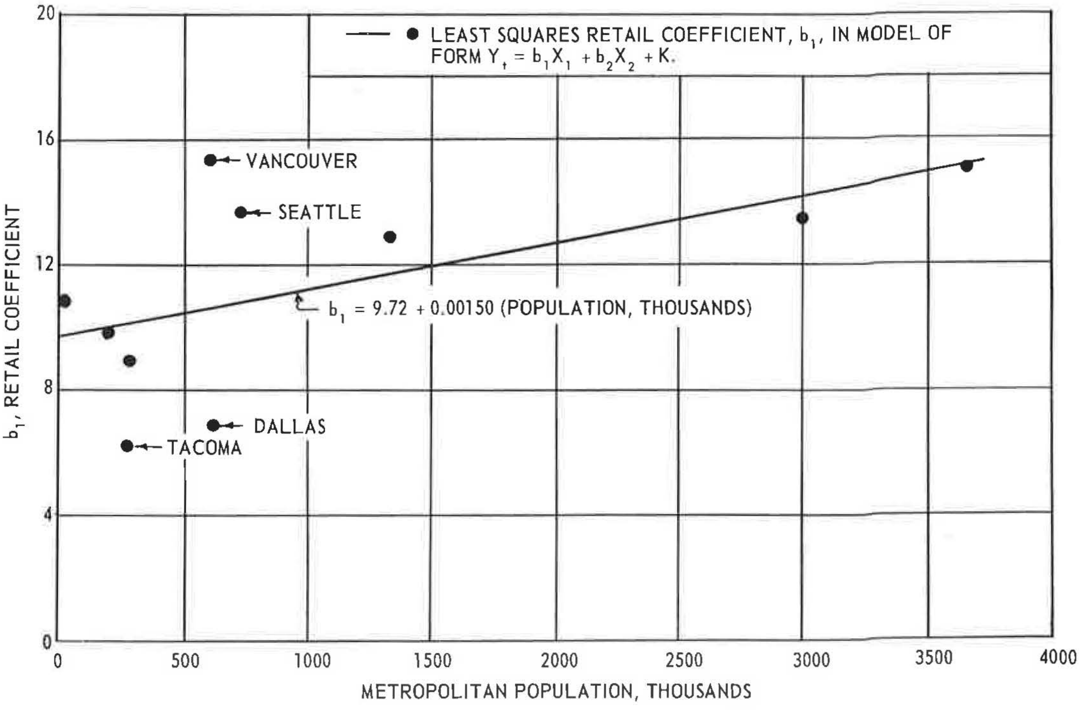

Figure 1. Relationship of retail coefficients to city population.

size. A comparison of certain economic measures of city vitality seems to mirror the differences noted in the traffic models. For example, it is probably more than coincidence that Charlotte, which had a higher retail coefficient, also exhibited higher per capita sales and a larger number of retail establishments per capita (4). It is also interesting to note that Charlotte, whose service-office coefficient was roughly twice that of Chattanooga, exceeds Chattanooga in employment in finance, insurance and real estate by approximately the same ratio (4).

It is hypothesized that a substantial portion of the variation of certain of the regression coefficients is due to the proximity of competing centers. For example, as indicated in Table 6, low retail and service-office coefficients were noted for Tacoma. Present knowledge of urban travel characteristics dictates that these values were influenced by the larger Seattle CBD which lies only about 30 miles away. There is also reason to believe that the low regression coefficients in the Dallas model may be partially explained by the competition of the Fort Worth CBD located only 30 miles away.

In summary, the results indicate that the construction of a total trip model from a consideration of population alone could lead to intolerable errors. Similarly, the application of a total trip model like those in Table 6 to another city of like size would be unwise. Either course of action would fail to take into consideration important values such as social, economic, and spatial considerations which remain unquantified.

Work Trip Models

Satisfactory work trip models were developed for Gainesville, Atlanta, and Pittsburgh, and the results indicated that work trips are most closely related to public, service, sales, and office floor space use.

Work trips to the Gainesville CBD are most closely related to service, office, and public floor space use. A least squares model relating these variables is as follows:

$$Y_W = 6.33 X_r + 2.61 X_o + 19.88 X_p + 67 \quad (8)$$

With an F ratio of 42.97, this model was significant at the 0.1 percent level. Its correlation coefficient was 0.940. Generally close agreement between the observed work trips and those computed with the model may be observed in Table 9.

TABLE 9

WORK TRIPS RELATED TO SERVICE, OFFICE, PUBLIC FLOOR SPACE USE—GAINESVILLE, GA.[a]

O-D Zone	Work Destinations	
	Computed	Observed
01-006	524	600
01-010	564	598
01-003	723	739
01-001	912	832
01-011	322	538
01-004	168	68
05-009	180	47
01-002	190	150
01-007	86	146
01-009	136	146
01-005	86	131
01-008	362	192

[a]Regression equation = Eq. 8; F ratio = 42.97; standard error, $S(Y_W)$ = 115; correlation coefficient, R = 0.9403; r^2 = 0.884; statistical data for regression coefficients:

Factor	Service, b_r	Office, b_o	Public, b_p
Level of significance (%)	1	5	0.1
Partial correlation coefficient	0.791	0.677	0.890
Standard error	1.734	1.004	3.601

Work trips to the Gainesville CBD did not appear to be closely related to sales, wholesale, manufacturing, or semi-public floor space use.

For Atlanta, a very satisfactory model was computed which relates work trips to the CBD to floor space use for retail sales and offices:

$$Y_W = 3.44 X_s + 5.39 X_o + 105 \quad (9)$$

Correlation coefficient for Eq. 9 was 0.937, and its standard error was 700 person destinations. With an F ratio of 126.66, the model is significant at the 0.1 percent level. A zone-by-zone comparison of observed work trips and those computed by Eq. 9 is given in Table 10.

Work trips to Pittsburgh's CBD evidenced a close relationship to retail and public floor space use. A multiple regression model relating these variables is as follows:

$$Y_W = 8.29 X_s + 14.44 X_p + 290 \quad (10)$$

This equation was characterized by very satisfactory correlation statistics, as were the regression coefficients. The model was significant at the 0.1 percent level. The coefficient of multiple determination indicated that more than 96 percent of the variation in traffic is explained by the model. For the seven most heavily traveled zones, computed traffic values vary less than 15 percent from the observed values. These data are given in Table 11.

Attempts to develop other work trip models indicated that work trips to Pittsburgh's CBD are not significantly related to heavy commercial, manufacturing, and service floor space use.

Shopping Trip Models

In this study shopping trips were found to be linearly related to sales, office, and public floor space use. However, the most satisfactory models were nonlinear equations relating shopping trips and retail floor space use.

Gainesville. —Eq. 11 is a least squares fit of the data for six of Gainesville's 12 zones and is weighted in favor of the most heavily traveled zones:

$$Y_S = 503.3 \ln (X_S) - 1299 \quad (11)$$

This model suggests that shopping trips to Gainesville's most attractive zones are closely related to the natural logarithm of retail floor space use. Trips computed by

TABLE 10

WORK TRIPS RELATED TO RETAIL, OFFICE FLOOR SPACE USE— ATLANTA, GA.[a]

O-D Zone	Work Destinations	
	Computed	Observed
144	3,452	3,369
146	4,224	4,178
148	4,711	4,170
150	2,889	3,032
152	3,903	2,472
155	2,028	2,254
156	6,840	6,976
157	3,822	4,046
158	1,852	2,485
161	6,478	7,217

[a]Regression equation = Eq. 9; F ratio = 126.66; standard error, $S(Y_W)$ = 700; correlation coefficient, R = 0.9373; r^2 = 0.879; statistical data for regression coefficients:

Factor	Retail, b_S	Office, b_O
Level of significance (%)	0.1	0.1
Partial correlation coefficient	0.930	0.908
Standard error	0.516	0.939

TABLE 11

WORK TRIPS RELATED TO RETAIL, PUBLIC FLOOR SPACE USE— PITTSBURGH, PA.[a]

O-D Zone	Work Destinations	
	Computed	Observed
60-80	6,503	4,710
80-80	6,724	7,384
40-60	14,664	14,500
60-60	11,765	10,385
80-60	10,841	11,925
40-40	2,676	3,673
60-40	8,743	7,699
80-40	19,552	20,568
60-20	1,160	1,792
80-20	4,919	4,911

[a]Regression equation = Eq. 10; F ratio = 238.58; standard error, $S(Y_W)$ = 1,211; correlation coefficient, R = 0.9824; r^2 = 0.965; statistical data for regression coefficients:

Factor	Retail, b_S	Public, b_P
Level of significance (%)	0.1	0.1
Partial correlation coefficient	0.974	0.918
Standard error	0.730	2.362

Eq. 11 closely resemble the observed trips as evidenced by the small standard error.

