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Forecasting Highway Trips

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Forecasting Highway Trips

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Integrating Land Use and Traffic Forecasting

CHARLES F. BARNES, Jr., Connecticut State Highway Department

● A TWO-YEAR STUDY of the transportation needs of the Greater Hartford Area was recently completed as a result of the combined efforts of the Connecticut Highway Department, the City of Hartford and the Bureau of Public Roads under the guidance of the Automotive Safety Foundation. As a consequence of this study there is a much clearer picture of the travel needs and desires of the area, and a better understanding of the changing urban travel patterns. Also, the study represented a wedding of the separate disciplines of the city planner and the traffic engineer, which in turn resulted in a new method of land-use analysis which may be the beginning of a better understanding of the factors affecting the growth of metropolitan areas, particularly with respect to the relationship between land use and highway development. This, in fact, may be the most important long-term outcome of the study, rather than the development of design traffic volumes which was the immediate study objective.

Actually, the study to date is only the first phase of a larger program which has as its aim the testing of alternate land-use patterns in an attempt to arrive at the most desirable arrangement from the standpoint of both highway and land-use development. This latter project is made possible only because of the basic information which has been derived from the land-use study.

The land-use analysis developed during the course of this study is actually a mathematical procedure (1) which can be used to forecast the future zone-by-zone distribution of population and employment areas. This information is a necessary prerequisite to and is used as input data for the traffic analysis.

The principal purpose of this paper is a discussion of the procedures used and the basic information learned during the development of the land-use analysis for the Hartford Area Traffic Study. However, because the purpose of the land-use study was to supply data for the traffic analysis, many of the procedures used are aimed strictly toward that end. Therefore, before discussing the details of the land-use study, it is necessary to explain briefly the traffic analysis to show just what land-use information is required.

TRAFFIC STUDY

The traffic analysis used for this study employed the Gravity Model technique developed by Voorhees (2). The gravity model derives its name from the fact that vehicle trips are distributed by a formula which closely resembles Newton's formula for the law of gravity. Newton's law states that objects attract each other in proportion to the mass of the objects and inversely as the square of the distance between them. Similarly, the gravity model distributes vehicle trips in proportion to the drawing power of an area which represents the mass, and inversely as some power of the distance between the areas. The distance is usually expressed in terms of travel time rather than in miles.

The actual formula can be expressed as:

$$\text{Trips}_{AB} = \text{Trip Production}_A \times \frac{\text{Trip Attraction}_B \times \text{Travel Time Factor}_{AB}}{\sum_A^n (\text{Trip Attraction} \times \text{Travel Time Factor})}$$

The traffic model being used by Connecticut is a four-purpose model; that is, separate distributions are made for each of the four trip purposes, these being: work, social, commercial, and non-home-based trips. Separate land-use information is required for each trip purpose, and for both trip production and trip attraction for each zone as described in the following.

Work Trips

Work trip production is based on the labor force which, in turn, is related to the population of the zone. For the distribution of work trips a measure of attraction for each zone must be developed. This measure can be any one of a number of factors: employment, floor area, gross sales, etc. Total employment was used, inasmuch as employment figures were readily available. The factors used for the distribution of work trips then, are: labor force (which is derived from population) and total employment, each on a zone-by-zone basis.

Social Trips

Social trips are defined as those trips made for the purpose of visiting friends. They are trips between residential zones and are therefore attracted by people. The trip production for social trips is based on car ownership which is directly related to population. Hence, the information required from the land-use analysis for the distribution of social trips is population and car ownership.

Commercial Trips

Commercial trips are those trips which are made between the home and an area of commercial land use. The attraction factor for commercial trips must be some measure of the intensity of commercial activity of the zone. Retail trade employment was used for this measure. As with social trips, the trip production factor for commercial trips is car ownership, so the only new information required of the land-use analysis for the distribution of commercial trips is retail trade employment.

Non-Home-Based Trips

Non-home-based trips are defined as trips which have neither origin nor destination at the home. They are composed of housewives shopping from store to store and salesmen or doctors traveling between calls, as examples. It is seen that some of these trips are related to commercial areas as with the housewife and, in part, the salesman. However, some salesmen's trips are to industrial areas and some are to residential areas. Doctors and home delivery trucks on non-home-based trips are related to residential areas. To account for these diverse trip types an index including population, total employment and retail employment was developed for their distribution. Note that no new information is required for this distribution.

In summary, the information to be derived from the land-use analysis is the location of: (a) labor force, (b) total employment, (c) car ownership, (d) retail trade employment, and (e) population. These factors and their function in the gravity model are given in Table 1.

TABLE 1

TRIP PRODUCTION AND ATTRACTION FACTORS

	Factors Related to:	
Trip Type	Trip Production	Trip Attraction
Work	Labor force	Total employment
Social	Car ownership	Population
Commercial	Car ownership	Retail employment
	Retail employment	Retail employment
Non-home-based	Total employment	Total employment
	Population	Population

This information will supply the trip production and trip attraction information; in fact, all the data necessary for the gravity model formula except the travel time factors. A brief discussion of the use and derivation of the travel time factors follows.

Travel Time Factors

Travel time factors are used to measure the resistance of motorists to travel time. For example, if travel time were of no significance, there would be as much likelihood of a resident of Hartford working in Boston as in Hartford, and the travel time factor would then be "one" for all trips. Realistically, it is known that people attempt to minimize travel time by living near their jobs and shopping near home. What needs to be known is the distribution of travel times between people, in general, and their places of employment and shopping.

It can be recalled from the formula that the travel time factor, as used in the gravity model, is the value comparable to the inverse square relationship in Newton's formula. If these two formulae were exactly comparable, there would be no need for travel time factors and the square of the travel time could simply be placed in the denominator of the equation. This, for many years, was the approach used but with little success.

Actually, the exponent of the travel time is not two; further, it is not the same for all trip purposes, and in fact, may not even be a constant exponent. For this reason it has been necessary to develop a factor for each interval of time for each trip purpose.

Travel time factors can be developed in several ways. The traditional method, and perhaps the most straightforward way of developing travel time factors, is to conduct a small home-interview survey designed for this purpose. This was one method used for checking the Hartford Area Traffic Study. Actually, however, it has been found that travel time factors are so nearly similar nationwide that very little error would be introduced by the use of standard curves. This suggests another way of checking—using standard curves to make the gravity model computations and then checking the trip length distribution thus obtained against known values from, for example, a roadside interview origin-destination survey. By grouping inter-zonal movements by travel times and comparing the volumes produced by the model with those shown by the roadside survey, a ratio of actual to theoretical values can be developed. A plot of this ratio versus the travel time will readily show any significant bias.

Figure 1 shows a plot of the travel time factors which were used; one curve for each of the four trip purposes. From these curves it can be seen that the average trip length varies by trip purpose, and even that the trip length distribution is different. Although these curves do not necessarily represent trip length distribution, they do give an indication. For example, the shortest trip type is the non-home-based trips, with commercial trips a close second. The longest trips are work and social trips, but even these are rarely as long as 50 min, with the vast majority less than 20 min. Note also the steepness of the curves for all trip types, accentuating the low values of travel time. This indicates the tendency for very short trips, and the attempt on the part of the motorist to minimize travel time. Although these curves do not consider terminal time at either end of the trip, there is some indication that they could be made more flexible by adding terminal time.

The gravity model method has been well covered in recent publications; the AIP Journal (3), the Civil Engineering Journal (4), as well as the various reports published by the municipalities which have used this method. Of course each time the method is used, the researchers add to and/or refine the method. It is this latest refinement, the land-use analysis, which is the primary purpose of this paper.

LAND-USE ANALYSIS

The basic determinant for the generation and distribution of traffic is the land use and intensity of land use of the area. Therefore any studies of traffic must, of necessity, begin with a study of land use. Furthermore, it is the projection of future land use which will determine the future traffic characteristics. In the Hartford Area Traffic Study a method of land-use analysis was developed which attempts to recognize the many diverse factors which influence metropolitan growth. Once these factors are known, objective analysis of them will produce much more reliable predictions of future travel.

The study of land use was based on analyses of past growth patterns for the period between 1947 and 1958. On the basis of these growth patterns, hypotheses were made of the factors influencing the trends and then these hypotheses were tested to check their validity and reliability, and to determine weights to reflect the relative magnitude of each variable. In this way the relative importance of the many factors involved was checked, and for the projection into the future, these weights were varied as necessary to adjust for changing trends.

The first task in studying land use was to determine which land-use categories would be included in the analysis; that is, which land uses should be studied separately. In order that a workable procedure be developed, it was necessary to keep the categories to a minimum, and to group the various factors by similar characteristics. At the outset, therefore, it was determined that population would be handled as a single factor. Employment, on the other hand, can be divided into any number of types depending on the particular characteristics involved. To determine just how many categories were required, a pilot study was made by the City of Hartford within the three major employment towns: Hartford, East Hartford and West Hartford. From this study it was recognized that at least three types of employment must be studied separately: manufacturing, retail, and service; the last category actually to include all types not covered by the first two. This seems to be a very realistic breakdown in that each of the three groups does include factors distinct from the others.

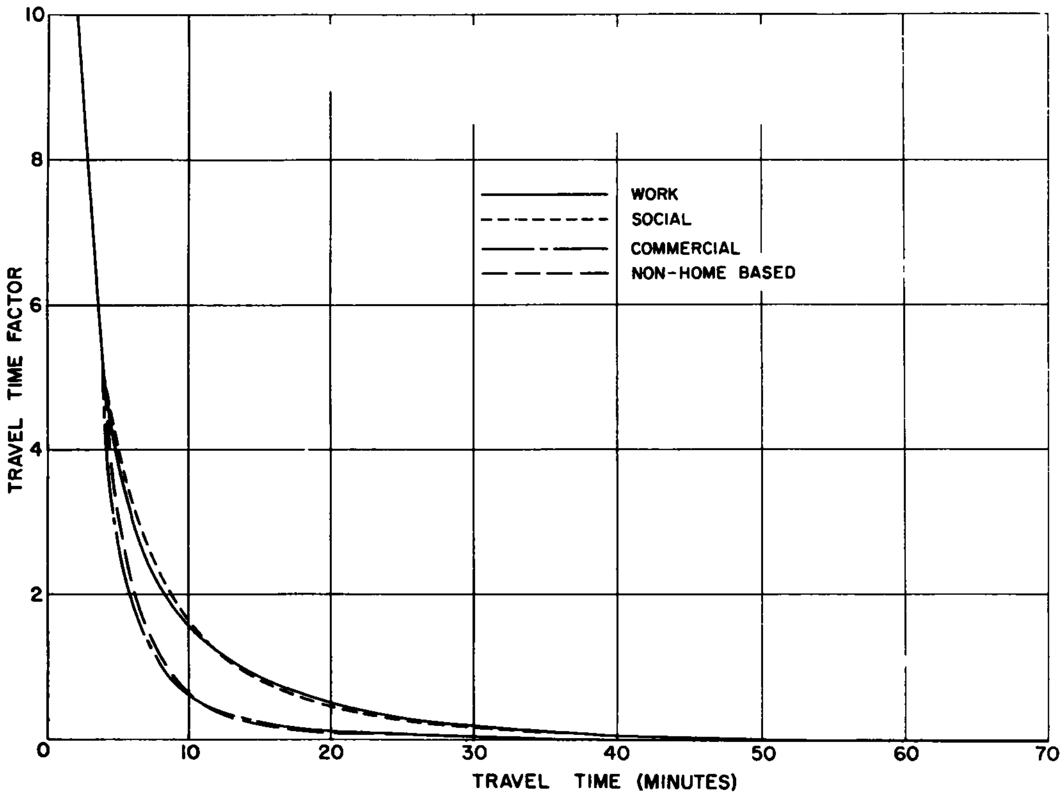

Figure 1. Travel time factors, Hartford Area Traffic Study.

For example, manufacturing employment (industry) may be dependent on rail service, whereas service employment (office buildings, principally) is relatively independent of it.

Generally, manufacturing employment will include blue-collar workers whereas service employment will include the white-collar workers, employees of insurance companies, utility companies, government agencies, etc. Retail employment must, of course, be studied separately because this is one of the categories used in the distribution of trips.

The final breakdown of land-use factors for the study was then: (a) manufacturing employment, (b) service employment, (c) retail trade employment, (d) population, and, as a by-product (e) car ownership. This breakdown seemed to work well in the Hartford area; however, some other city may require a more (or less) detailed breakdown, or perhaps different category divisions. It is expected that a larger city would require more categories.

Each of these five separate categories, which indicate land-use activity, was studied separately. The following is a discussion of the procedures used and the information derived from this study as well as the methods developed for predicting the future distribution of land use activities.

Manufacturing Employment

Study of the factors related to the distribution of new manufacturing employment began with a series of multiple correlation analyses in an attempt to determine precisely what variables affect this growth. For these analyses a number of variables were correlated with the known past growth in new manufacturing employment. Ultimately nine variables were used, these being:

Highway Accessibility to the Labor Force (1).—This is measured by the equation:

$$A_1 = \frac{P_1}{T^x_{1-1}} + \frac{P_2}{T^x_{1-2}} + \ldots + \frac{P_n}{T^x_{1-n}}$$

in which

A = accessibility index of a zone to population;
P = zone population at beginning of projection period; and
T = travel time between employment zone and residential zone as measured by the assumed highway network at end of projection period.

Availability of Industrial Land or "Holding Capacity".—This is the additional acreage in each zone which is available for industrial development.

Tax Rate.—Reduced to a common base.

Sewer Facilities.—Primarily a consideration of the capacity of the sewer system in the zone.

Rail Service.—A subjective rating based on the adequacy of service.

Water Facilities.—Related primarily to the capacity of the system in the zone.

Travel Time to Airports.—There is only one major airport in the area and this rating varied inversely with the travel time from the airport.

Promotion.—Primarily a measure of the town's activity in promoting industrial development.

Industrial Land Bordering Expressway.—This rating was obtained by giving a numerical weight of "one" to each acre of industrial land within ¼ mile of a freeway, a weight of ½ for acreage between ¼ and ½ mile, and a weight of ¼ for industrial land between ½ and 1 mile of a freeway. The expressway system at the end of the study period was used. This factor is not a measure of highway access but rather a measure of the importance of the advertising potential and prestige of being located near an expressway.