A plot of Eq. 11 may be seen as Figure 4. Statistical data for this equation are given in Table 12.

In Figure 4, it will be observed that several of the zones in the Gainesville CBD had relatively large areas of retail floor space use, but exhibited little attractiveness to shopping trips. Examination of the type of floor space within these zones showed that these stores were inherently different from those which attracted large shopping trip volumes. Typical floor space uses included in the "sales" category for these zones were service station, pawn shop, used cars, photo studio, auto accessories store, boat sales, drug stores, and small eating establishments.

The Gainesville data support the thesis that shopping trips to certain retail floor space uses such as large department and variety stores are closely related to floor space area. In contrast, shopping trips to certain of Gainesville's smaller shops and establishments are only slightly related to floor space in use. Certain of these "retail" stores evidently attract few shopping trips, but depend on CBD employees and shoppers that are attracted to the larger stores.

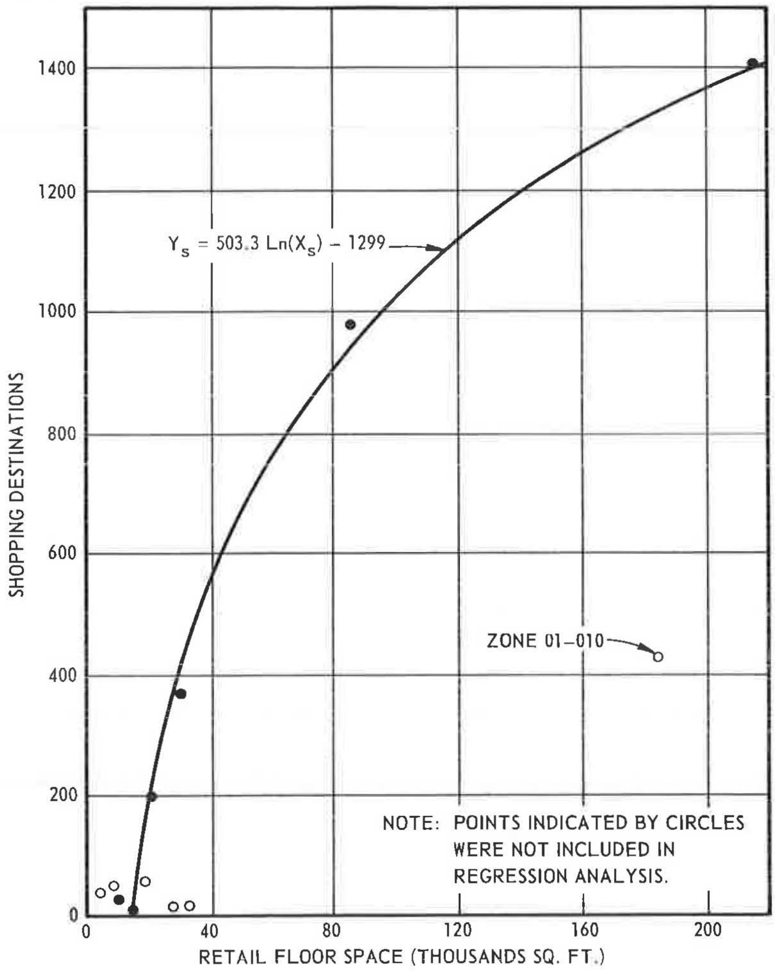

Figure 4. Relationship of shopping trips to Gainesville CBD to retail floor space use.

TABLE 12

SHOPPING TRIPS RELATED TO RETAIL FLOOR SPACE USE—GAINESVILLE, GA.[a]

O-D Zone	Shopping Destinations	
	Computed	Observed
01-006	402	368
01-003	946	976
01-001	1,406	1,407
05-009	84	3
01-002	0	26
01-007	215	199

[a]Model developed for six selected zones—zones 01-011, 01-004, 01-009, 01-010, 01-005, and 01-008 omitted; regression equation = Eq. 11; F ratio = 329.76; standard error, $S(Y_S) = 68$; correlation coefficient, R = 0.9942; r^2 = 0.988; regression coefficient $\ln(X_S)$: level of significance 0.1 percent, partial correlation coefficient 0.994, standard error 27.146.

It is evident from this study that more meaningful models could have been developed if a more detailed breakdown of "retail" floor space used had been provided. It would have been instructive, for example, to relate shopping trips to two subclassifications of floor space use: one group including the major attractors of shoppers such as the large department and variety stores, and another group including all other retail uses.

Atlanta. —Attempts to develop nonlinear models relating shopping trips and retail floor space for Atlanta produced the following second-degree equation:

$$Y_S = 0.00362X_S^2 - 1.71X_S + 274 \quad (12)$$

With an F ratio of 197.70, Eq. 12 was highly significant. The correlation coefficient for the model was 0.993 and its standard error was 369. For zones 148 and 161, where retail sales activity was highest, excellent agreement between the observed shopping trips and those computed with the model was noted (Table 13). A graph of Eq. 12, along with observed data, is shown in Figure 5.

Pittsburgh. —Eq. 13, a quadratic model relating shopping trips to the Pittsburgh CBD and retail floor space use, was highly significant:

$$Y_S = 0.0112X_S^2 - 1.37X_S + 110 \quad (13)$$

Statistical data for this model are given in Table 14. A plot of Eq. 13 and the observed data are shown in Figure 6.

With a high correlation coefficient and a small standard error, Eq. 13 is statistically satisfactory. However, the linear term was negative and exhibited a very small partial correlation coefficient, suggesting that the "true" shopping model for Pittsburgh might take the form of a pure quadratic equation.

TABLE 13

SHOPPING TRIPS RELATED TO RETAIL FLOOR SPACE USE—ATLANTA, GA.[a]

O-D Zone	Shopping Destinations	
	Computed	Observed
144	237	109
146	145	209
148	1,983	2,241
150	114	185
152	805	52
155	143	106
156	84	367
157	175	594
158	220	35
161	8,709	8,715

[a]Regression equation = Eq. 12; F ratio = 197.70; standard error, $X(Y_S) = 369$; correlation coefficient, R = 0.9927; r^2 = 0.985; statistical data for regression coefficients:

Factor	$b\ (X_S^2)$	$b\ (X_S)$
Level of significance (%)	0.1	N.S.
Partial correlation coefficient	0.956	-0.650
Standard error	0.00042	0.756

Personal Business Trip Models

The Gainesville and Pittsburgh data suggest that personal business trips are most closely related to sales, public, and and office floor space use. In the Atlanta study, personal business trips were not given as a separate trip purpose but were included as "miscellaneous" trips.

The best personal business trip model for Gainesville was a four-dimensional model including service, office, and public floor space use as the independent variables:

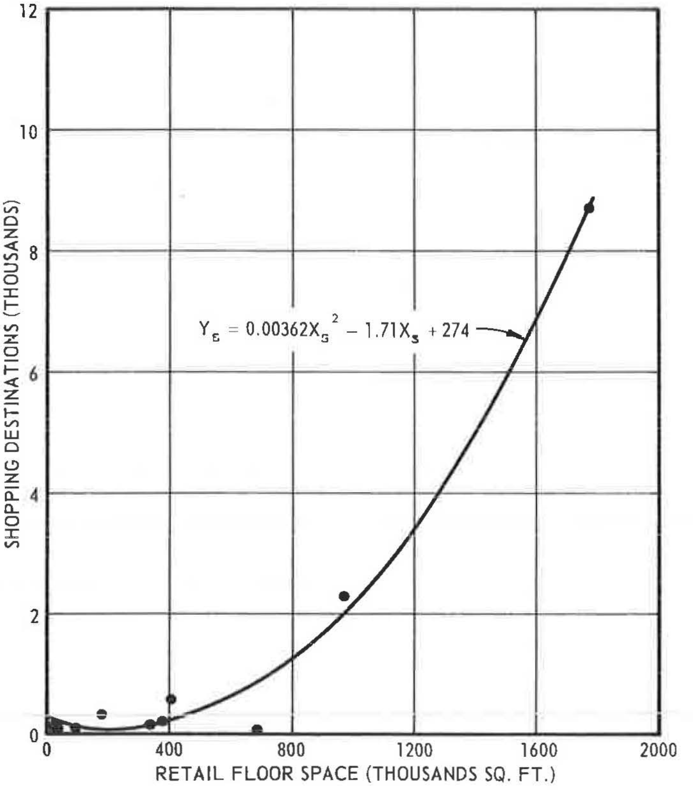

Figure 5. Relationship of shopping trips to Atlanta CBD to retail floor space use.

$$Y_b = 3.60X_r + 5.62X_o + 15.03X_p + 29 \tag{14}$$

Statistically, this model was less satisfactory than the work and shopping trip models for Gainesville. The model was significant at the 0.1 percent level, but barely so. The correlation coefficient was only 0.9089, implying that only about 82 percent of the variation in business trips is associated with variations in floor space use. The computed business trips did not closely agree with the observed values, as indicated by the large standard error of estimate.

According to Eq. 14, public floor space use in Gainesville attracts about four times as many business trips as service use and about 2.5 times as many as office use. Personal business trips to Gainesville were not significantly related to sales, wholesale, and semi-public floor space use.

Personal business trips to central Atlanta were grouped with medical, dental, and eat-meal trips as "miscellaneous" trips. Miscellaneous trips to the Atlanta CBD were related to sales and office floor space use:

$$Y_m = 0.91X_s + 0.88X_o + 144 \tag{15}$$

Although Eq. 15 was significant at the 0.1 percent level, its correlation coefficient of 0.867 suggests that only about 75 percent of the variation in traffic is explained by the model. Partial correlation coefficients for the sales and office variables were, respectively, 0.867 and 0.679.

The best business trip model for Pittsburgh related business trips to the CBD to retail sales and public floor space use:

TABLE 14

SHOPPING TRIPS RELATED TO RETAIL FLOOR SPACE USE—PITTSBURGH, PA.[a]

O-D Block[a]	Shopping Destinations	
	Computed	Observed
33-64	74	27
42-48	69	114
43-69	3,753	5,700
48-63	3,148	1,783
57-54	612	775
64-49	371	817
71-64	7,579	6,111
73-45	12,282	12,933
75-75	106	552
59-73	99	5

[a]Model developed from data from 37 blocks, 10 of which are shown; regression equation = Eq. 13; F ratio = 298.40; standard error, $S(Y_s)$ = 511; correlation coefficient, R = 0.9793; r^2 = 0.959; statistical data for regression coefficients:

Factor	$b\ (X_s^2)$	$b\ (X_s)$
Level of significance (%)	0.1	N.S.
Partial correlation coefficient	0.855	-0.199
Standard error	0.0012	1.159

$$Y_b = 1.85X_s + 4.56X_p - 295 \qquad (16)$$

This equation exhibited very satisfactory correlation statistics. The model was significant at the 0.1 percent level, and its correlation coefficient was in excess of 0.97. Close agreement between the computed and observed traffic data was obtained, and the standard error of estimate was small. The variation between the computed and observed traffic values was 10 percent or less for six of the ten O-D zones. Very good statistical data for the regression coefficients were also noted.

Statistical data for Eqs. 14, 15 and 16 are given in Tables 15, 16, and 17, respectively.

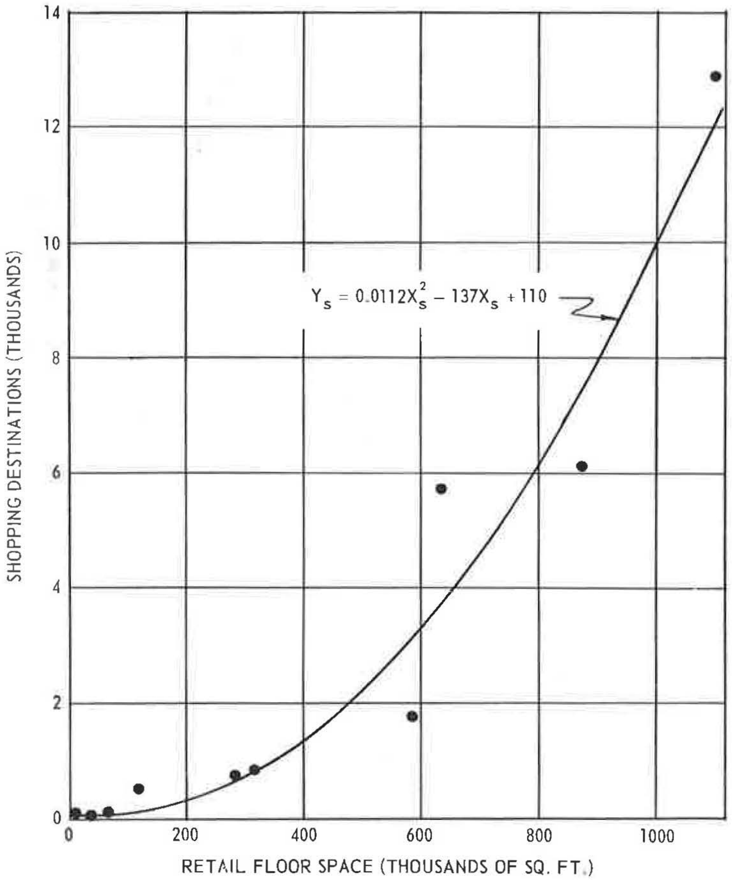

Figure 6. Relationship of shopping trips to Pittsburgh CBD to retail floor space use.

TABLE 15

BUSINESS TRIPS RELATED TO SERVICE, OFFICE, PUBLIC FLOOR SPACE USE—GAINESVILLE, GA.[a]

O-D Zone	Business Trips	
	Computed	Observed
01-006	511	904
01-010	342	278
01-003	982	900
01-001	760	684
01-011	220	233
01-004	206	66
05-009	94	56
01-002	160	93
01-007	44	135
01-009	76	74
01-005	70	76
01-008	182	142

[a]Regression equation = Eq. 14; F ratio = 20.21; standard error, $S(Y_b)$ = 160; correlation coefficient, R = 0.9089; r^2 = 0.826; statistical data for regression coefficients:

	Service, b_r	Office, b_o	Public, b_p
Level of significance (%)	N.S.	1	5
Partial correlation coefficient	0.465	0.816	0.725
Standard error	0.768	0.444	1.595

TABLE 16

MISCELLANEOUS TRIPS RELATED TO RETAIL, OFFICE FLOOR SPACE USE—ATLANTA, GA.[a]

O-D Zone	Miscellaneous Destinations	
	Computed	Observed
144	701	501
146	951	986
148	1,235	1,225
150	720	1,232
152	1,007	852
155	493	248
156	1,312	1,294
157	895	1,201
158	442	308
161	1,810	1,720

[a]Regression equation = Eq. 15; F ratio = 49.23; standard error, $S(Y_m)$ = 269; correlation coefficient, R = 0.8674; r^2 = 0.752; statistical data for regression coefficients:

Factor	Sales, b_s	Office, b_o
Level of significance (%)	1	5
Partial correlation coefficient	0.867	0.679
Standard error	0.198	0.361

TABLE 17

BUSINESS TRIPS RELATED TO RETAIL, PUBLIC FLOOR SPACE USE—PITTSBURGH, PA.[a]

O-D Zone	Business Destinations	
	Computed	Observed
60-80	1,491	1,481
80-80	1,421	1,413
40-60	3,215	3,337
60-60	2,351	1,771
80-60	2,129	2,369
40-40	377	755
60-40	1,932	1,860
80-40	4,814	5,051
60-20	0	179
80-20	1,148	603

[a]Regression equation = Eq. 16; F ratio = 127.36; standard error, $S(Y_b)$ = 373; correlation coefficient, r = 0.9735; r^2 = 0.948; statistical data for regression coefficients:

Factor	Retail, b_s	Public, b_p
Level of significance (%)	0.1	0.1
Partial correlation coefficient	0.952	0.921
Standard error	0.224	0.727

Social and Recreation Trip Models

Predictive models for social and recreation trips were consistently poor, and the results of this study indicate that social and recreation trips are not closely related to the area of floor space in use. Although several of these models produced satisfactory correlation statistics, certain of the regression coefficients were negative, casting doubt on the predictive value of these equations.

CONCLUSIONS

1. The number of people attracted to a zone within a city's CBD is closely related to the amount of floor space used for various purposes within that zone. The results of this study indicate that both total trips to the CBD and trips made for work, shopping, and business purposes are significantly related to the area of certain classifications of floor space use (Fig. 7).

2. With but few exceptions, this research failed to show any significant relationships between social and recreation trips and the area of floor space use within the CBD.

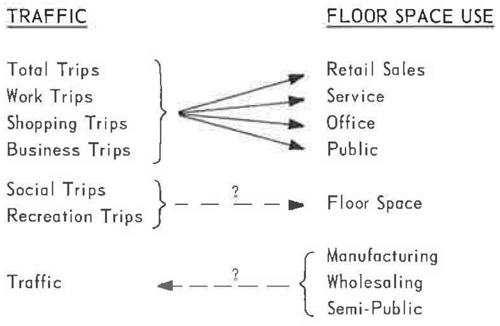

Figure 7. Relationships between traffic attracted to zones in a city's CBD to various classes of floor space use.