Some of the variables used in this analysis, such as sewer facilities, water facilities and promotion, must be based primarily on subjective judgment. However, most can be rated objectively by numerical analysis. All ratings were reduced to a scale varying from 1 to 50 before they were entered into the multiple correlation equation.

The coefficients developed from the multiple correlation for the three most successful analyses are shown in Figure 2. The shaded band represents the coefficient of each variable, this being the relative importance of the various factors. Shown next to each shaded band is a black band which represents the level of significance of each variable. A value of one or more (that is, above the horizontal black line) indicates a highly significant correlation; below the value of one indicates questionable significance.

The first analysis, shown at the top, considered only six variables; that is, highway access, availability of land, tax rate, sewer facilities, water facilities, and rail service. For the second analysis the factor for water facilities was deleted and airport accessibility and promotion were added. The third analysis considered all nine factors. The absolute magnitude of the weights for the various analyses differ; however, the relative size of the weights is nearly identical.

Perhaps the most significant finding from this analysis is that transportation is not the dominant or controlling factor in shaping cities. With the mobility provided by the automobile, industries have been freed of distance limitations in choice of location and are now able to give more attention to other factors.

From these data it is evident that of prime importance to the location of new industry are availability of land, and sewer facilities. Highway access, rail service and airport access are second in order of importance. Of relatively minor importance are tax rate, water facilities, industrial land bordering freeways, and promotion.

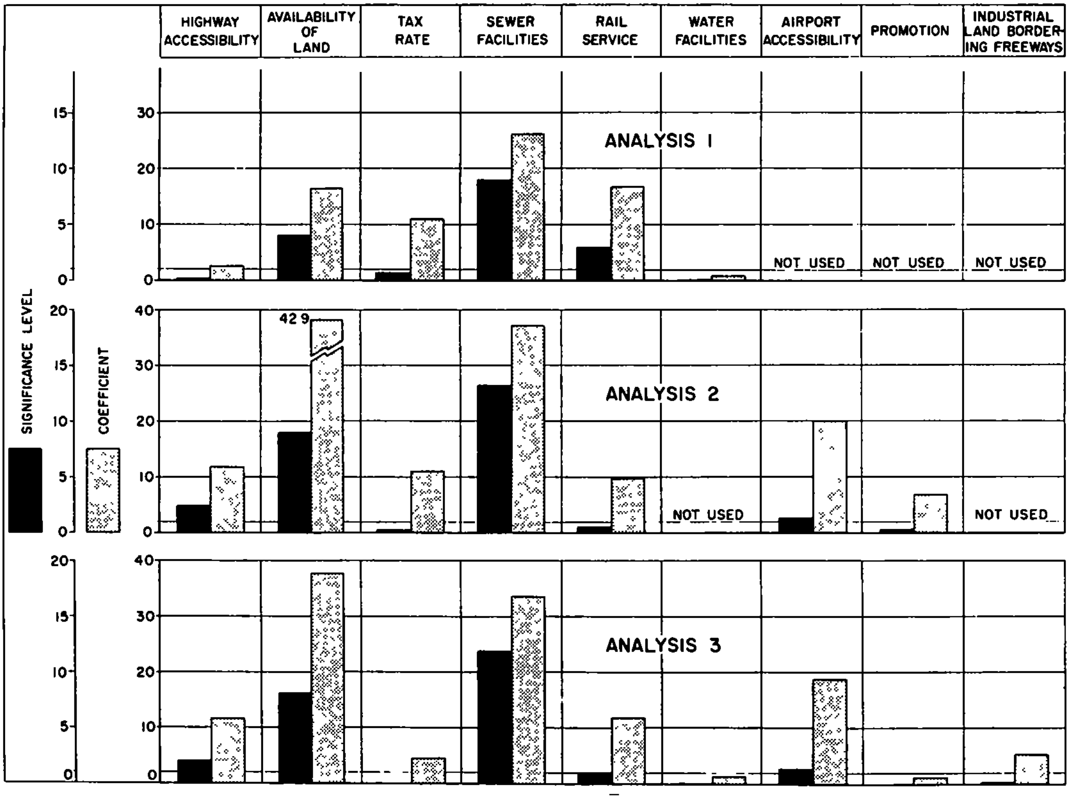

Figure 2. Multiple correlation analysis, Hartford Area Traffic Study.

From the formula developed through this analysis it is possible to calculate a growth index for each zone which, when compared to the sum of the growth indices for all zones, represents the percentage of total growth which can be expected in each zone. This formula is:

$$\text{Growth Index} = 12x_1 + 37x_2 + 5x_3 + 34x_4 + 12x_5 + 2x_6 + 19x_7 + 1x_8 + 5x_9 + 120.$$

in which the "x" values represent the magnitude of each of the 9 variables previously described and the coefficient of the "x" values is the relative importance of that variable, the height of the shaded bars in Figure 2.

The true test of an analysis such as this is how closely the formula thus derived can predict the actual growth of the area. To test this the actual known growth on a town-by-town basis was compared with the theoretical growth predicted by the formula. From this comparison it was found that in one more or less continuous corridor the actual growth was considerably higher than the theoretical growth predicted. Inasmuch as this particular corridor was the area where most of the industrial development was occurring, this higher than anticipated growth was attributed to a prestige factor for industrial development. To account for these differences a ratio of the actual to theoretical values was taken, these values were grouped by areas, and the resulting weights were used as adjustments in the formula for future predictions.

Actually, with further analysis, it is now believed that there may be a factor missing in the equation. This factor might be called a "self-generation factor" for manufacturing employment and could be related as a weight to the existing employment of the zone. The next step in the analysis of manufacturing employment must therefore be to study this in greater detail in an attempt to enter this factor in the multiple correlation analysis. This, it is believed, will be a significant addition to the equation.

Service Employment

Actually, relatively little is known about service employment except that it must be accessible to population for its labor supply and that, to a certain extent, it is related to commercial areas and tends to locate near them. Therefore, an index was developed which included both highway accessibility to population and a factor for holding this increase close to the retail areas. The highway accessibility index is the same as was used for the distribution of manufacturing employment in the preceding step. This index was multiplied by the retail trade employment for the preceding period and the product was used as a distribution factor for the distribution of the new service employment.

Retail Employment

For the study of retail trade employment the hypothesis was made that the future distribution was dependent solely on the distribution of the new increase in population. This was checked by projecting the increase from 1947 to 1955 on the basis of the hypothesis, and comparing the theoretical distribution thus obtained with the actual growth. The resulting comparison is plotted on a map of the study area (Fig. 3). It is seen that generally this is a good check; however, some of the towns in the core area have a disproportionate share of the increase, indicating that these may be developing into regional shopping areas.

Although this may be the case, as shown by this comparison, there is no past trend data to support this assumption—and in one case at least, all indications point the other way. Whereas it is recognized that there are some discrepancies in the assumption that retail trade employment follows population exactly, it is believed that this is as far as present knowledge can logically be expected to extend, and for the future prediction no adjustment was made.

An attempt was made to carry through this study the basic theme of using as few arbitrary correction factors as possible. It would be possible to account for all discrepancies noted in the past trend analysis simply by applying correction factors to the theoretical values. However, although such a procedure would result in good checks for past trends, each factor would have to be evaluated to determine if it would remain constant for the period of future projection, or whether, in reality the dis-

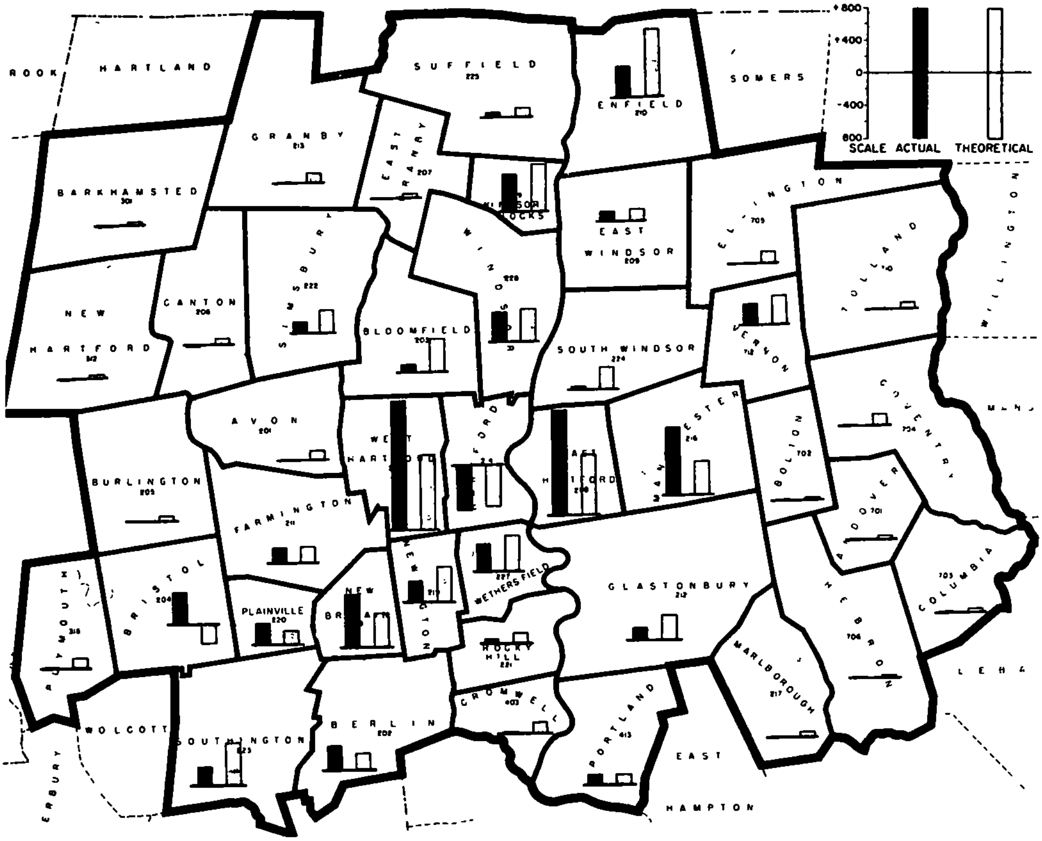

Figure 3. Retail employment change, 1947-1955, by towns—Hartford Area Traffic Study.

crepancy is not simply the result of an isolated change such as the opening of a new shopping center. For this reason no factors were used to account for small localized differences unless there was a very definite trend, and one which appeared to be stable and long term.

Similarly, no attempt was made to predict the location of new shopping areas as it was felt that realistically this was little more than a guess, and that the procedure used would result in a smaller error of estimate.

Population

As a first approximation in developing a rational method of distributing population growth it was hypothesized that the new population would distribute itself in accordance with highway accessibility to employment at the end of the study period and the "holding capacity" of the zone. In a manner similar to that used for manufacturing employment, predictions of the population growth were made for each town on the basis of accessibility and holding capacity only, and this theoretical value was then compared with the actual known growth. These values, for each town, are plotted on a map of the study area (Fig. 4). It is seen that there is considerable variation between these actual and theoretical values.

In an attempt to determine the unknown factors causing these differences, the aid of the residential developers in the area was sought. Questionnaires were mailed to all developers in the area with a request to rate any or all of the towns with which they were familiar. An over-all rating from one to five was requested for each town and in addition, the questionnaires requested that unfavorable conditions be noted. These returns, together with the researchers' knowledge of the area, formed a basis for explaining the variations noted on the map.

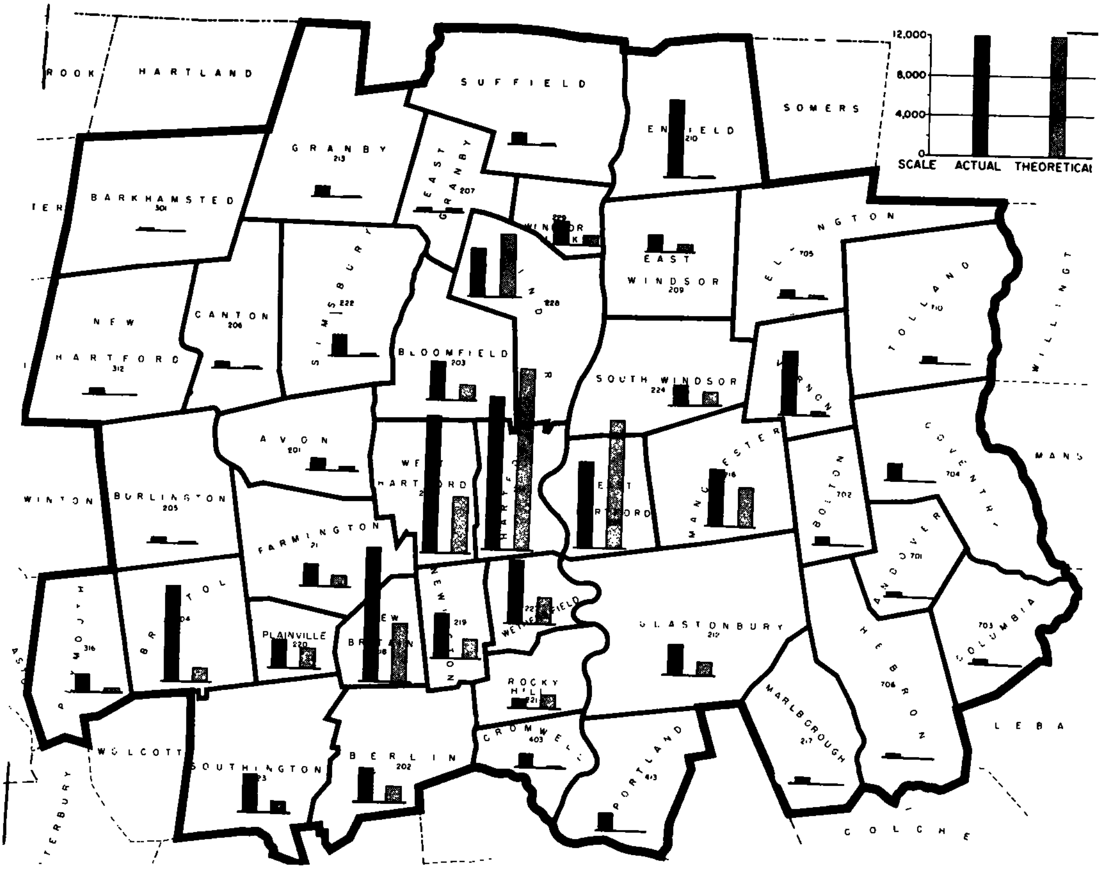

Figure 4. Population change, 1950-1958, by towns—Hartford Area Traffic Study.

For example, it was found that poor sewer and/or water facilities, or prohibitively costly installation, reduced the potential growth of a town by 50 percent. Unreasonable lot size, or house size controls, each resulted in a growth of only 75 percent of that which would have occurred under more reasonable conditions. Land shortage, or high land cost, reduced growth to 75 percent of that which might have occurred. Likewise, lack of large development tracts—that is, divided ownership—reduced growth by a factor of 0.75. In two towns it was noted that large land areas were being held for speculative purposes in the hope that prices would increase. This seemed to reduce growth to only 50 percent of that which would have normally occurred. On the plus side, the factors increasing growth appeared to be (a) lax building codes which triple growth, (b) picturesque home sites which double growth, and (c) prestige which may double or triple the rate of growth depending on the strength of this factor.

By studying the area on a town-by-town basis and applying these weights it was possible to account for most of the disparity between the actual and theoretical values to produce the comparison shown in Figure 5. This was the extent of the investigation as this provided a very close check. For projection into the future, these weights were investigated in an attempt to predict which could change, and more importantly, which were likely to change, with time. Perhaps the most important of the changing weights is prestige. Over a period of time it was observed that the prestige areas for residential development do change, generally moving toward the west as the suburban sprawl continues.

Figure 5. Population change, 1950-1958, by towns—Hartford Area Traffic Study.

Car Ownership

Although car ownership is not a land-use category, it is nevertheless a measure of land-use activity, and inasmuch as it is such an important part of the analysis, the study of these changing patterns is included here. Car ownership increases as a result of two factors: (a) more cars in the future due to a greater population, and (b) a higher rate of car ownership.

For the last 10 years or so, real income has been increasing at a rather constant rate of about 2 percent per year, nationally. This increase in buying power has enabled more families to own cars, and has also resulted in more two-car families. Of course, the car ownership rate will not continue to rise indefinitely; in fact, investigations in Beverly Hills and Washington, D.C., have shown that there appears to be a very definite ceiling on car ownership, above which it will not rise. This ceiling is different for various residential density classes. Figure 6 indicates the interrelationship between these factors for four densities of residential development. This chart shows that the rate of car ownership increases up to an income level of $8,000 to $10,000 per year, at which point it levels off at 0.6 cars per person for estate areas, 0.5 for suburban areas, 0.4 for two family residential development, and as low as 0.3 cars per person for apartment house developments. These ceilings check very well with the actual rates now noted for the high income level areas around Hartford for the corresponding density classes. In accordance with these curves, it is assumed that the car ownership rate for the present population will increase at a rate of three percent per year up to the ceiling car ownership rate for the particular density class.

The increase in the number of cars due to increases in population was handled simply by adding the new population to the zone at the maximum car ownership rate for that particular zone.

These assumptions on car ownership were checked by making a projection from 1950 to 1958 and comparing the projected estimates with the known growth. The theoretical and actual increases are plotted side by side on a map of the study area (Fig. 7). This is without doubt the best correlation made for the entire study, and it was felt that, at this stage, the technique could not be improved.

Land-Use Forecasting Technique

The way in which the various pieces of the land-use puzzle fit together into a whole for purposes of projection is an important part of the analysis. During

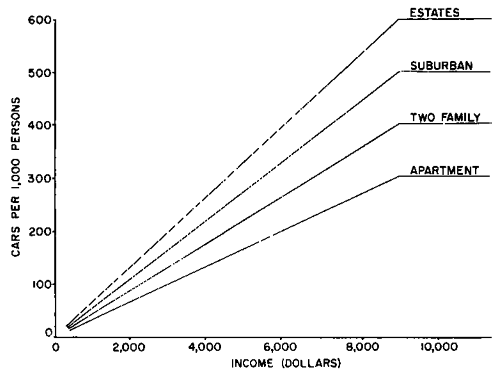

Figure 6. Car ownership ceiling for different residential density patterns. (Source Alan M. Voorhees, paper presented at Nice, France, September 1960.)

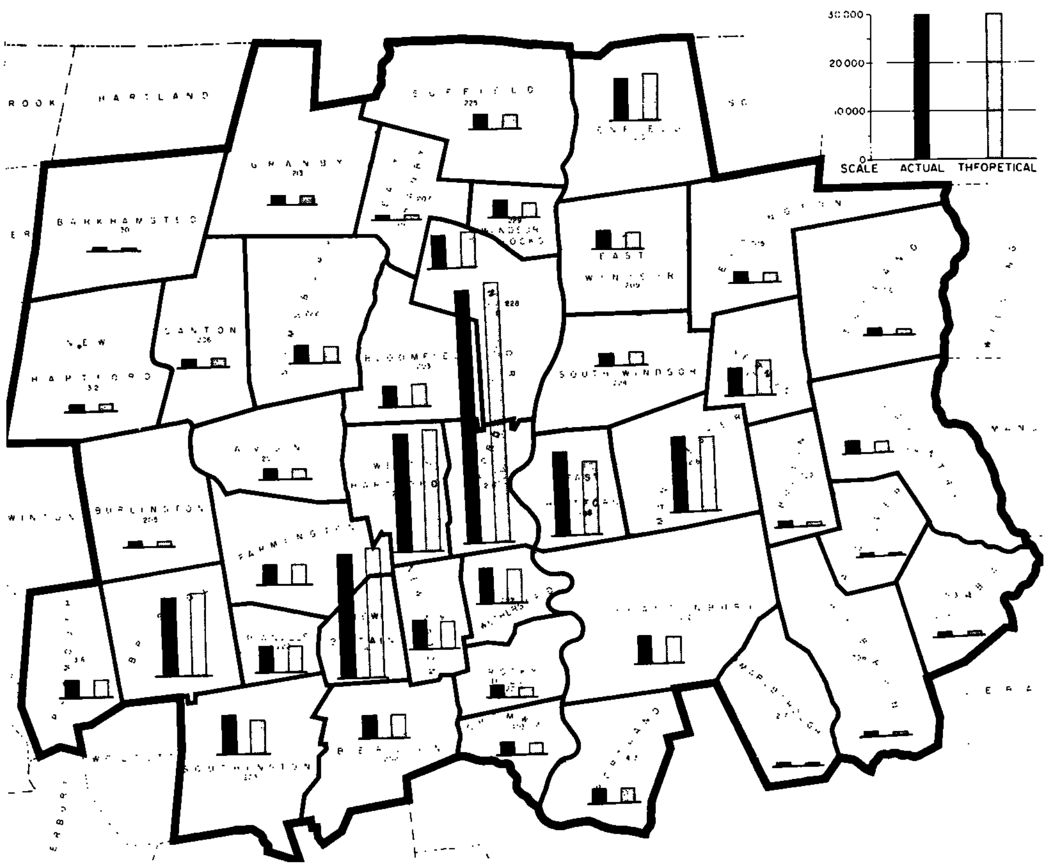

Figure 7. Car ownership change, 1950-1958, by towns—Hartford Area Traffic Study.

the course of the study it was found that some of the categories of land use were more "alert" to the influences of future change than others. By treating each category in the order of its "alertness", a very logical chain reaction of development resulted.

Increases in new employment—that is, the location of plants and offices—are the most alert to future changes which will affect their business interests. For this reason the increases in manufacturing and service employment were distributed first, and the factors determining these distributions were related to the future year. For example, the travel times reflected the assumed highway system for the target years.

After the new employment was "located" the population was distributed in relationship to it. The highway accessibility index for this distribution reflected the relationship of highways and employment in the target year.

Finally, the increase in retail employment was distributed in accordance with the increase in population just determined. Car ownership, of course, is also related to the new population distribution.

Briefly, then, the increases in employment were distributed first, it being assumed that this category was most alert to change. Second, because people choose their places of residence in relationship to their places of employment, the increase in population was distributed in this manner. Finally, the increase in retail employment, which follows population, was distributed last.

PROJECTION PROCEDURE

It is becoming apparent to the researchers close to the field of traffic forecasting that to obtain realistic estimates of future traffic, the feedback effect of changes in the highway network on the future land-use distribution must be considered. To accomplish this it is necessary to build the city up in steps over time. For example, instead of projecting from 1960 as a base year directly to the design year, 25 years or so hence, it is necessary to consider intermediate points and make projections in perhaps 5-yr intervals. The Hartford Area Traffic Study considered the years 1965, 1975, 1990 and the "horizon year", which in the Hartford area is about the year 2010. In this way the procedure was able to recognize the effect of the changes occurring throughout the period, such as the radically expanding highway system, which influences the future distribution of land use.

Such a procedure requires working through the entire projection process from beginning to end for each projection period and would result in a time-consuming, expensive operation unless a systematic, efficient flow of data from one process to the next were obtained. One advantage of the system developed for the Hartford Area Traffic Study is the complete interrelationship between the land-use and the traffic analyses. Figure 8 shows the flow of data through the process.

This diagram shows the continuous, orderly flow of land use and travel-time information toward the gravity model where the inter-zonal trips are calculated and thence into the traffic assignment. It is seen that in virtually every phase of the analysis, including the land use, travel-time information is required. The key to the process then is the tree building program, used to develop the inter-zonal travel times and trip traces, which is used over and over again, first in the land-use analysis for calculating the accessibility indices, again in the gravity model for calculating the distribution of trips, and finally in the assignment program for cumulating the link volumes. The feedback, previously

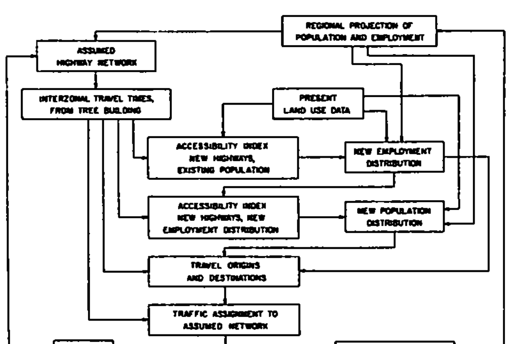

Figure 8. Flow diagram for Hartford Area Traffic Study.

mentioned, is readily apparent from Figure 8 also, for it is obvious that a major change in the highway network, such as the addition of a new expressway route, will have a profound effect on the entire process.

CONCLUSION

These investigations have shown that the traffic portion of the analysis—that is, the gravity model—is very reliable and given accurate land-use information will accurately predict the future distribution of trips. The land-use analysis, on the other hand, is probably the weakest link in the entire projection process. For this reason the major portion of the investigation for the Hartford Area Traffic Study was centered about the study of land use in an attempt to supply the most reliable information possible to the gravity model.

Although the work to date is a first step toward complete understanding, nevertheless, through this analysis many of the complex and diverse variables which affect the growth of metropolitan areas have been quantified. It is believed that the method is a vast improvement over previous methods, a step in the right direction which, with further work and study, can ultimately predict the future distribution of people and jobs with the same certainty with which population growth is now predicted.

In conclusion, the important part of the Hartford Area Traffic Study is the method of land-use analysis and the basic information learned from this analysis. Through this analysis the growth of a metropolitan area has been simulated mathematically, and it has been shown that cities grow as a result of rational decisions made by individuals which, when grouped together as a whole, are predictable. This study has afforded a great deal of insight into the future growth patterns and has, it is believed, pointed the way for future analysis. It is hoped that the work to date will form a base for additional research in this field which will be even more productive.

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Traffic Interactance Between Cities

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The majority of research work in traffic-demand evaluation and projection in the United States naturally and properly has been based on a given large city or a single metropolitan complex. The unique feature of the study covered by this paper is that it evaluates the traffic "interactance" or exchange between five independent cities and towns, remote from each other, but in the same vicinity.

A group of independent cities in the central Piedmont section of North Carolina are expanding and growing toward each other, tending to form a metropolitan complex. Their mutual economic and sociological affinity is great and is increasing. These cities are Greensboro, Winston-Salem, High Point, Thomasville and Lexington, varying in population from 125,000 down to 16,500 (est. 1958). Their nature is primarily industrial and distribution. Combined, they seem to be forming a new interrelated but multi-centered community.

In cooperation with the Urban Studies Program (Institute of Research, University of North Carolina), an area origin-destination study was made to reveal the traffic "interactance" between these cities. A reliable expression of the gravity model was developed involving only population and distance, and this formula was applied to all city pairs in the state for long-range traffic estimation purposes. Coordinate studies by the USP include other aspects, including land use, urban development, economic, governmental, and sociological trends and relationships.

● THE traffic study was accomplished by means of a special type of origin-destination traffic survey and analysis. Some 35 roadside interview stations were selected to intercept all movements into, out of, and between the five cities (at the 35 stations). Station locations were purposely chosen at expected "traffic valley" points between the centers, to avoid the mass of short "commuter" trips, these not being of interest in the stated purpose of the study. A total of 118,603 roadside interviews were made, this being a 98 percent sample.

Special techniques were required in the analysis to avoid duplication of trip data brought about by interviews of equivalent trips at different points on different interview dates. These exhaustive and intricate adjustments removed the equivalent of about one-third of the total trips, and reduced the adjusted net trip summary to 98,277 total daily trips.

Although the five cities varied widely in size, with populations of 16,500 up to 125,000, there was a very close relationship in their traffic interchange in proportion to combined population and in inverse relation to distance. This fact is developed more fully in subsequent discussions.

Perhaps the major result of the traffic study was the development of an expression of the "gravity" formula indicating the values for traffic interaction between city pairs in terms of population and distance. The report on the Origin-Destination Traffic

Survey at Five-City Crescent Area (N.C. State Highway Commission and U.S. Bureau of Public Roads, November 1959) discussed both the strength and the weakness of such a formula approach.