3. Both total trips made to CBD zones and trips made for work, shopping, and business purposes are most closely related to floor space use classification of retail sales, service, offices, and public use.

4. Traffic attracted to the CBD is not statistically related to manufacturing, wholesaling, and semi-public floor space use.

5. Regression coefficients in models of the type constructed in this study are critically affected by the size of O-D zones. The selection of small homogeneous zones tends to produce better stratification and increased reliability of the data. In future O-D studies, therefore, it is recommended that trips to the CBD be reported by a large number of homogeneous zones, preferably by city block.

6. In this research, significant regression models were constructed by relating traffic to only one or two classes of floor space use. In fact, the simpler two- or three-dimensional models frequently exhibited better correlation statistics than those which included additional variables.

7. Wide variations of floor space use were noted within certain of the floor space classifications, impairing the usefulness of the models as means of estimating future traffic. These variations were especially noticeable for the retail variable for Gainesville which included such uses as large department stores, used car lots, pawn shops, and small eating establishments.

8. For certain of the floor space classifications, a part of the variation in regression coefficients may be due to differences in intensity of floor space use. For example, overcrowding may have partially caused the remarkably high public regression coefficients for Gainesville. It is also likely that certain of the differences noted in the retail and service-office regression coefficients for cities of different sizes are due to variations in intensity of floor space occupancy.

9. In three-dimensional linear models relating total CBD person destinations and retail and service-office floor space use, the retail regression coefficients increase linearly with city population. In these models, the service-office regression coefficients decrease with logarithmic increases in population. Although the regression coefficients in these equations were significantly related to urban population, substantial deviations from the least square curves were noted, suggesting that it would be unwise to attempt to construct such a model based on urban area population alone or to apply one city's model to another of similar size.

10. In the four-dimensional linear model proposed by Harper and Edwards (2) in which total trips are related to retail, service-office, and manufacturing-warehousing floor space use, the manufacturing-warehousing coefficient is not statistically significant.

11. There is a close relationship between the number of shopping trips to an area in the CBD and the amount of retail floor space in use within that section of the CBD. The results of this study indicate that the relationship between retail floor space use and shopping trips is nonlinear.

12. The reliability of floor space models as a means of forecasting traffic depends on whether the regression coefficients remain constant with time. The effect of time on the regression coefficients was not tested in this research, but would be a profitable subject of future studies.

ACKNOWLEDGMENT

The author gratefully acknowledges the financial assistance of the Institute of Traffic Engineers, sponsors of the research.

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San Francisco-Oakland Bay Bridge Trans-Bay Bus Riders Survey

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This survey was conducted to determine if an exclusive bus lane provided in 1961 on the Bay Bridge caused a significant number of people to change from auto to bus travel. The findings are not directly applicable to the question of capacity of freeways with reserved lanes for buses because the buses shared a lane with other vehicles at the actual bottleneck, the 2-lane approach to the traffic signal at Yerba Buena Island. Also, we did not determine how many bus riders switched from bus to auto travel during the test period.

The study indicated that patronage increased 6 percent from 1961 to 1962, coinciding with the inauguration of the exclusive lane, but also increased 6 percent from 1960 to 1961, before the exclusive lane was established. There is no evidence that the exclusive bus lane caused a major increase in bus patronage or a significant reduction in auto traffic on the bridge. Three percent of the bus passengers interviewed had switched from auto travel during the exclusive lane period. Of these, 38 percent said they switched to bus travel because it was more convenient, and 23 percent said they did so because the bus was faster. Only one out of 239 former auto users said specifically he switched because of the exclusive bus lane.

Changes in place of employment or residence caused large shifts in bus patronage. Twenty-three percent of all interviewed bus riders were new during 1962, but the net increase in patronage was only 6 percent and the "switches" from auto travel were only 3 percent. The increase (1962 over 1961) in the number of people crossing the bridge in autos was greater than the increase in bus riders; 533,000 bus riders accounted for 46 percent and 636,000 auto users for 54 percent of the total increase.

•WHEN THE rail transit operation on the San Francisco-Oakland Bay Bridge was discontinued in April 1958, it became necessary to pave the former track area on the lower deck and to reconstruct the decks in the Yerba Buena Island Tunnel, an integral part of the overall bridge between San Francisco and Oakland. During reconstruction in the tunnel, the capacity of the upper deck was reduced and the lower deck was restricted to two very substandard lanes at the approach to a temporary traffic signal at the east end of the tunnel (Fig. 1). All of this caused delays and queues of mixed autos, buses, and trucks on the lower deck, especially in the eastbound direction during the evening peak hour.

In December 1961, pavement on the lower deck had been completed on the portion of the bridge west of the Island, so that in the eastbound direction there were three 12-ft lanes available for evening peak traffic approaching the 2-lane section in the tunnel. The queue lined up three abreast, but the capacity of the signal was still limited

Paper sponsored by Committee on Freeway Operations.

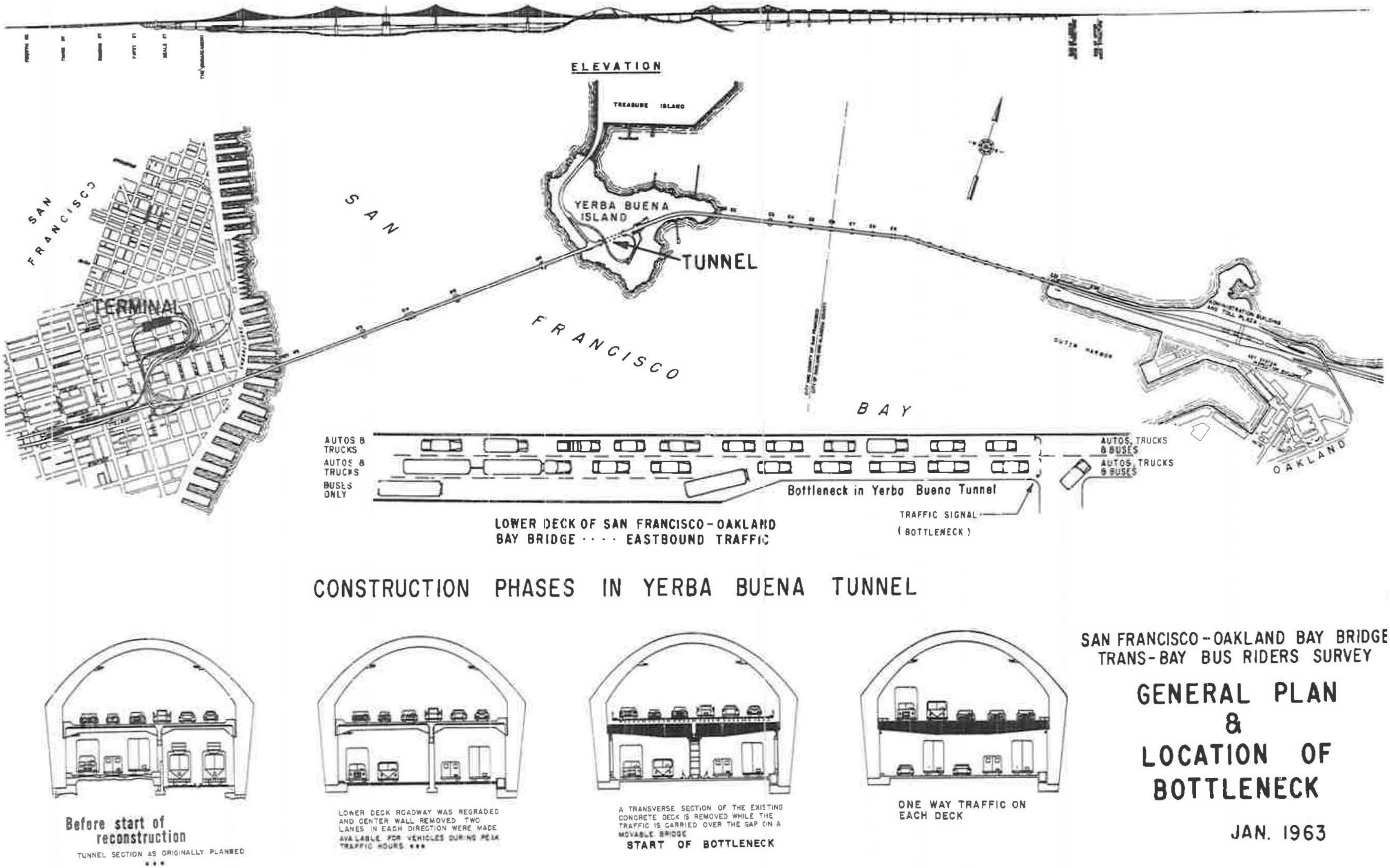


Figure 1. General plan and location of bottleneck.

by the two lanes at that point; in other words, the signal at the east end of the tunnel was a bottleneck with far less capacity than even two of the three lanes west of the tunnel.