After much trial and mathematical exploration, Eq. 1 was derived as the best expression to fit the basic data, this being a quadratic type of equation:

$$T = 0.04m^2 + 4.9m + 160 \tag{1}$$

in which

T = number of 24-hr (September-October 1958) weekday trips starting in City A and ending in City B, plus vice-versa; excluding any partial or through trips; and

m = square root of the product of the population of City A and City B, divided by the square of the travel distance between chosen centroids in Cities A and B. To clarify:

$$m = \frac{\sqrt{\text{pop. A} \times \text{pop. B}}}{(\text{distance A to B})^2} \tag{2}$$

Eq. 2 has been developed and used for many years and is commonly referred to as an expression of the "gravity model." It was discussed and used by Willa Mylroie in HRB Bulletin 119, and in "Highway Traffic Estimation," by Schmidt and Campbell, published by the Eno Foundation for Traffic Control, 1956. For a given situation, the value "m" in Eq. 2 becomes a constant for "T" in Eq. 1.

Eq. 1 represents a quadratic adaptation of this relationship to more nearly fit the refined intercity data from the Five-City Crescent Origin-Destination Traffic Survey. It is likely that other adaptations might fit other conditions in other localities equally well.

Having been derived as the relationship giving the best "fit" to the O-D data for the optimum number of city pairs, Eq. 1 was applied first to these pairs, with results given in Table 1.

TABLE 1

City Pairs	No. Trips O-D Data	No. Trips Formula	Difference
Greensboro - Winston-Salem	3,037	2,825	-212
Greensboro - High Point	5,257	5,317	60
Greensboro - Thomasville	659	710	51
Greensboro - Lexington	401	390	-11
Winston-Salem - High Point	2,040	2,375	335
Winston-Salem - Thomasville	751	998	247
Winston-Salem - Lexington	1,293	1,142	-151
High Point - Thomasville	6,138	6,676	538
High Point - Lexington	830	912	82
Thomasville - Lexington	1,316	1,253	-63
Totals	21,722	22,598	
Totals of differences, arithmetic	1,750		
Gross arithmetic differences	8.1%		
Total of differences, algebraic	876		
Gross algebraic difference	4.0%		
Average of individual percentage errors	10.2%		

It will be observed that one of the largest percentage differences is for the Winston-Salem - High Point combination, with 335 fewer actual O-D trips than the formula would indicate. These cities are in different counties. High Point's "traditional" affiliation has been with Greensboro, its county seat and main line neighbor, rather than Winston-Salem which is farther away, and largely self-contained. Winston-Salem's major working force is in the manufacturing of cigarettes and other tobacco products for world-wide distribution. High Point's major industry is the manufacture of furniture. It may be that the difference in skills and material serves to further depress the traffic interaction which would otherwise be expected. This theory is supported also in the Winston-Salem - Thomasville pair. Similar reasoning might be applied to other variations.

It was found that the quadratic form of expression was advisable, as contrasted with the linear, to damp or minimize the effect of these variations.

FURTHER TESTS OF FORMULA

Following this test of the formula, and desiring further verification, Eq. 1 was applied to data on trips between the five cities and more remote counties outside the five-city area. These included comparisons with trip data having termini in Wake, Alamance, Durham, Rowan, Mecklenburg, and Iredell Counties. Each of these counties contains a sizable city near its center, with the city dominating the traffic pattern for the whole county, and representing an acceptable centroid for the purpose of population and distance determination. It was found that the formula provided equally satisfactory results when compared with trips having one terminus in the five cities and the other terminus in these counties as listed above. This further verified the value of the formula as a tool for prediction of traffic interaction.

The formula was put to still a third test. Data obtained from the 1959 Concord, N.C., Origin and Destination Traffic Study, involving trips between many North Carolina cities and counties were compared with the interaction indicated by the formula. In cases where there were as many as about 175 trips between places, the formula provided values with differences of less than 20 percent as compared to origin-destination values. The accuracy was best where the distances between points being compared were less than about 50 miles. With distances of over 100 miles, the formula could not be compared, due to the small number of long trips. Population data for 1959 was of necessity estimated, but seems to be reliable, based on 1960 census data since obtained.

In general, the tests on the formula showed that the level of confidence in its use is better than 80 percent for any pair of cities in North Carolina which are reasonably near each other, under normal seasonal conditions. This relationship may hold in other states.

There is some indication that the existence of a sizable third town C, between two major towns A and B, may decrease the amount of interaction between A and B below the value which would be indicated by the formula.

Limits

It should again be emphasized that the formula is not intended to develop total traffic to be counted or expected at any point, unless it is applied in increments to all overlapping pairs of trip loci which may be involved.

Adaptation of Formula

The significance of the survey lies mainly in the possible use of the formula in trip prediction for long-range planning for highway expressway and arterial street design. If land-use predictions may be made in terms of future residences, work sites, shopping centers, etc., even in rural areas involving clusters of independent cities and towns, the formula or some form of it, could be used with reasonable confidence in forecasting the traffic interaction demand between such areas and between cells within these areas.

Such an adaptation has been made for statewide long-range highway planning in North Carolina. Using a digital computer to handle the enormous bulk of the arithmetic involved in applying the formula, together with manual adjustments and adaptations of the formula values for every pair of places in and near the state, traffic volume projections to 1980 were obtained on every corridor-segment of the entire state highway system.

Using this and other data, internal state systems have been developed in terms of relative importance as a guide in the establishment of design standards and construction programming for the next 15 years. A complete statewide needs study to the year 1975, based on these data, has recently been published and adopted by the North Carolina State Highway Commission.

Other corollary reports, including much of the traffic data developed in this study, are to be published by the Urban Studies Program relating to land use, and to economic and sociological interaction in a metropolitan complex believed now in process of formation.

Forecasting Transit Use

ARTHUR SCHWARTZ, Pittsburgh Area Transportation Study

This paper presents a discussion of some of the procedures available for forecasting transit use. In particular, it first demonstrates that transit trips are not a single category within the universe of person trips, but are, in fact, several distinct subcategories. It then breaks down a group of variables into three types. Major variables, namely automobile ownership and net residential density, are those characteristics of the environment in which trips are made, that most strongly affect transit use. Supplemental variables are those characteristics of the environment which have a less strong effect on transit use. Finally, transit service itself is considered as a variable which has an effect on transit use.

Then, the application of the results of this investigation to the forecasting of transit use in the Pittsburgh area is described, along with the results of this forecast.

● IN forecasting future travel in the Pittsburgh Area Transportation Study area, it is necessary to divide the previously derived total person trips by mode of travel. Three generalized mode groups have been used: automobile driver; automobile, truck and taxi passenger; and transit passenger. The forecasting of the amount of travel by this last mode group (transit passenger) is the subject of this paper. Transit trips are defined as those made on public carriers of persons, locally within the study area. This includes trips by bus (both commercial and school), streetcar, suburban railroad, and inclined plane. Travel on inter-city bus and railroad operations is excluded, as are all types of air travel.

Transit trips, it is thus assumed, have distinctive properties that set them apart from the population of all trips. The identification of these properties and their use in forecasting are the subjects of this paper. At first glance, the population of transit trips appears to resemble the total trip population, except that it is smaller; but several structuring elements soon become apparent (Fig. 1). The inner areas receive a higher proportion of transit destinations than do the outer areas. The CBD is a much more dominant feature of the distribution of transit trips. Certain areas that do not immediately appear to have any particular identifying characteristics have unaccountably large numbers of transit trips. On closer examination, these are found to contain large schools.

It thus appears that a high degree of concentration of activity on land is the principal organizing factor in the distribution of transit trips. However, certain types of transit trips, namely school trips, have a pattern of concentration different from that of the population of all trips. Therefore it was decided that school trips would be treated separately from the remainder of transit trips. The exceptionally high number of transit trips to or from the CBD also appears to require further examination. This fact is made even more obvious when it is known that 51.4 percent of all reported trips to the CBD are by transit, whereas only 15.2 percent of all other reported trips are by transit. The CBD has more than twice the proportion of all of its trips by transit as does the next innermost ring (ring 1 with 23.3 percent of person trip

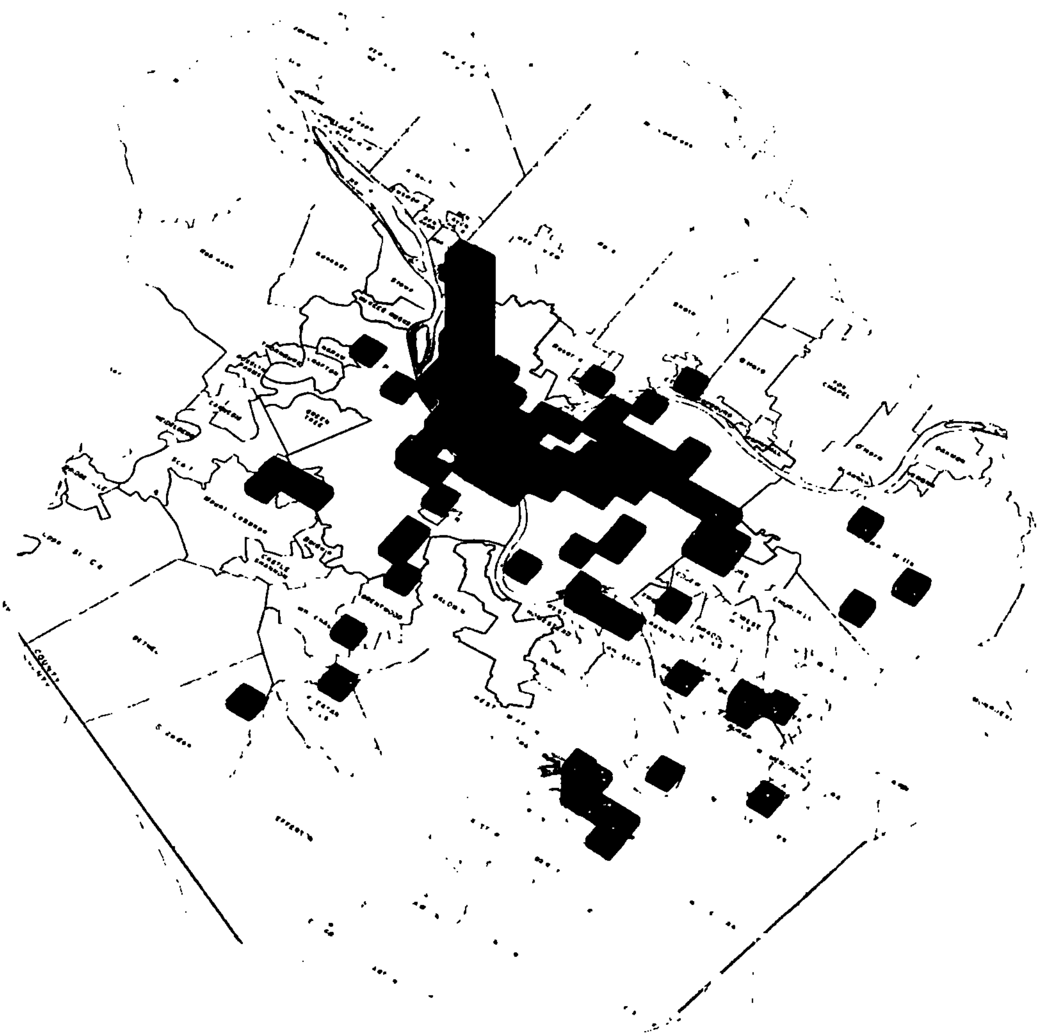

Figure 1. Model depicting mass transit trip destinations, by $\frac{1}{4}$-sq mi grid.

destinations by transit). Therefore it was decided to treat transit trips to the CBD separately. Also, it is possible that other breakdowns of transit trips would be usable. For example, 66 percent of all transit trips except school trips are to or from work, whereas 43 percent of all internal trips (by all modes, but excluding school trips) are to or from work. This suggests another possible specialization that could be used as a breakdown. However, detailed subdivision by land use, trip purpose, special areas, population characteristics and many other possible characteristics is limited by the need to maintain adequate sample size so that the detailed subdivision will produce meaningful results. For example, figures for school trips by two-car households in ring 1 would be based on a sample of only five trips (unexpanded).

With the principle of subdivision of transit trips decided on, the variables to be examined had to be determined. From preliminary examination of Pittsburgh Area Transportation Study (PATS) travel survey information it was felt that the various expressions of automobile ownership and residential density were the most significant independent variables available for forecasting transit. Automobile ownership was chosen as an important variable because it is the best measure of the availability of a usually preferred alternate mode of travel. Availability of an automobile normally implies its use. A non-auto-owning household is dependent on transit for all trips except when travel times and destinations happen to coincide with those of an automobile driver among friends or relatives. Given the usual household and automobile sizes, transportation capacity is available for all members of an automobile-owning household. The use of this capacity is again dependent on the coincidence of time and destination of trips. The ownership of more than one car simply increases the probability of automobile transportation being available to any member of the household at a given time.

Net residential density is the most valuable measure of concentration of persons on land. Although it does not measure concentrations of persons in an area directly (something that would be almost impossible to do, because this would be constantly changing) it measures the concentration of persons at the place where they can perhaps best be enumerated, their place of residence. Not only is residential density valuable as a measure of the intensity of residential activity, it is a very good index of the over-all intensity of land development, which is even more important in influencing mode choice.

However, several other variables were felt to be worthy of examination. These include measures of the characteristics of the trip maker, the trip, and the service provided. Although the concentration of persons, and the availability of alternate forms of travel are most important in mode choice, these "minor" variables act to modify the effects of the major variables, and to account for residual variation after the effects of the major variables have been determined.

SUBDIVISION OF TRANSIT TRIPS

The first step in the preparation of a transit use forecast was to divide transit trips into three categories—CBD trips, school trips, and the remaining transit travel or other trips. Aside from the fact that each category of trips constitutes about one-third of the total number of transit trips, they have many distinctive properties.

School trips (trips made to or from trip purpose "school"), for example, are largely noncompetitive with the automobile. For instance, 64.1 percent of school trips are made by transit, 27.5 percent as auto passengers, and only 8.4 percent are made by auto drivers. Because most school trips are made by children under the age at which a drivers' license is obtainable, it is unlikely that many of these trips will be convertible to automobile driver trips. In addition, school trips are usually everday occurrences, characterized by extreme specialization in time and definite geographical concentrations. These occur both at the school end and within the system of school districts with limited areas, and are the most favorable to transit operations.

CBD trips (all trips to or from the CBD plus intra-CBD trips) characterize a situation in which transit is competitive with the automobile. The high trip density (302,875 trip ends reported in 1958 on an area of 472 acres) makes possible volumes of travel to this area sufficient to support transit service from most parts of the study area that have urban residential density characteristics. This high travel volume concentrated over a small area, plus a definite peaking effect in time, make automobile travel on the approaches to the CBD generally less convenient than it is in most portions of the study area. High volumes converging on a limited area result in congestion, and high land values tend to put a limit on the amount of parking space, as well as increasing the cost of providing such space. Despite these difficulties, 43.5 percent of internal trips to or from the CBD are by automobile and only 56.5 percent are by transit, as contrasted with Chicago's 70.9 percent.

Unfortunately, it is nearly impossible to examine adequately the influence of area size and over-all density, and the density and size of the CBD, in determining the modal split of CBD trips in a report based only on information from a study of one metropolitan area.

The remaining transit use is largely of a noncompetitive nature. Except for a few concentrations of commercial and manufacturing activity, transit service to the remainder of the study area is provided incidental to service to the CBD. Trip densities are usually low and trip patterns show relatively little concentration in time or space. This pattern of travel favors the automobile. Low trip densities make relatively uncongested movement possible. Parking can be provided easily, as land costs are low. Transit travel, except between points on the same CBD radial or to a few secondary concentrations, requires the use of an often indirect and time-consuming route. The low volume of travel between most origins and destinations makes effective transit service over much of the study area unlikely. This is indicated by the fact that although the "other" transit trips form the largest portion of transit travel, they are a very small proportion of all non-CBD and non-school travel (Table 1).

TABLE 1

DISTRIBUTION OF TRANSIT TRIPS

Trip	Amount	Percent	Percent of Total Internal Survey Trips in This Category by All Modes
CBD	155,563	32.8	56.5
School	152,559	32.2	64.1
Other	165,628	35.0	9.7
Total	473,750	100.0	21.7

MAJOR VARIABLES

Automobile Ownership and Residential Density

Automobile ownership is the most important single variable in the determination of the demand for transit. Automobile ownership is the best measure of the availability of an alternative mode of travel. As can be seen from Table 2A, households without cars make about twice as many transit trips per capita as do households with cars. The difference between one- and multi-car households does not show up in the transit trip rate per capita, as the decrease in the proportion of trips by transit for multi-car households is almost exactly balanced by the increase in total trip making. Thus the effect of increasing automobile ownership from one car to more than one car is to increase total trips substantially. At the same time it reduces the proportion of transit trips so that the net demand for transit remains approximately the same.

TABLE 2A

TRANSIT TRIPS PER CAPITA BY CAR OWNERSHIP GROUP

Autos per Household	Transit Trips per Capita	Percent of Total Internal Person Trips
0	0.74	64.3
1	0.30	17.6
2	0.26	10.8
Over-all	0.32	21.7

The availability of automobile transportation obviously is not measurable solely by automobile ownership. The probability of the automobile or automobiles being in use by another member of the household, as well as the ability to drive, restrict the choice of travel mode. This is most evident in school trips, where age is the controlling factor.

Automobile ownership is also very valuable in determining what type of transit trips are made. For example, only 9.7 percent of all transit trips by 0 car households are to or from school, whereas 51.8 percent of all transit trips by multi-car households are to or from school. Due to the fact that there is such a wide variation between the transit use patterns of car-owning and non-car-owning households, and a much smaller variation between one- and multi-car households, (that is, the relationship between automobile ownership and transit use is nonlinear), the usual measure of automobile ownership as an average (cars per household, car per 1,000 persons, etc.) has been discarded in favor of stratification of transit trips into zero car, one car, and multi-car household categories for analytic purposes.

Net residential density, as the basic measure of concentration of people in a given area, acts in two ways on the behavior of persons when they choose a mode of travel. One, it serves as a measure of the ability to satisfy a travel desire by walking. Obviously, in a more densely developed area, more potential destinations will be within walking distance and less use will be made of vehicular travel of one type or another. This is particularly noticeable for school trips. The fixed-fare characteristics of transit make this travel mode particularly subject to competition from walking for short trips when an automobile is not available. Conversely, net residential density influences the relative convenience of automobile and transit use. Increasing density, by increasing the number of automobiles within a given area makes automobile transportation less convenient, both because of the increase in congestion caused by conflicts of moving vehicles, and by the attendant reduction in the availability of parking space (that is, in a more densely developed area, a person is less likely to be able to park near his destination). At the same time increased density makes transit service more available, as the densely developed areas are able to support more frequent service, both in terms of headways and in terms of route spacing, thus reducing both walking distance and waiting time. It must be noted that the effects of the two variables are not independent, as density and automobile ownership are fairly closely related. With increasing density, average auto ownership decreases, and the proportion of households not owning automobiles increases.

Table 2B indicates that residential density has only a negligible over-all effect on per capita transit use. It is known that the total number of trips per capita increases with decreasing density. Thus the percentage of transit to total trips must decline at a rate equal to the increase in total trips. However, because residential density acts in different ways on the three segments of transit travel, the over-all figures mask the true effect of density (Table 3).

TABLE 2B

TRANSIT TRIPS PER CAPITA BY DENSITY CLASS

Net Residential Density (persons per acre)	Transit Trips per Capita
0 - 14.9	0.36
15 - 29.9	0.32
30 - 59.9	0.32
60 - and over	0.31
Over-all	0.32

The first consideration was the general effect of automobile ownership and residential density; the influence of these variables on the three categories of transit trips is the next concern. School trips, unlike the other types, seem negatively associated by residential density. In part 1 of Table 3 it can be seen that a rapid rise in the rate of school transit trips per 1,000 population occurs with declining net residential density in the automobile-owning households and a less rapid rise occurs in non-automobile-owning households. This difference appears to be due to the existence of a larger proportion of one- and two-person households (households without children) in the zero car group (Table 2C). A slightly lower rate of school trips per 1,000 population is

TABLE 2C

AVERAGE PERSONS PER HOUSEHOLD BY AUTO OWNERSHIP CLASS

Autos Owned	Persons per Household
0	2.35
1	3.52
2	4.00
Over-all	3.26

TABLE 3

TRANSIT TRIPS CONTROLLED BY DENSITY AND CAR OWNERSHIP

Trip Types	Cars per Household	Persons per Net Residential 60+	30-60	15-30	0-15	Acre Over-all
School transit trips/1,000 population	0	28	54	82	88	46
	1	39	73	166	286	117
	2	36	56	155	250	127
Total		35	66	157	267	104
CBD transit trips/1,000 population	0	145	197	138	109	163
	1	104	110	90	64	98
	2	92	90	55	43	69
Total		117	126	87	59	106
CBD total trips/1,000 population	0	159	221	170	177	187
	1	202	196	164	142	182
	2	334	248	177	148	214
Total		195	209	167	145	188
Transit as per-cent of CBD total	0	88.2	89.1	81.5	61.5	87.5
	1	51.3	55.9	55.2	45.3	53.8
	2	27.6	36.4	30.1	28.9	32.1
Total		59.7	60.1	51.9	40.5	56.5
Other transit trips/ 1,000 popula-tion	0	239	290	284	136	263
	1	108	91	69	38	82
	2	92	74	38	22	50
Total		156	126	87	59	113

evident for multi-car households than for one-car households, because in these households there is a greater opportunity to drive or be driven to school, particularly as the usual multi-car household has more drivers than the usual one-car household. The behavior of school transit trips is quite different from that of other types of transit trips. This is because school transit trips are made largely by non-drivers, and except for those who are able to obtain rides, the usual choice between automobile travel and transit is not availabele.

The CBD presents another special case. Looking at Table 2, part 2, it is fairly obvious that CBD (here including all trips with one, but not both, ends in the CBD) transit trips are influenced by both automobile ownership and residential density. (A word of caution is in order here. Because, unlike the other two categories, trips to the CBD are trips to one small portion of the study area, and because residential density is quite closely related to distance from the CBD, much of the apparent effect of change in density is probably due to change in distance from the CBD.) The rate of

CBD transit trip making per 1,000 population declines both with increasing automobile ownership and with decreasing density. However, in looking at parts 3 and 4 of Table 2, the different relationships that make up the distribution of trips shown in part 2 are obvious. In part 3, the distribution of all CBD (here including all trips with one, but not both, ends in the CBD) trips (auto drivers, auto passengers and transit riders) per 1,000 population is shown. Density appears to be the more significant variable in this case, although a uniform pattern is not present. (A more uniform result is present when distance from the CBD is used.) With regard to auto ownership, zero- and two-car households appear to make more trips to the CBD per 1,000 population. Looking at simply the percentage of CBD trips made by transit, automobile ownership is the predominant factor. In fact, the similarity of the percentages for the four density groupings within each auto ownership class is very striking, although there appears to be a slight decline with decreasing density. The slightly lower percentages for the highest density class as compared with the next lower class are due largely to the inclusion of four zones less than one mile from the CBD. Trip desires that are satisfied by transit in other zones may be satisfied by walking from these zones to the CBD. Excluding these zones, the percent of transit trips to total CBD trips becomes, for the density group 60 persons per acre and over, 89.1 percent, 52.6 percent and 36.1 percent, respectively, for the three-car ownership classes.

While "other" transit trips, as shown in part 5 of Table 3, show the expected decline in trips per 1,000 persons with both increasing auto ownership and decreasing density, the most striking fact about these trips is the major difference in the rates for all density classes between car-owning and non-car-owning households. In fact 46.9 percent of all "other" transit trips are made by the 20.7 percent of the population in zero-car households. Persons in zero-car households make "other" transit trips 3.2 times as often as persons in one-car households, whereas persons in multi-car households make "other" transit trips only 0.6 times as often as persons in one-car households. Apparently "other" transit trips are made largely by those who have no alternative means of transportation available.

The Supplemental Variables

The minor variables are those that, although they are not of universal application, are valuable in the forecasting of the various subdivisions of transit trips. Also included in this category are variables which are not suitable for forecasting purposes because of the difficulty of application to a future situation or because their effects are almost completely masked by another factor. However, they are valuable in that their examination improves one's understanding of the reasons behind the mode choice.

The first of the minor variables to be considered are those that act as modifiers to net residential density. Net residential density is a measure of the concentration of residential development on the land allotted to such development. However, other density measures may be more appropriate for some purposes. Total trip density, which is a measure of the concentration of all trip making activities on the land, seems to be a suitable measure in cases where nonresidential trips are principally under consideration. In dealing with the concentration of population, net residential density is in imperfect measure, as it deals only with land actually used for residential purposes.

Net residential density is not always the best measure of the concentration of persons or trips. Inasmuch as it is a measure of the concentration of people on residential land, it does not take into account the relationship of residential development to the total land of an area. The most direct means of doing this is by simply measuring the percent of residential to the total land. Another useful measure of this is the percent of developed land to total land. For certain purposes, a combination measure, containing both the relationship of people to residential land and of residential to total land, is useful. Such a measure is gross residential density, or the relationship of people to total land.

Measures of trip type are useful, particularly in determining the nonresidential ends of trips. Certain trip-type classifications are inherent in the stratification procedure. The school trip, for example, is a classification by purpose and also inherently by land use. Also contained in this particular breakdown is a tying of the non-school ends to residential land, since 98.5 percent of the nonschool ends of school trips are to residential land. CBD trips are an example of stratification by trip concentration. The zones with the highest trip density are here taken as a special case. "Other" transit trips are the remaining transit trips after these two special cases are removed.

Although "other" trips are not selected as to any category, they also have significant properties. Most important is that 65 percent of them are to or from work as compared with 40 percent of all internal person trips; 16.5 percent of these trips are to personal business—a sort of catch-all trip purpose, although trips for medical and legal-governmental reasons predominate. Therefore "other" transit trips, aside from the 53 percent destined to residential land (as compared with 50.3 percent destined to home), will principally have their destinations at work places, public buildings and offices.

Transit Service as a Variable

Transit service as a variable in forecasting transit use has to be restricted to those measures that can be quantified readily and which are not subject to rapid change. Measures of transit capacity, unlike those of highway capacity do not meet the latter test. In most cases (some rapid transit lines in the largest cities of the country are exceptions) capacity can be adjusted to volume simply by the addition of vehicles to a route. Although in these days of generally declining transit patronage, service is not often increased, most transit companies attempt to adjust service to demand as closely as possible.

Transit speed is a better measure of transit service. To test the effects of transit speed four test areas were chosen. The first test area consists of eight zones (area one in Table 4, also see Fig. 2), served by a moderately high-speed, private right-of-way electric railway line. This is 12.8 miles long, with a branch of 10.8 total route miles. The average scheduled speed on the line (in the midday period) is 17.7 mph on the main line and 16.6 mph on the branch. Being entirely on private right-of-way except for about one mile downtown, the line is largely free from traffic tieups which occur in this area at the slightest hint of bad weather. Test area two consists of two zones served by an electric railway line that is largely on private right-of-way except for the downtown area and a short distance on minor streets. The 5.0 miles of line are covered at an average speed of 13.0 mph, only slightly higher than the street lines in the area. However, the line, being largely on private right-of-way, is largely free of delays caused by traffic congestion. Test area three is actually two areas—one consisting of two zones served by express bus service along the Penn Lincoln Parkway east and the other consisting of three zones served by express bus service using the Penn Lincoln Parkway west. Scheduled (midday) speeds of these lines are 24.1 and 21.8 mph for the lines using the Parkway east. These lines are, of course, not free from congestion problems. The fourth test area is in the same direction from the CBD as are test areas one and two and part of area three. It, however, is served by bus service operating over arterial streets with limited stops between this area and the CBD. This route operates at an average speed of 13.6 mph. This area was included for the purpose of a control, to see if the south and southwest areas of the city, with their restricted auto travel facilities, do have a higher level of transit use than does the study area as a whole. This portion of the city is restricted in its highway access to the CBD by the need for all major highway routes to either tunnel through the ridge just south of the CBD or to go through one of the few natural openings in the ridge, some of which are characterized by quite steep grades. As a result, the principal highway routes from the CBD to the south and southwest operate over capacity, which, in itself, seems to make transit more attractive, even when operated over the same streets as used by most automobile traffic.