In January 1962, an order was issued restricting the eastbound shoulder lane of the west bay crossing for the use of buses only (Fig. 2). This did not change the capacity of the signal at Yerba Buena Island, but it enabled the buses to bypass the queues of autos and trucks which now had to line up two abreast on the west bay crossing while waiting for their turn to go through the bottleneck. This gave the buses an advantage of about 9 min as compared with the autos and trucks which were bypassed, and it was hoped that this would induce sufficient auto riders to switch to buses to reduce vehicular volume to a figure more comparable with capacity of the bridge.

PURPOSE OF STUDY

During the period in which the exclusive bus lane was in operation, bus patronage did increase. This study of the bus riders was made to determine if the exclusive bus lane caused a significant number of people to change from auto to bus travel across the Bay.

STUDY PROCEDURE

In October and November 1962 a survey of bus patrons was conducted to determine how many of them had changed from auto travel and the reasons for the change. Eastbound bus commuters using the San Francisco Terminal Building were interviewed between 4:00 to 6:00 p.m. on Tuesdays, Wednesdays, and Thursdays only. Generally, only two bus lines were surveyed on a given day. The interviewing started on Oct. 23 and was completed on Nov. 7.

The bus riders were interviewed while waiting in line for their bus. Some of the riders arriving just as the bus was leaving were not interviewed. Ninety-one percent of the 11,000 bus riders were interviewed.

From the interview it was determined if the bus rider was a regular commuter. If so, did he become a regular bus commuter in 1962? Was he a new commuter or a former auto commuter? If he was a former auto commuter, the following questions were asked:

Figure 2. Exclusive bus lane.

1. How did you commute across the Bay before you became a regular bus commuter?
2. How did you get to the Terminal Building?
3. Where did your trip begin in San Francisco?
4. How will you travel to your destination after you get off this bus?
5. Where is your destination?
6. Why did you start riding the bus?

Postcards were distributed to former auto users when time did not permit a complete bus-side interview; 62 percent of the 187 distributed postcards were returned.

Travel time studies of eastbound buses and autos were also made during the evening peak period. Bus passenger statistics received from Alameda-Contra Costa Transit District and Greyhound were analyzed. Traffic volume and classification data from the Bay Bridge toll records and the University of California Institute of Transportation and Traffic Engineering were also analyzed.

FINDINGS

Changes in Mode of Travel

It was found that 3.1 percent of the peak hour patrons using buses in October and November 1962 had changed from autos to buses during the 10 months since the exclusive lane was established. The number of former auto users who had been drivers or had shared driving in car pools (as distinguished from riding as passengers) represents five bus loads of passengers or a 1.6 percent reduction in the evening peak eastbound vehicular traffic. The increased number of buses or the reduction in total traffic volume was not significant enough to be recognized by the average bridge user.

Reasons for Changing from Auto to Bus Commuting

Approximately one-third of the former auto users gave more than one reason for changing to bus commuting. Convenience was the most frequently mentioned reason (38 percent) for changing to the bus. In addition to the exclusive bus lane, the new buses and expanded service could have been strong factors influencing convenience.

Figure 3. Bus loading, San Francisco Terminal Building.

Another factor influencing convenience of bus riding is the inconvenience of parking an automobile in downtown San Francisco.

Twenty-seven percent of the former auto users said that they changed to bus travel because the bus was cheaper. The fact that the bus travel is cheaper than auto travel for some people may bear little relation to the exclusive bus lane.

Twenty-three percent of the former auto users said that they changed to bus travel because the bus was faster. The bus trip may be slower in some cases than the auto trip when the total time from trip origin to destination is considered. All time savings can be lost if more than a few minutes are spent waiting for the bus. Even on two lines operating with the shortest headways, some passengers had to wait in line for five or more min (Fig. 3).

Seventeen percent of the former auto users said that the car pool in which they were riding broke up. Some of these people further stated that they would return to pool riding as soon as they could get another started.

Among the miscellaneous reasons stated for changing to the bus was the congestion on the bridge or approaches (8 percent). Some of the bus riders said they no longer had a car available or they could no longer drive. Only one person out of 239 mentioned the exclusive bus lane as a reason for changing to bus travel.

Former Mode of Commuting

Approximately half (51 percent) of the former auto users drove their own cars. The remainder either shared driving in a pool (28 percent) or were always auto passengers (20 percent). One percent was undetermined.

Increase in Bus Patronage

Bus Riding Trend. —The trend in Trans-Bay commuter bus riding has been counter to the national trend. On both the Alameda-Contra Costa Transit and Greyhound Bus Company's Contra Costa lines the patronage has shown significant increases in the past 3 years (Fig. 4). The increases on the two bus lines and for autos crossing the bridge during common 10-month periods are given in Table 1.

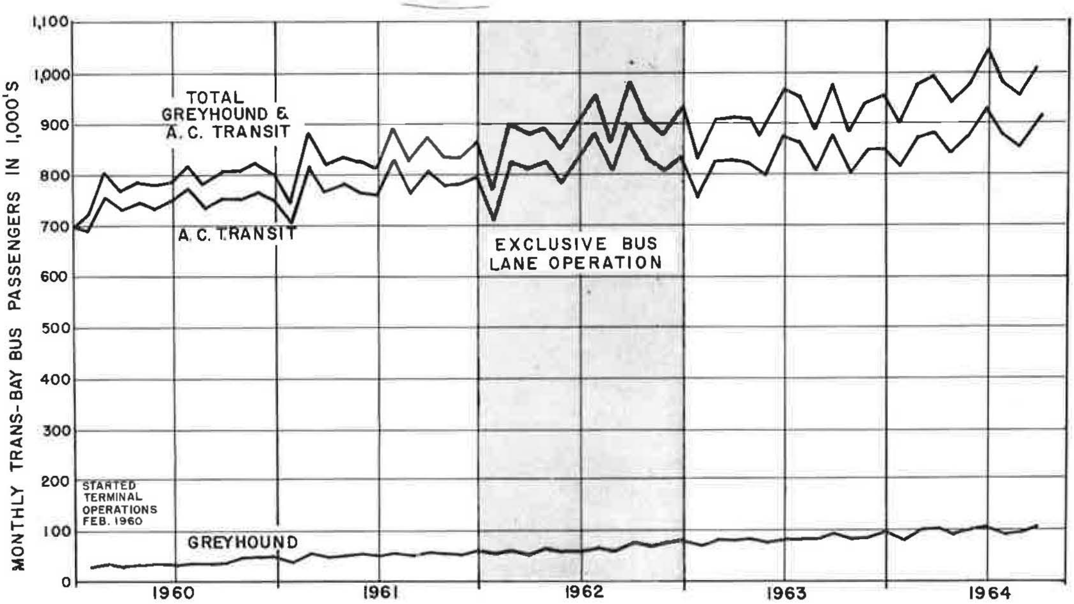


Figure 4. Monthly Trans-Bay bus passengers using San Francisco Terminal Building.

TABLE 1

TRANS-BAY COMMUTER TRAVEL INCREASE

Travel Method	Percent Increase		
	1960-1961	1961-1962	1960-1962
A-C Transit	4.50	5.40	10.14
Greyhound	37.46	18.86	63.39
Total Bus Riders	6.28	6.34	13.02
Autos	3.64	1.32	5.01

New Bus Riders. —The new bus riders are new commuters who have changed jobs or place of residence in the first 10 months of 1962 and former auto users who were either auto drivers or riders in 1961. The new bus riders account for a little less than one-quarter of the bus riders. This ratio was about the same for both A-C Transit and Greyhound (Table 2). The former auto users were 3.1 percent of all bus riders and 14 percent of the new bus riders. These percentages are about the same for both bus companies (Table 2).

Following is an estimate of the change in the number of persons crossing the bridge between comparable periods in 1961 and 1962 (Feb. 1 to Nov. 30). The daily commuters are about two-thirds of all Trans-Bay bus riders. For this estimate, it is assumed that they are representative of all bus users.