The detailed results of these tests are given in Table 4 and the generalized results in Table 5. The expected values given in Table 5 were calculated by applying the method used to forecast CBD trips (as shown in the section on forecasting techniques) to the total CBD trips given in Table 4. This procedure is designed to control both auto ownership and residential density, as well as total trip volumes. Looking at Table 4, it can be seen that the combination of higher than average transit speed and freedom from congestion produces almost a 40 percent increase over the expected

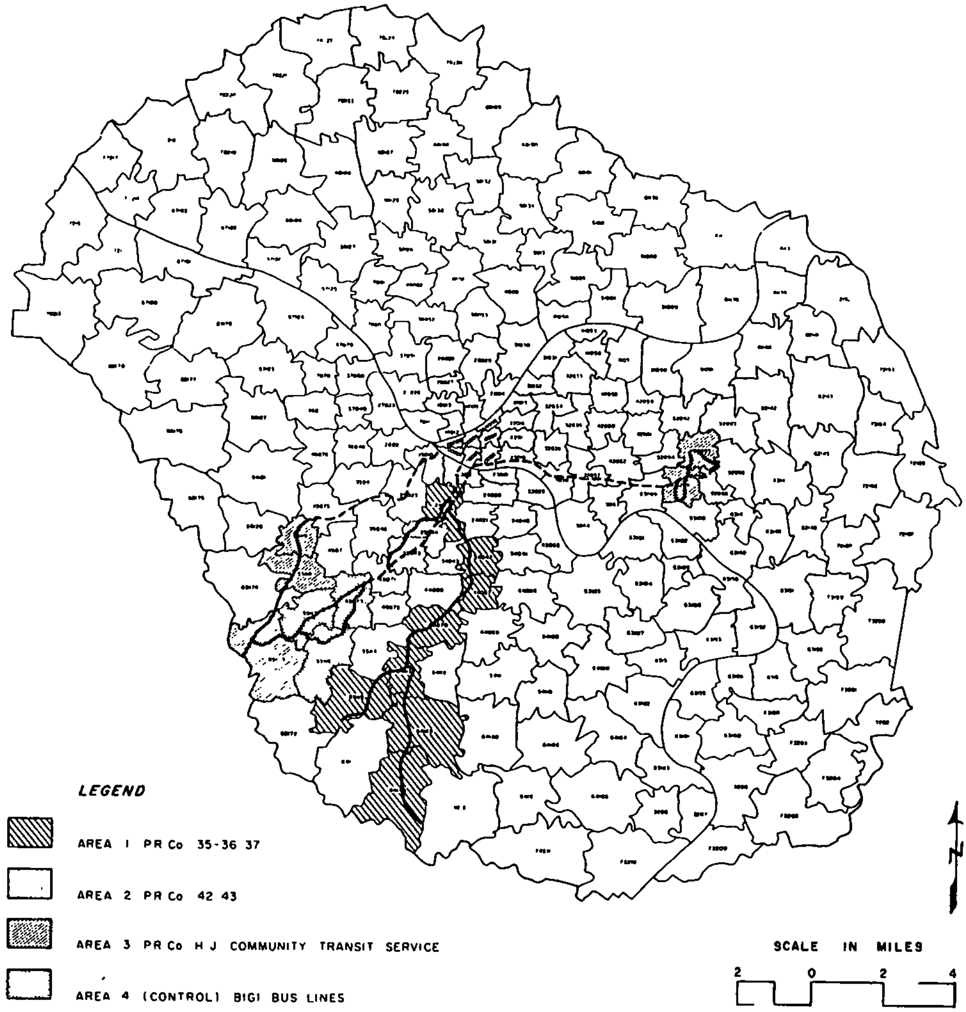

Figure 2. Test areas—effect of transit improvements.

number of transit trips. Freedom from congestion and higher than average free running speed alone produce about a 20 percent increase over the number of transit trips, while the control area has only an 8 percent increase over the average level of transit trips, despite the advantages to transit riders of good service (this area is served by one of the most progressive suburban bus companies) and relatively difficult automobile access. Of course, these comparisons were made only for CBD trips, as all the lines involved are CBD oriented. Increased speed probably has some effect on trips between points other than the CBD that are directly connected by superior transit service. However, the effect on "other" and school trips in these zones is minimal, as the difficulties of multiple transfer and indirect routings override the time savings on the one leg of the trip, for trips outside of the local area. School trips being largely noncompetitive with auto driver trips, as well as being very short (1.9 mile average), are not affected by transit speed.

This test examined only one portion of transit travel time, that time which is actually spent on the vehicle. The total transit trip actually includes walking time at origin and waiting time at origin and at any intermediate transfer points. What portion these parts are of the total transit journey (at least to the CBD) is given in Table 6.

TABLE 4

EFFECTS OF TRANSIT SERVICE—FOUR CASES

Zone	CBD Transit Trips Car/Household 0	1	2+	CBD Total Trips Car/Household 0	1	2+	Percent Transit to Total Car/Household 0	1	2+	Net Res'd Density
Area 1										
24022	561	1,288	354	561	1,806	645	100.0	71 3	54 9	49 6
34042	484	1,049	172	512	1,612	316	94 5	65 1	54 4	42 3
44067	309	711	84	309	1,491	483	100 0	47.6	17 4	33 9
44070	56	904	87	66	1,327	344	100 0	68 1	25 3	22 5
54113	290	627	86	319	945	400	90.9	66 3	21 5	15 2
55115	-	654	112	62	880	426	0 0	74 3	26.3	8 8
64169	-	776	367	-	21	483	-	84 3	76 0	10.1
64170	116	488	56	116	544	140	100.0	89 7	40 0	10 5
Total	1,816	6,497	1,318	1,935	9,526	3,237	93 9	68 2	40 7	
Area 2										
35044	439	1,225	382	439	1,723	616	100 0	71 1	62 0	38 5
35045	1,352	2,066	548	1,409	3,720	1,002	96 0	55.5	54 7	52 4
Total	1,791	3,291	930	1,848	5,443	1,618	96.9	60 5	57 4	
Area 3										
52095	596	1,138	163	677	1,893	461	88.0	60 1	35 3	71.0
52097	513	972	272	621	1,460	380	82 6	66 6	71 6	56 8
55118	84	168	28	112	398	84	75 0	42.2	33 3	20.1
55119	56	593	28	56	985	114	100 0	60 2	24.6	38 9
65173	58	369	114	58	514	228	100 0	71 8	50 0	21.8
Total	1,307	3,240	605	1,524	5,250	1,267	85.8	61 7	47 8	
Total of 15 zones	4,914	13,028	2,853	5,307	20,219	6,122	92.6	64 4	46 6	
SA Avg.	-	-	-	-	-	-	87 5	53 8	32 1	
Area 4[1]										
45073	202	1,502	401	202	2,328	1,023	100 0	64 5	39 2	17 9
55116	-	141	230	-	456	514	-	33 1	44 8	14.4
55117	-	620	140	56	1,328	388	0 0	46 7	36 1	22 0
Total	202	2,263	771	258	4,112	1,925	78 3	55 0	40 0	

[1]Control.

TABLE 5

DIFFERENCE BETWEEN ACTUAL AND EXPECTED TRIPS FOR CAR-OWNING HOUSEHOLDS IN FOUR TEST AREAS

Test Groups	Actual Trips	Expected[1] Trips	Percent Difference
1. Pittsburgh Railways (Route 35-36-37)	7,815	5,590	+39.8
2. Pittsburgh Railways (Route 42-43)	4,221	3,422	+23.3
3. Pittsburgh Railways (Bus Routes H-J) Community Transit Service	3,845	3,208	+20.2
4. Bigi Bus Lines	3,034	2,806	+ 8.1

[1]Calculated on the basis of the car ownership, density and distance class rates used in the forecast of CBD trips.

TABLE 6

DISTRIBUTION OF CBD TRANSIT TRIPS BY TRIP LENGTH AND TRAVEL TIME

Trip Length	No. of Samples	Average Time (min)	MPH	MPH[1] (-20-min base)
0- 0.9	209	20	1.5	-
1- 1.9	779	29	3.1	10.0
2- 2.9	841	31	4.8	13.1
3- 3.9	1,103	34	6.3	15.2
4- 4.9	856	37	7.3	15.5
5- 5.9	712	41	8.0	15.3
6- 6.9	435	43	8.8	17.1
7- 7.9	260	44	10.1	18.3
8- 8.9	122	47	10.8	18.5
9- 9.9	117	54	10.6	16.7
10-10.9	77	55	11.4	17.8
11-11.9	59	53	12.9	20.5
12-12.9	30	52	14.5	23.6
Total	5,600			
Mean		36	7.1	15.6

[1]This speed was derived by subtracting 20-min base time from the mean travel time for each trip length class.

From this, it can be seen that an average transit journey that, over-all, consumes 36 min at an average speed of 7.1 mph can be broken down into a non-CBD running time of 16 min at 15.6 mph and a walking, waiting and intra-CBD travel period of 20 min or 54 percent of total travel time. Thus, cutting running time in half would decrease elapsed time to 28 min and increase average speed to 9.1 mph. Cutting the walk and wait time in half would decrease elapsed time by 10 min and increase average speed to 9.83 mph. From Table 7, it can be seen that the average total (origin and

TABLE 7

TRANSIT TRIPS—BLOCKS WALKED BY AUTOS OWNED AND DRIVER/NON-DRIVER

Cars per Household	Driver/Non-Driver	Average Total Blocks Walked
0	Driver	2.57
0	Non-driver	2.46
1	Driver	2.73
1	Non-driver	2.02
2 or more	Driver	2.61
2 or more	Non-driver	1.66
All trips		2.30

destination) distance walked (for all transit trips) is under three blocks. In terms of time, this means approximately 7 to 8 min. This would be very difficult to decrease. Thus, the major decreases in the base time of 20 min could be obtained by shortening the wait time and time spent traveling within the CBD. (Another note of caution: In many studies, waiting time is taken as one-half of the average route headway. Carrying this to its logical conclusion, waiting time on a route that runs once per day is 12 hours. This is an absurdity. Obviously, persons tend to schedule their trips so that waiting time is minimized, especially on lines with infrequent service.)

Table 7 gives a rather surprising distribution of average walking distance for transit trips by availability of automobile transportation. The figures given are very regular, and do not show that walking distance decreases regularly with automobile availability, as might be expected. For drivers, the average walking distance remains practically constant, whereas for nondrivers, the average walking distance decreases with increasing auto ownership. If school bus trips could be excluded, nondriver trips would probably show the same lack of variation as trips by drivers.

Transit costs form another variable that may have some significance in mode choice. However, within one metropolitan area it would be difficult to test the significance of this variable. Cost can be shown to be important, though, in the choice between transit modes. Table 8 gives the effects of cost and time, among railroad, express bus and streetcar travel between Pittsburgh and Wilkinsburg. Although there is low commuter fare, this is available only to everday riders; however, other factors may also be important, such as the poor location of the railroad station with respect to the CBD.

TABLE 8

TRANSIT SERVICE, COST AND TRAVEL VOLUME COMPARISON

Transit Alternative	Fare	Number of Trips in P.M. Peak Hr.	Travel Time	Volume of Riders
Railroad	44 ¢ (cash) - 31¼¢ (monthly ticket)	4	20 min	135
Express bus	31½ ¢ (ticket)	4	29 min	1,762 (Express bus and Streetcar combined)
Streetcar	26¼ ¢ (tokens)	9	39 min	

Of course, many other variables could be introduced. Particularly, supposed measures of the quality of transit service, such as the percentage of standing passengers, have been suggested. However, most of these are of a subjective nature and are not particularly suited to measurement or forecasting.

FORECASTING TECHNIQUES

The forecast of transit use was broken down into three parts, as described previously. The three parts were forecast in quite dissimilar ways.

CBD Trips

CBD trips were forecast as percentages of a previously determined total number of CBD trips by all modes. The effects of four variables have been taken into account. First a basic forecast of CBD trips was made. This assumed that transit service in 1980 would be of an adequate amount to meet the calculated demand, but that no service of an improved nature (rapid transit or express bus) would exist. This estimate was calculated on the following basis:

PERCENT OF CBD TRIPS BY TRANSIT

Autos per Household	Zones Under 1 Mi from CBD	Zones Over 1 Mi NRD 12 or More	From CBD NRD Under 12
0	77.0	88.0	61.0
1	35.5	53.5	36.0
2 or more	13.5	31.5	20.5

The two special cases (zones under 1 mi from the CBD and zones with a net residential density of under 12) can be readily accounted for. The four zones under 1 mi from the CBD tend to have CBD transit trips replaced by walking trips, as the fixed fare nature of transit acts as a deterrent to very short trips. Also these zones have a much higher percentage of trips between the CBD and nonresidential land (71.3 percent as compared with 10.1 percent for the study areas as a whole), which tend to be by automobile (27.9 percent of nonresidential trips are by transit as compared with 56.5 percent of all internal CBD trips). The 39 zones with a net residential density of under 12 persons per acre were found to comprise the outer suburban areas where it is impossible to provide complete transit service because of low densities.

After this estimate had been made a generalized estimate of the effects of improved transit service was made. For this purpose the following routes were assumed: rail rapid transit between Mt. Lebanon and Swissvale, with feeder bus service on the Parkway East—east of Swissvale; private right-of-way streetcar service to Library, Drake, and Dormont; and express bus service over all or parts of the Penn Lincoln Parkway East and West, Ohio River Boulevard, East Street Expressway, and Route 28 Expressway (Fig. 3). Zones served by these routes had their transit trips by car-owning households increased 30, 20 or 10 percent depending on the type of service and the distance of the zone from the high-speed facility.

The results of this forecast are given in Table 9. The column marked 1980-A shows

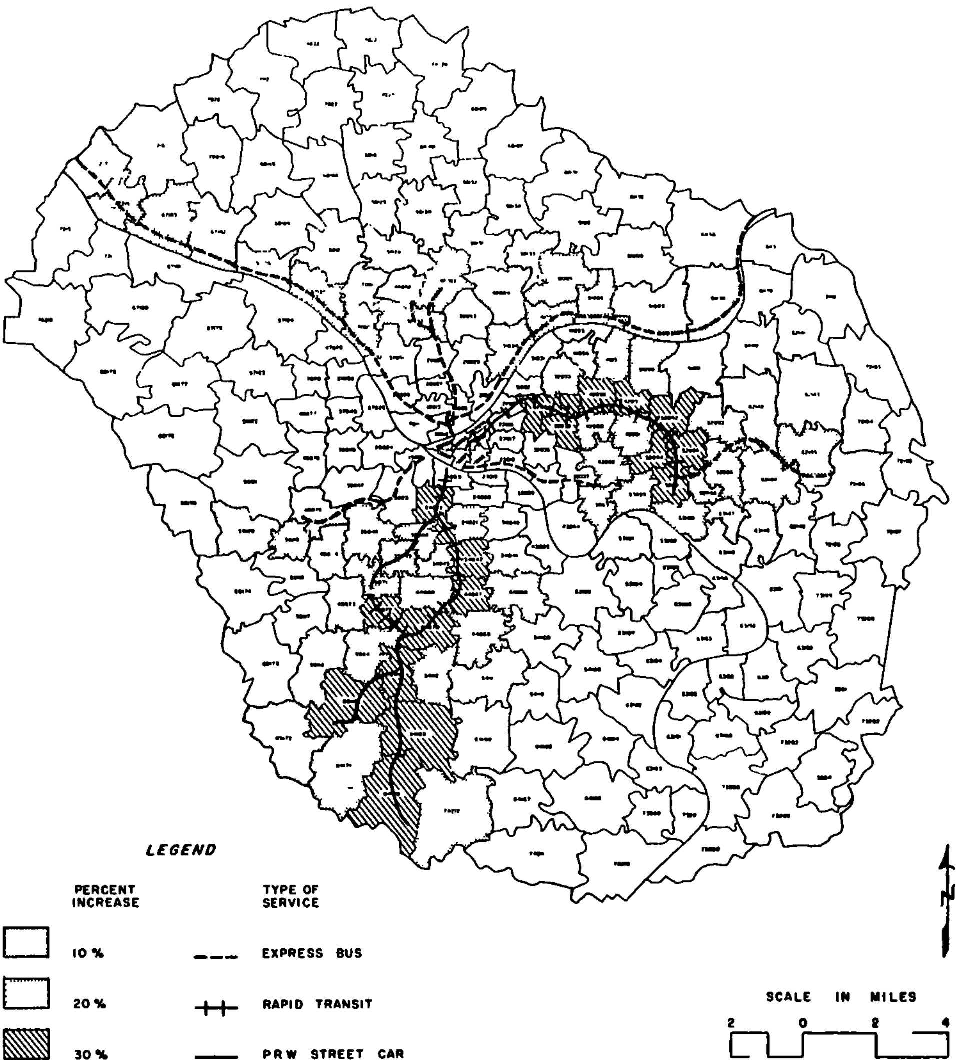

Figure 3. Assumed 1980 transit service improvements.

the forecast without additions due to improved transit, while the forecast with these additions is shown in column 1980-B.

TABLE 9

1958 AND 1980 CBD TRANSIT TRIPS BY NON-CBD RING

Ring	1958	1980-A[1]	Change	% Change	1980-B[2]	Change	% Change
1	9,545	8,322	-1,223	-12.8	8,322	-1,223	-12.8
2	22,692	16,725	-5,967	-26.3	17,383	-5,309	-23.4
3	39,569	31,215	-8,354	-21.1	34,087	-5,482	-13.9
4	38,825	32,611	-6,214	-16.0	37,601	1,224	- 3.2
5	29,929	30,053	124	0.4	33,667	3,738	12.5
6	11,508	16,666	5,158	44.8	17,381	5,873	51.0
7	3,135	6,813	3,678	117.3	6,990	3,855	123.0
Total	155,203	142,405	-12,798	- 8.2	155,431	228	0.1
Intra-CBD	360	360	0	-	360	0	-
Grand Total	155,563	142,765	-12,798	- 8 2	155,791	228	0.1

[1]Transit trips without improved transit service.
[2]Transit trips with improved transit service.

School Trips

The second part of the transit forecast was the forecast of school transit trips. Because there was no previously determined population of school trips, the problem was to forecast school transit trips independently of the total number of school trips. Thus the trips were forecast on a per capita basis.

Two relationships were developed that satisfactorily described the variation in 1958 school transit trips. These were based on net residential density and gross residential density. Both relationships can be described by fitted curves. These are:

$$\text{Log } Yc = 3.30 - 0.91 \text{ Log } X_2 \qquad X_2 = \text{net residential density}$$
$$\text{Log } Yc = 3.02 - 0.60 \text{ Log } X_3 \qquad X_3 = \text{gross residential density}$$
$$Yc = \text{school transit trips per 1,000 population}$$

The X_2 equation has an r of -0.75 and an s of 0.33.
The X_3 equation has an r of -0.78 and an s of 0.31.

Although the gross density equation produces a slightly better statistical result, the two are almost equivalent. However, it was decided to use the net residential density equation to forecast 1980 trips for several reasons (Fig. 4). One, it appears that net density is the more stable relationship. The rate of school trips per 1,000 population by ring is given in Table 10. It should be noted that the gross density equation has a much greater tendency to flatten these rates, while the net density equation maintains them at much nearer their 1958 levels. Particularly in the inner rings, which are fully developed in 1958, the rates should not change greatly between 1958 and 1980. The change in rates produced by the gross density equation in the outer rings implies that as a low density area is more completely developed, trips that were formerly made by school bus become walking trips. However, while at first glance, this hypothesis seems reasonable, it has several major faults. One it assumes that additional school needs are met by increasing the number of schools and decreasing school spacing, rather than by enlarging existing schools. The latter seems to be just as popular an alternative as the former. Second, with increased development, traffic on suburban roads will increase. This will make more and more roads that do not have sidewalks (and the suburban communities in the Pittsburgh area are extremely reluctant to build them) too hazardous for school children to walk along, thus requiring school buses for shorter trips than are usually provided for. Finally, the maximum walking distance that is acceptable for school children has been declining over time, and will probably continue to decline in the future.

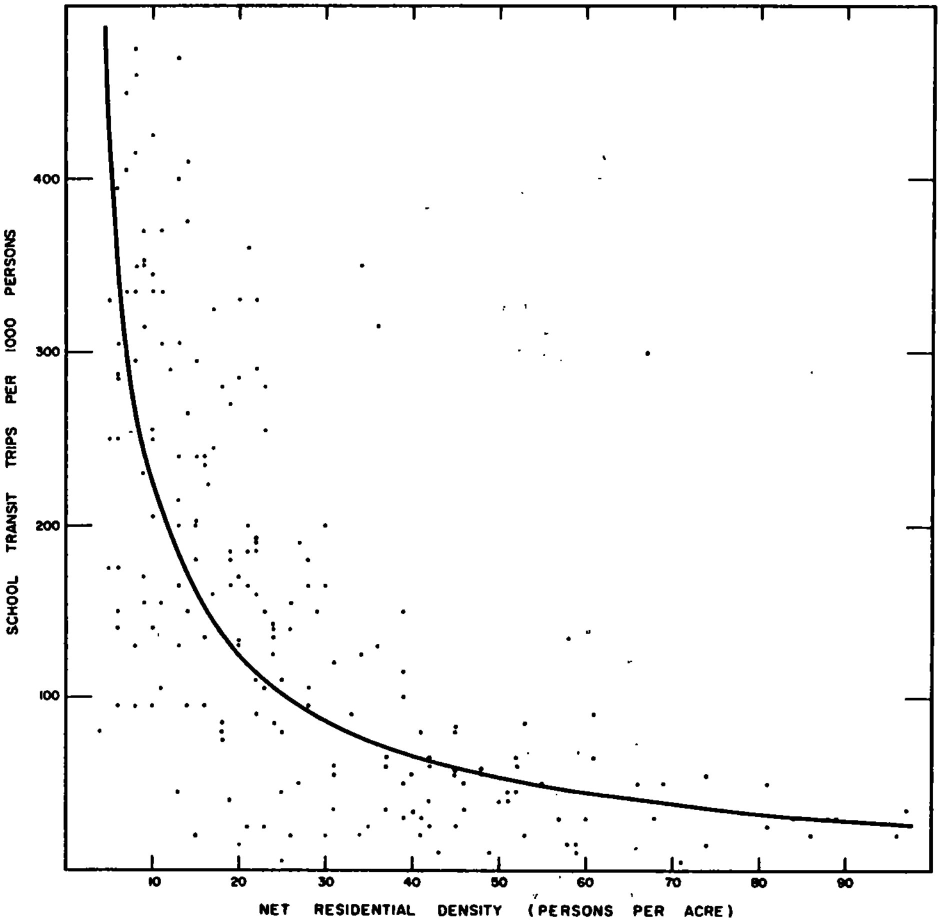

Figure 4. School transit trips as related to net residential density.

TABLE 10

SCHOOL TRANSIT TRIPS PER 1,000 POPULATION BY RING—1958 AND 1980

Ring	1958	1980 - NRD[1]	1980 - GRD[2]
1	25.8	26.3	38.0
2	48.0	46.4	45.4
3	57.0	58.9	48.2
4	89.1	78.3	54.9
5	118.9	108.7	74.0
6	159.2	139.6	96.6
7	180.0	175.1	121.4
Study Area	110.8	104.1	74.5

[1]Trip calculated on the basis of the net residential density equation.
[2]Trips calculated on the basis of the gross residential density equation.

Other Transit Trips

These include all transit trips not covered in the foregoing two categories. These were forecast as a per capita rate on the basis of automobile ownership and residential density. The relationships are shown in Figure 5. (Figure 5 does not show the distribution of trips by 2-car households. As only 443 other transit trips by 2-car households were reported, no distribution by district was prepared. Instead, the parameters of a curve similar to those for 0- and 1-car households were obtained by using 6 density class values.) Although a wide variation in trip rates exists, much of this variation is removed when these rates are stratified by auto ownership class. Much of the remaining variation can be accounted for by residential density. The relationships shown indicate that for a given auto ownership class, transit trips rise with increasing density up to a maximum point and then begin to decline slowly at higher densities. This shows the influence of several forces. The increasing trip rates are undoubtedly a function of the increasing convenience of transit and the decreasing convenience of automobile travel as density increases. However, above a certain point, the influence of density in reducing the number of total trips also appears for transit trips. Accentuating this effect is that imposed by the fixed fare nature of transit which tends to discourage very short trips. (In fact, transit is the only mode which has fewer trips under 1 mile in length than between 1 and 2 miles in length.) Within high density areas, where it is possible to meet many travel needs within a short distance, fewer transit trips will, therefore, be made, as short trips will either be by automobile or walking trips.

SUMMARY OF FORECAST

Tables 9, 11 and 12 present the results of the forecast of transit use by analysis ring, as compared to trips reported in 1958. Table 13 is a summary of over-all results. It should be noted that even with extensive transit improvements, transit trips to the CBD remain almost unchanged in number, although the total person miles of CBD

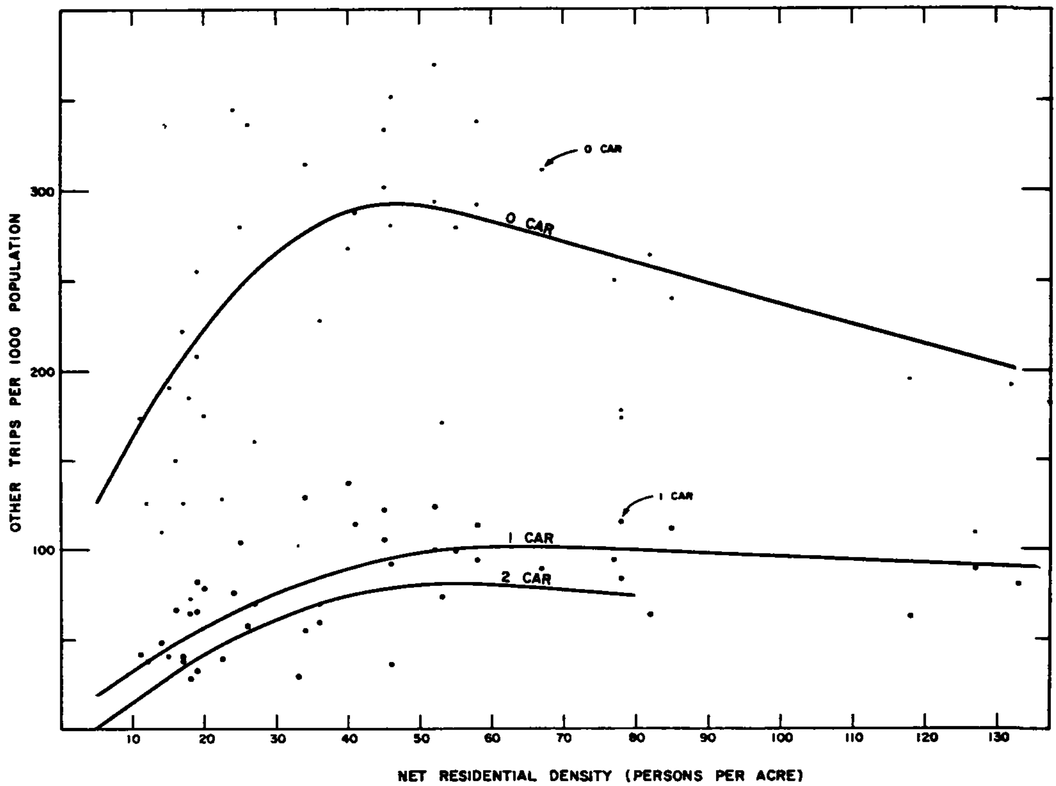

Figure 5. Other transit trips by car ownership and net residential density.

transit travel will increase with increasing average CBD trip length. School trips show a substantial increase, largely in the outer rings. In the category of other transit trips an absolute decline is evident. This is to be expected, as these trips are particularly sensitive to automobile ownership. Only the outermost ring shows an increase, due to its very large increase in population. The forecast therefore can be seen as a continuation of existing trends. A general decline in transit travel, except for school trips, is the result. However this decline is forecast to be slower than in the past 15

TABLE 11

SCHOOL TRANSIT TRIPS BY RING OF NON-SCHOOL TRIP END

Ring	1958	1980	Change	% Change
1	1,713	1,586	-127	-7.4
2	7,348	7,128	-220	-3.0
3	13,748	15,537	1,789	13.0
4	24,538	24,208	-330	-1.3
5	39,719	48,482	8,763	22.1
6	46,959	63,111	16,152	34.4
7	18,534	37,703	19,169	105.9
Total	152,559	197,755	45,196	29.6

TABLE 12

OTHER THAN SCHOOL OR CBD TRANSIT TRIPS BY RING OF RESIDENCE

Ring	1958	1980	Change	% Change
1	9,427	7,997	-1,430	-15.2
2	22,804	18,675	-4,129	-18.1
3	30,421	29,529	-892	- 2.9
4	30,083	28,645	-1,438	- 4.8
5	36,121	33,102	-3,019	- 8.3
6	29,883	28,942	-941	- 3.1
7	6,889	10,914	4,025	58.4
Total	165,628	157,804	-7,824	- 4.7

TABLE 13

SUMMARY OF TRANSIT FORECAST

Trip Type	1958 Trips	% of All Trips	1980 Trips	% of All Trips	% Change 1958-1980
CBD	155,563	51.4	155,791	47.1	0.1
School	152,559	15.2	197,755	10.2	29.6
Other	165,628		157,804		-4.7
Total	473,750	19.8	511,350	13.3	7.9

years, as the critical transfer of population from non-car-owning to car-owning households has already taken place for 80 percent of the population. School transit trips are forecast to act substantially as they have in the past; that is, rise rapidly in the outer areas and remain nearly stable in the inner areas. Thus it is apparent, that for planning purposes the population of transit trips can be regarded as one that is stable or even declining slightly. Even with major transit improvements, the number of transit trips to the CBD was not noticeably increased over the 1958 level. Under the conditions of rapidly increasing automobile ownership and a slowly growing central area, this condition appears to be inevitable.