1. Change in bus patronage:

Former auto users	+ 278,000
Other new bus riders	+1,769,000
1961 bus riders lost in 1962 (computed)	-1,514,000
Net gain in 1962 (from bus passenger records)	+ 533,000

2. Change in auto users:

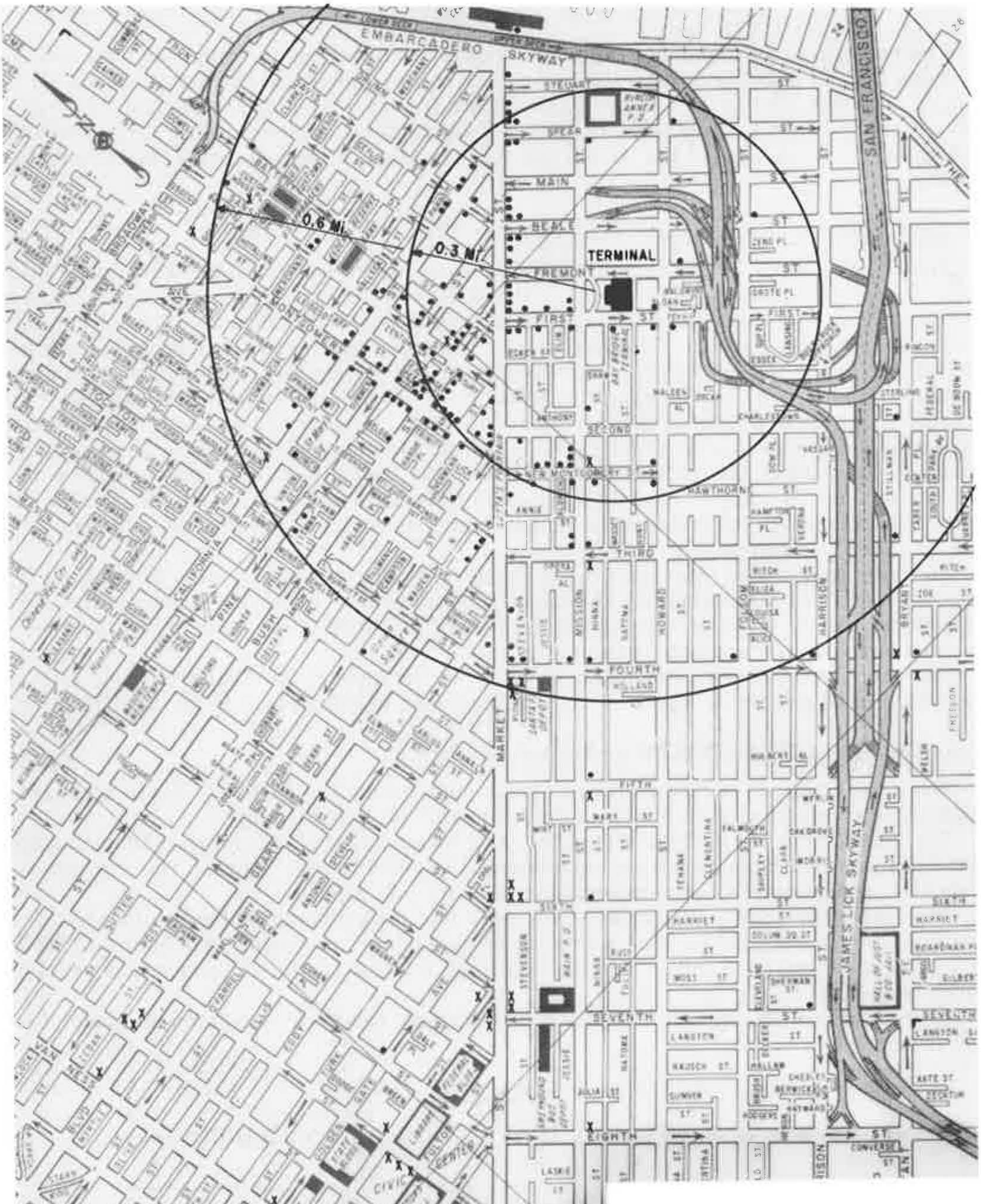
Former auto users now in buses	- 278,000
New auto users	+ Unknown
1961 auto users lost in 1962	- Unknown
Former bus users now in autos	+ Unknown
Net gain in 1962 (from SF-OBB toll records)	+ 636,000

3. Total net gain in bus and auto riders +1,169,000

TABLE 2

NEW BUS RIDERS, TRANS-BAY, 1962

Bus Line	New Bus Riders		Former Auto Users		
	No. Interviewed	Percent Total Interviewed	No. Interviewed	Percent of All New Riders	Percent of All Bus Riders
A-C Transit	1,863	23	256	14	3.1
Greyhound	415	24	54	13	3.1
Total	2,278	23	310	14	3.1



NOTE: 7% OF ORIGINS ARE OFF OF THIS MAP.

BASE MAP COURTESY OF CALIFORNIA STATE AUTOMOBILE ASSOCIATION

Figure 5. Origins of former auto riders.

The net gain in auto and bus riders in 1962 is 2.07 percent as compared with 1961.

Less than 18 percent of the 1961 bus riders (1,514,000 in the estimate) are no longer crossing the San Francisco-Oakland Bay Bridge. Some of the person trips no longer riding buses undoubtedly are included among the auto users. The large losses and gains in the number of bus riders are an indication of the mobility of the Bay Area population.

Mode of Travel at Ends of the Trans-Bay Bus Trip

In San Francisco, 71 percent of the former auto users walked to the Terminal Building. Eighty-five percent of those who walked listed their trip origin as being less than 0.6 mile from the Terminal Building. This area includes the financial district and the area of high parking costs. The 1961 traffic survey data from the San Francisco-Oakland Bay Bridge* was revealing. Approximately 2,400 auto trips crossing the bridge between 4 and 6 p.m. had destinations in the area served by Trans-Bay buses and originated within 0.6 mile of the Terminal Building. It is not known how many of these have changed to buses or are potential bus users. Figure 5 shows the location of 93 percent of the known trip origins in San Francisco. In the East Bay, 50 percent of the former auto users walked from their bus stop to their destination. The distribution of trip destinations for walkers did not indicate any particular concentration as in the San Francisco origin area.

Auto was the second most used mode (35 percent) for continuing trips in the East Bay. Three lines accounted for 57 percent of this mode. These bus lines are the longest and serve areas of lower population density. None of the former auto users arrived at the San Francisco Terminal by auto.

The use of a local bus, streetcar, or jitney at the ends of the Trans-Bay bus trip amounted to 25 percent of the trips in San Francisco and 8 percent in the East Bay.

Trip Time Across San Francisco-Oakland Bay Bridge

The travel time of eastbound evening peak hour buses was checked. Their average speed on the bridge was 27.6 mph, with a range of 11.8 to 35.2 mph.

The travel time for autos on the upper deck was measured by timing eastbound autos and making travel time and delay trips during the evening peak hours. The average speed by each method was approximately the same, 21 mph.

The travel time for autos on the lower deck (the deck containing the bus lane) was measured by making travel time and delay trips during the evening peak hours. The average speed was 15.2 mph. The average time lost for traffic stoppages was nearly three times that on the upper deck.

Table 3 shows the average speed and travel times based on a common distance of 5.3 miles.

TABLE 3

AVERAGE SPEED AND TRAVEL TIMES, SAN FRANCISCO-OAKLAND BAY BRIDGE

Vehicle	Avg. Speed (mph)	Avg. Time (min)	Min Slower Than Buses
Buses	27.6	11.5	—
Autos on upper deck	21.0	15.1	3.6
Autos on lower deck	15.2	20.9	9.4

*Origin and destination survey of bridge users was made by the Division of San Francisco Bay Toll Crossings as part of their study of additional bay crossings. The original O-D survey cards for the SF-OBB were analyzed for the bus riders survey.

TABLE 4

COMPOSITION OF BRIDGE TRAFFIC EASTBOUND, OCTOBER 1962 (WEEKDAY), 4 TO 6 P.M.

Deck	Veh Type	No. Veh	No. Persons	Persons/Veh
Upper	Auto	8,044	13,031	1.62
Lower	Auto	2,448	3,966	1.62
	Lt. truck	292	380	1.30[a]
	Truck	564	620	1.10[a]
	Local bus	280	10,724	38.30
	Other bus	60	1,200	20.00[a]
	Misc.	17	21	1.25[a]
	Total	3,661	16,911	4.62
Both	Total	11,705	29,942	2.56

[a]Estimated occupancy.

TABLE 5

SUMMARY OF COMPOSITION OF BRIDGE TRAFFIC EASTBOUND, OCTOBER 1962 (WEEKDAY), 4 TO 6 P.M.

Veh Type	Vehicle		Person		Persons/Veh
	No.	Percent	No.	Percent	
Auto	10,492	89.64	16,997	56.77	1.62
Bus	340	2.90	11,924	39.83	35.07
Other	873	7.46	1,021	3.40	1.17
Total	11,705	100.00	29,942	100.00	2.56

TABLE 6

AUTO-PERSONS OCCUPANCY[a]

Persons/Auto	Percent of Autos	Percent of Persons
1	63.95	39.43
2	22.39	27.61
3	6.26	11.58
4	4.02	9.91
5	2.30	7.08
6	0.75	2.76
7	0.23	0.99
8	0.05	0.28
9	0.00	0.00
10	0.05	0.36

[a]Average occupancy 1.62 persons/auto.

Composition of Eastbound Traffic, San Francisco-Oakland Bay Bridge

Between 4 and 6 p. m. on an average weekday, buses carry 40 percent of the eastbound persons in 3 percent of the vehicles and autos carry 57 percent of the persons in 90 percent of the vehicles. The remainder are in trucks (Tables 4 and 5). The average number of persons per vehicle is 35.2 for buses, 2.56 for all vehicles, and 1.62 for autos (Table 6).

CONCLUSIONS

Patronage increased 6 percent from 1961 to 1962, coinciding with the inauguration of the exclusive lane, but patronage also increased 6 percent from 1960 to 1961, before the exclusive lane was established. There is no evidence that the exclusive bus lane caused a major increase in bus patronage or a significant reduction in auto traffic on the bridge.

Three percent of the bus passengers interviewed had switched from auto travel during the exclusive lane period. Of these, 38 percent said they switched to bus travel because it was more convenient, and 23 percent said they did so because the bus was faster. Only one out of 239 former auto users said specifically he switched because of the exclusive bus lane.

Changes in place of employment or residence caused large shifts in bus patronage. Twenty-three percent of all interviewed bus riders were new, but the net increase in patronage was only 6 percent and the "switches" from auto travel were only 3 percent. The increase (1962 over 1961) in the number of people crossing the bridge in autos was greater than the increase in bus riders.

RESERVING BUS LANES ON FREEWAYS

The findings of this study cannot be directly converted into an answer to the question of what effect an exclusive bus lane on a freeway would have on total capacity or total person-minutes. On the Bay Bridge, a lane was not reserved in the bottleneck (Fig. 1).

Because the demand rate of flow exceeded the capacity of the bottleneck, long queues of vehicles formed on the 3-lane approach. Buses could bypass the queues because a lane was reserved for them on the approach to the bottleneck. This resulted in great time savings for the buses and some loss in time for the autos and trucks, but it did not significantly change the capacity or the number of vehicles passing through the bottleneck. Each bus occupied about 5 sec of time in the traffic stream at the bottleneck, and thus added about 5 sec of delay to all other vehicles in the queue at the particular instant that the bus arrived at the bottleneck. However, other vehicles were allowed to use the bottleneck at all times between bus arrivals, about 75 percent of the time. If a lane had been reserved for buses in the bottleneck itself, the total vehicular flow would have been drastically reduced; in fact, it would have been little more than half of what it actually was, because the bus lane would have delivered only about 25 percent of its vehicular capacity.

If there is a delay, it can be only shifted from buses to autos; almost invariably, total delay increases by the assignment of an exclusive lane to buses. The delay cannot be eliminated because as soon as it is, the exclusive lane would be meaningless to the buses. The assignment of an exclusive lane to one class of vehicle which is not used to a capacity equivalent to those of the remaining lanes will reduce the total capacity of the freeway.

It is very possible that a section of road could be operating well within capacity with mixed traffic so that an exclusive lane is unnecessary, but that this same section of road could become a bottleneck incurring huge delays to autos if one lane were reserved for buses, even though the traffic volume and number of buses remained constant. In short, the assignment of an exclusive lane could well introduce a large amount of delay where none now exists.

1964—TWO YEARS AFTER

The bottleneck in Yerba Buena Tunnel was removed in January 1963 and the exclusive bus lane was opened to all traffic. In October 1963 the lower deck of the bridge was made one way for westbound traffic and the upper deck was made one way for eastbound traffic.

The average evening peak period eastbound bus speed was 32.4 mph in December 1964, an increase of 4.8 mph or 17 percent from the average speed recorded during the operation of the exclusive bus lane. The number of bus riders increased by 9.4 percent in the 2-year period since the exclusive bus lane was eliminated. The growth was 13.0 percent for the previous 2 years. The number of autos crossing the bridge increased by 15.4 percent in the past 2 years and 5.0 percent in the previous 2-year period.

Discussion

KARL MOSKOWITZ, Assistant Traffic Engineer, California Division of Highways—In any discussion of the advisability of reserving a freeway lane for the exclusive use of buses, one of the factors to be considered is the effect of an exclusive lane on average delay for all persons, whether they ride buses or not. With a given percentage of all persons traversing a bottleneck riding buses, if the vehicular capacity is exceeded, all persons will be delayed a calculable amount if buses and autos share all lanes. With the same number of persons and the same percentage riding buses but with one lane reserved for buses only, delay to those riding buses will be eliminated but delay to those in autos and trucks will be increased. Diversion from auto riding to bus riding in this situation would have to be enough to reduce overall delay before an exclusive bus lane would prove advantageous.

Enough is known about highway capacity to make a close estimate of this overall delay, based on various stipulations. For example, it could be stipulated that the demand (or desired through-put) at a bottleneck is 20,000 persons/hour. A chart can then be drawn showing person-minutes of delay for various percentages of people riding buses with and without an exclusive bus lane. Figure 6 is such a chart, based on a stipulated demand of 20,000 persons/hour at a bottleneck where four lanes are available for one direction of travel. Other stipulations are four lanes in direction of major flow, 40 passengers/bus, 1.75 persons/auto and truck, uniform rate of demand for 1 hr, and total delay computed for the first 20,000 persons.

Two calculations can now be made:

1. Mixed traffic, no exclusive bus lane—If 12.5 percent (or 2,500 persons) ride in 62 buses, 17,500 persons will ride in 10,000 cars and trucks. The total number of vehicles required for the first 20,000 persons after the queue begins to form will be 10,062. Since each bus is known to be equal to about two cars on level grade, the equivalent number of vehicles will be 10,125. Since the capacity of the section is 7,200 veh/hr, in a mixed traffic stream the 10,125th vehicle will enter the bottleneck 10,125/7,200 = 1.41 hr after the queue starts to form, and the maximum delay will be 0.41 hr or 24.5 min. Based on a uniform demand rate, the average delay is 24.5/2 or 12.25 min, and the total delay is 12.25 × 20,000 or 245 person-minutes. This is shown in Figure 6 as point "A."

2. With an exclusive bus lane—The 2,500 bus riders will suffer no delay, but there will only be three lanes with a capacity of 5,400 veh/hr for the other 17,500 persons in 10,000 veh. The 10,000th vehicle will enter the bottleneck 10,000/5,400 = 1.85 hr after the queue starts to form, and the maximum delay will be 0.85 hr or 51 min. The average delay will be 25.5 min for 17,500 persons, or 447,000 person-minutes. This is shown in Figure 6 as point "B."

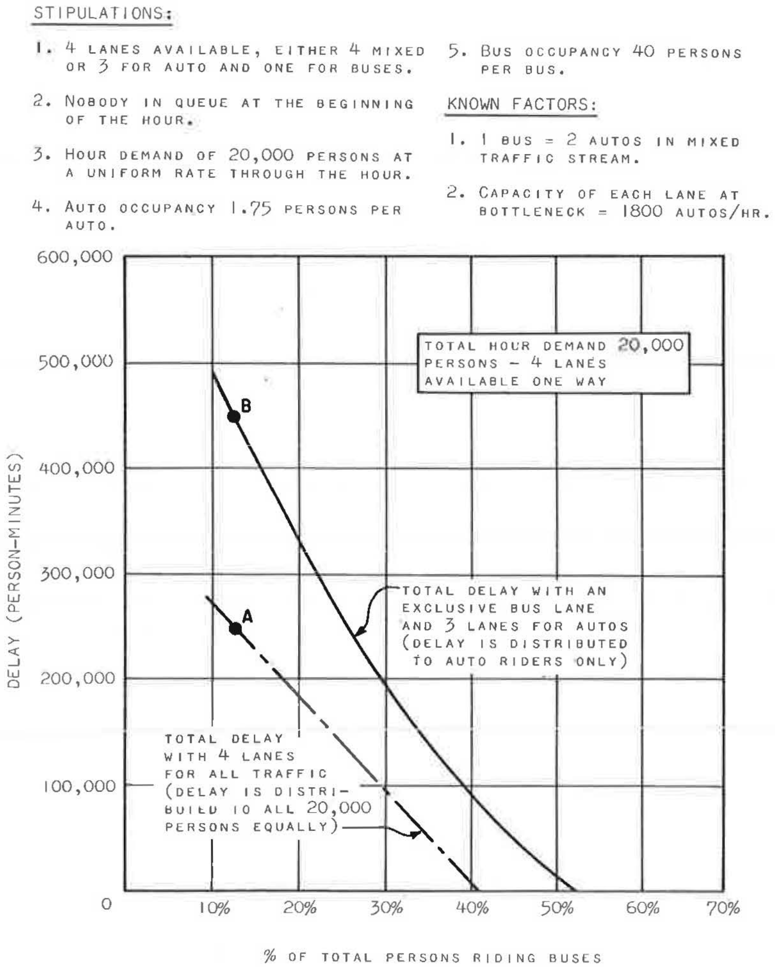


Figure 6. Relation between delay, assignment of lanes, and percent of total demand riding buses.

Enough other points were calculated for different percentages of persons riding buses to draw both curves in Figure 6. It will be noted that if 40 percent of the persons ride buses, there will be no delay for anybody if mixed traffic is allowed on all four lanes, but there will be approximately 100,000 person-minutes of delay if one lane is reserved for buses and the other vehicles are confined to three lanes.

Under the stipulated conditions, 53 percent of all persons must ride buses to eliminate delay if one lane out of four is reserved for buses. However, if 53 percent rode buses and mixed traffic were allowed on all four lanes, there would be no delay for anybody and there would be considerably more freedom of movement in the traffic stream; in other words, the freeway would be operating at about 82 percent of capacity with mixed traffic in all four lanes, but at 100 percent of capacity with one lane for buses and three lanes for autos and trucks.

Other charts can be drawn for other stipulated demands or widths of freeway. Examples are shown in Figures 7 and 8. A more sophisticated approach would involve a rising and falling rate of demand spread over a 2-hr period.

There is no question that if demand exceeds capacity, delay will be reduced as the proportion of bus riders increases. However, it appears that reserving an exclusive lane for buses, under such circumstances, would normally increase total delay although

STIPULATIONS:

1. 4 LANES AVAILABLE, EITHER 4 MIXED OR 3 FOR AUTO AND ONE FOR BUSES.
2. NOBODY IN QUEUE AT THE BEGINNING OF THE HOUR.
3. HOUR DEMAND OF 15,000 PERSONS AT A UNIFORM RATE THROUGH THE HOUR.
4. AUTO OCCUPANCY 1.75 PERSONS PER AUTO.
5. BUS OCCUPANCY 40 PERSONS PER BUS.

KNOWN FACTORS:

1. 1 BUS = 2 AUTOS IN MIXED TRAFFIC STREAM.
2. CAPACITY OF EACH LANE AT BOTTLENECK = 1800 AUTOS/HR.

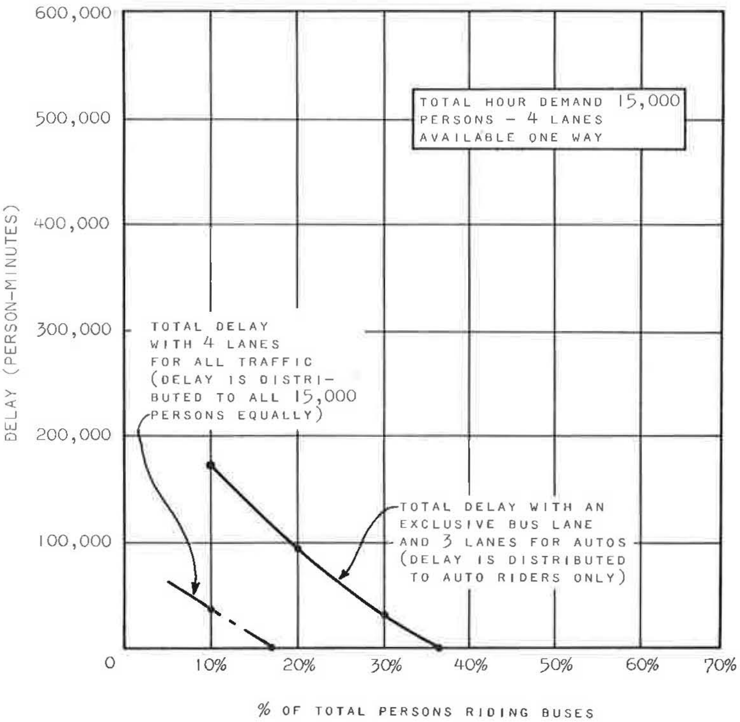


Figure 7. Relation between delay, assignment of lanes, and percent of total demand riding buses.

reducing it for some. The only result of the reserved lane that could be considered "beneficial" would be the possible coercion of auto riders to switch modes of transportation, and thus reduce the demand-capacity ratio.

Philosophic questions would have to be resolved regarding the equity of delaying one group of people more than another group before it could be stated that this was a "benefit," and the question of which group is paying most for the facility should enter into such a philosophic decision.

It must be kept in mind that if there is no delay, there is no point in setting aside an exclusive lane, and if there is delay, it can only be shifted by the assignment of an exclusive lane. It cannot be eliminated because the minute all delay is eliminated, the exclusive lane is meaningless to the buses. It is certain, however, that assignment of an exclusive lane for one class of vehicles will reduce the vehicular capacity of the bottleneck.

It is very possible that a section of road could be operating well within capacity with mixed traffic so that an exclusive lane is unnecessary, but that this same section of road could become a bottleneck incurring huge delays to autos if one lane were reserved for buses, even though the traffic volume and number of buses remained constant. In short, the assignment of an exclusive lane could well introduce a large amount of delay where none now exists.

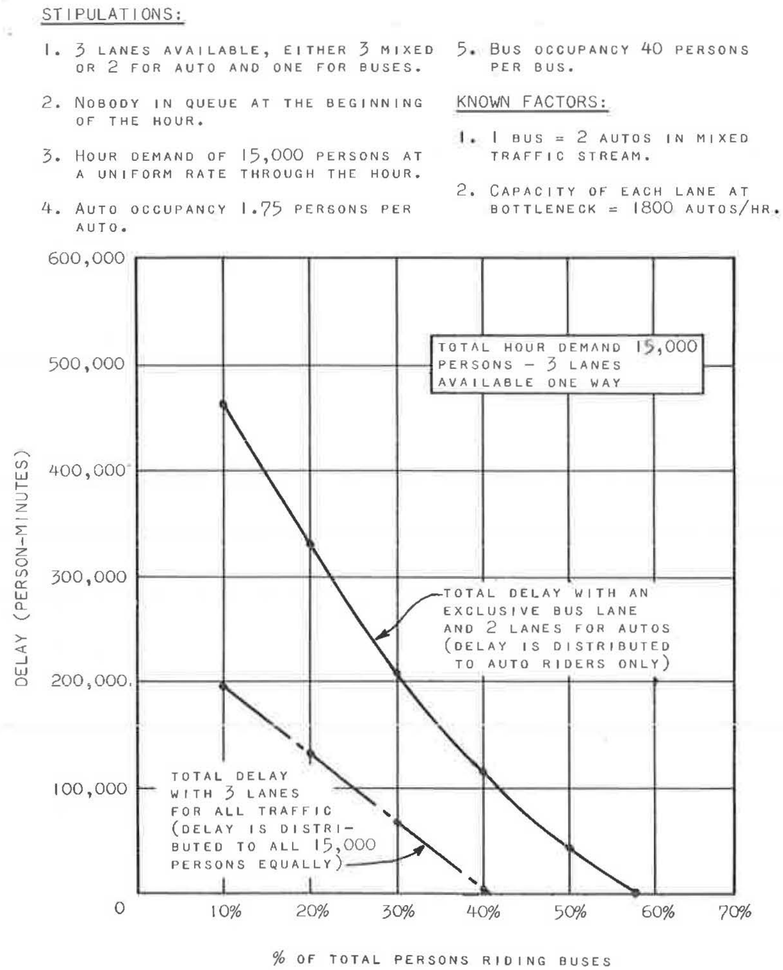


Figure 8. Relation between delay, assignment of lanes, and percent of total demand riding buses.

The same reasoning would apply to the design of a future freeway. For example, a freeway could be designed for three auto-and-truck lanes and one bus lane in each direction, but would probably cost as much as five lanes for mixed traffic in each direction. (The separate bus lane design would include separation strips and a few pedestrian overcrossing and station platforms.) The three-lane plus one-lane alternative could well produce gigantic delay for the autos and trucks, whereas the mixed five lanes could accommodate all the autos, trucks, and buses, with no delay for anybody. And the more people riding buses, the more excess capacity the five lanes would provide.

If a way could be found for buses and autos to share all lanes at a short bottleneck, but at the same time for the buses to be able to by-pass the queue of autos waiting upstream of the bottleneck, total delay would not be increased. However, it appears that it would almost always be less expensive to widen the bottleneck than it would be to provide a separate roadway enabling this type of operation.