CONCLUSION

Because the objective of the transit planning work to be done at PATS is to locate major transit facilities needed between now and 1980, the three types of transit trips are of varying importance in this problem. CBD trips constitute the basis for the demand for major transit improvements. Other trips and school trips serve only to add to this demand. Although other trips can do so in substantial numbers, being largely concentrated in the inner rings, school trips, due to their largely peripheral location and their short average length, cannot substantially add to the demand for major facilities.

ACKNOWLEDGMENTS

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Results of Pre-Interview Contacts in Philadelphia

GEORGE V. WICKSTROM and RICHARD ESTES, respectively, Supervising Traffic Engineer and Transportation Planning Technician, Penn-Jersey Transportation Study, Philadelphia, Pa.

● CHECKS of travel data obtained from home-interview traffic surveys have confirmed that total daily trips are under-reported by household members. To minimize the amount of under-reporting, a pre-interview travel log had been used in New Orleans. A significant gain in trip reporting seemed to result, with households filling out the log averaging 8.5 trips/day, and those not filling it out 6.0 trips/day. The results obtained in New Orleans were encouraging enough to warrant its use in the Philadelphia area and the Penn-Jersey Transportation Study (PJ) decided to use such a log.

New Orleans had suggested that the original log used be greatly simplified, in order to increase response. It was found that the log used in Philadelphia by PJ and the simplified log later used in New Orleans were remarkably similar, although designed independently.

PJ LOG FORM

The log form used in Philadelphia area is shown in Figure 1. Two or more logs were left with, or mailed to, adult household members prior to interviewing. The form was not intended to substitute for interviewing, but rather to act as a reminder for the respondent.

It was small enough to be carried conveniently, and the respondent was asked to note all trips made on a certain day by origin, destination, mode(s) of travel, and time of day.

METHOD OF TESTING

At the suggestion of G. William Blake, PJ's Data Processing Supervisor, it was decided to give the log a full-scale controlled test rather than delivering it to all households scheduled for interviewing. One-half of the households scheduled for interviewing each day were to receive the log, the other one-half were not. Five hundred and twelve interviews were scheduled daily. In practice, the first four of the eight interviews selected for each interviewer per day received the log, the last four did not.

The first test was to involve a pre-interview contact by the interviewer, where he would deliver the log, explain its use, and later return to collect it and conduct the normal home interview.

The second test was to mail the log with the pre-interview letter and did not involve any direct pre-interview contact by the interviewer.

OVER-ALL RESULTS

As the data for the first test came in, total trips reported for the first four interviews each day were compared to the total trips reported for the last four interviews each day for each interviewer. A 6-week test involving 15,360 households was made. The results of this test are given in Table 1.

The 7,680 households that received the log produced 40,697 reported trips and 1,184 non-interviews.

The 7,680 households that did not receive the log produced 43,562 trips, 2,865 more trips than households that had received it, and 1,143 non-interviews.

PJ

PENN-JERSEY TRANSPORTATION STUDY

51 Street and Parkside Avenue, Philadelphia 31, Pennsylvania. TRinity 8-6100

Dear Neighbor:

The Penn-Jersey Transportation Study, an official agency, is asking members of several families in each neighborhood to keep track of all trips made on a certain day. This information is needed to improve roads and rail service in the Penn-Jersey area. You can help greatly by filling in the other side of this card. Please show each trip you make on

____

Your PJ interviewer will call at your home on the following day to pick up this card. If no one will be home, please call and let me know so that we can set a more convenient time.

Interviewer's Name ____________________ *Telephone No.* ______________

THANK YOU FOR YOUR HELP

Note: Regulations require us to keep all information confidential.

LIST EACH TRIP MADE (GIVE ADDRESS OR NEAREST STREET INTERSECTION)	HOW DID YOU TRAVEL? (AUTO,RAILROAD,EL-SUBWAY, BUS, STREETCAR,TAXI, ETC.)	TIME OF DAY (YOU LEFT OR ARRIVED)
FROM (START) *321 Main St. Trenton*	EXAMPLE *Auto & Railroad*	LEFT *8:05 AM*
TO: *5101 S. 2nd St. Phila*		ARR: *9:10 AM* LEFT: *11:15 AM*
FROM (START)		LEFT:
TO:		ARR: LEFT:
THEN TO:		ARR: LEFT:
THEN TO:		ARR: LEFT:
THEN TO:		ARR: LEFT:
THEN TO:		ARR: LEFT:
THEN TO:		ARR: LEFT:

Figure 1. Pre-interview log form.

The results were consistent week by week, with non-log households constantly producing more trips. The over-all average was 5.30 trips/interview with the log and 5.67 trips/interview without the log. After removing non-interviews, the figures were 6.27 trips/household and 6.67 trips/household, respectively.

With these rather surprising results, completely contrary to what had been expected, the mail log test was started and delivery of logs stopped.

Week after week, the mail log test produced almost identical results. After six weeks of testing involving 14,848 households (512 less than the previous six weeks due to a holiday), 7,424 households receiving the mailed log produced 41,438 trips and the same number of households not receiving the log produced 42,757 trips, or 1,319 trips

TABLE 1

COMPARISON OF NUMBER OF REPORTED TRIPS AND NUMBER OF NON-INTERVIEWS WITH AND WITHOUT LOG

(a) Delivered Log Vs No Log

Week No.	Total			Delivered Log			No Log		
	Interviews	Trips	Non-Interviews	Interviews	Trips	Non-Interviews	Interviews	Trips	Non-Interviews
1	2,560	14,045	387	1,280	6,413	214	1,280	7,632	173
2	2,560	14,800	380	1,280	7,186	187	1,280	7,614	193
3	2,560	14,388	395	1,280	6,957	207	1,280	7,431	188
4	2,560	13,716	443	1,280	6,783	219	1,280	6,933	224
5	2,560	14,028	379	1,280	6,918	186	1,280	7,110	193
6	2,560	13,282	343	1,280	6,440	171	1,280	6,842	172
Totals	15,360	84,259	2,327	7,680	40,697	1,184	7,680	43,562	1,143

(b) Mailed Log Vs No Log

Week No.	Total			Mailed Log			No. Log		
	Interviews	Trips	Non-Interviews	Interviews	Trips	Non-Interviews	Interviews	Trips	Non-Interviews
1	2,560	14,001	332	1,280	6,878	169	1,280	7,123	163
2	2,560	13,448	379	1,280	6,611	173	1,280	6,837	206
3	2,048	12,023	222	1,024	5,940	106	1,024	6,083	116
4	2,560	15,041	270	1,280	7,434	126	1,280	7,607	144
5	2,560	15,162	275	1,280	7,498	144	1,280	7,664	131
6	2,560	14,520	315	1,280	7,077	157	1,280	7,443	158
Totals	14,848	84,195	1,793	7,424	41,438	875	7,424	42,757	918

more. Non-interviews totaled 43 less with the log, the figures being 875 with and 918 without. Trip averages were 5.57 trips/interview with, and 5.75 trips/interview without the log. After removing non-interviews, the averages were 6.32 trips/household and 6.56 trips/household, respectively.

SIGNIFICANCE OF RESULTS

Assuming a normal distribution of trip reporting, the differences in mean values were shown to be highly significant. The standard error of the mean was less than 0.1 trips in all cases. The differences between means were significant at the 0.01 level for the delivered log and at the 0.05 level for the mailed log. Rather than improving trip reporting, the results indicate a significant decrease in trip reporting for those households where the log was delivered or mailed. These decreases amounted to 0.40 trips/household for the delivered log and 0.24 trips/household for the mailed log.

Differences in the non-interview rates were shown to be insignificant.

SAMPLE ANALYSIS

To find out why the logs failed to produce more trips in the Philadelphia area, a 20 percent sample of the interview days involved in the test was drawn at random. Households which did not make any trips were separated, because these households could not have filled out the log even if they wished to. Trip averages reported in this sample analysis are therefore averages of households which made trips.

The number of samples obtained by income group (low, medium, high, or not reported) are given in Tables 2 and 3.

Because of the low number of samples (232) obtained for households completing the delivered log, an additional sample of six days was drawn to provide a more reliable trip average for this group. This sample produced 262 more households completing the log, so that these averages could now be based on a total of 494 interviews.

The average number of trips per household (for families who made trips) are given in Tables 4 and 5. For the delivered log, households completing the log reported an average of 1.4 trips more than those which received the log and did not complete it.

The latter group had an average of 0.6 trips/household less than those not receiving a log.

TABLE 2

NUMBER OF SAMPLES BY INCOME GROUP

Household Income Group	Log Delivered: Completed	Log Delivered: Not Completed	Log Delivered: Total	Log Not Delivered	Households Making No Trips: Log Delivered	Households Making No Trips: Log Not Delivered
Low ($0-4999/year)	55	244	299	300	108	92
Medium ($5000-7999/year)	83	304	387	397	17	17
High (over $8000/year)	53	131	184	214	4	6
Not reported	41	171	212	211	40	42
Totals	232	850	1,082	1,122	169	157
Non-interviews			285	257		
Total interviews			1,536	1,536		

TABLE 3

NUMBER OF SAMPLES BY INCOME GROUP

Household Income Group	Log Mailed: Completed	Log Mailed: Not Completed	Log Mailed: Total	Households Making No Trips
Low	22	342	364	121
Medium	52	363	415	23
High	34	165	199	6
Not reported	14	158	172	40
Totals	122	1,028	1,150	190
Non-interviews			196	
Total interviews			1,536	

Population standard deviations were estimated from sample data and the standard error of the means calculated. These differences in trip averages were shown to be significant at the 0.01 level. A significant difference was also shown within each income group for those completing the log.

The mail log comparison indicated that families completing it averaged 1.8 more trips than families failing to fill out the log.

Over-all results were similar to the two 6-week tests. No increase in trip reporting could be attributed to the log. The families filling out the log simply made more trips than those that did not when compared to households not receiving a log.

RESPONSE TO THE LOG

Table 6 shows the variation in response (percent of households completing the log) by income group. This variation in response was even more marked in the mail log than the deliver log samples.

About one in five households completed the log where it was delivered, and only one in ten when it was mailed.

The difference in response by income group were highly significant (at the 0.05 level). Households with higher incomes make more trips than those with lower incomes and also complete more logs, percentagewise.

TABLE 4

TRIP REPORTING BY INCOME GROUP
(AVERAGE TRIPS PER HOUSEHOLD[1])

	Log Delivered			
Household Income Group	Completed	Not Completed	Total	Log Not Delivered
Low	6.2	4.6	5.1	5.1
Medium	7.8	7.4	7.6	7.6
High	9.6	8.7	9.1	9.8
Not reported	9.6	7.2	8.1	7.7
All groups	8.1	6.7	7.2	7.3

[1]For households that made trips.

TABLE 5

TRIP REPORTING BY INCOME GROUP
(AVERAGE TRIPS PER HOUSEHOLD[1])

	Log Mailed		
Household Income Group	Completed	Not Completed	Total
Low	7.5	5.1	5.2
Medium	8.2	7.0	7.8
High	9.4	10.2	10.1
Not reported	10.5	7.4	7.7
All groups	8.7	6.9	7.4

[1]For households that made trips.

TABLE 6

RESPONSE TO DELIVERED AND MAILED LOGS
BY INCOME GROUP
(PERCENT OF HOUSEHOLDS COMPLETING LOG)

Income Group	Delivered Log, %	Mailed Log, %
Low	18.4	6.0
Medium	21.4	8.0
High	28.8	17.1
Not reported	19.3	8.2
All groups	21.4	10.6

TABLE 7

REASONS FOR NON-RESPONSE TO DELIVERED LOG

	Households	
Reason	No.	(%)
Did not bother or did not have time	496	58
Forgot	89	10
Did not receive log	89	10
Did not understand log	71	9
Lost log	65	8
Other reasons	40	5
Total	850	100

Slightly over 60 percent of family members (over 5 years of age) making trips completed logs in households where at least one log was filled out. Trips reported on logs represented 53 percent of the total trips reported for households filling out logs. No significant variation by income group could be found in either statistic.

Reasons for the low response were analyzed and are presented in Table 7.

Almost six of every ten households failing to fill out at least one log gave as a reason that they "did not bother or did not have time." Less than one household in ten claimed failure to understand the log. These percentages did not vary significantly by income group.

SUMMARY

Pre-interview contacts through the use of a travel log failed to produce additional trip reporting by households in the Philadelphia area. Although households completing logs had a significant increase in average number of trips over those that failed to complete them, this increase is apparently due to a bias in household response to the log.

Results of Use of Pre-Interview Contacts in Pittsburgh

S.W. SULLIVAN and C.E. PYERS, Pittsburgh Area Transportation Study

The purpose of this report is to give an evaluation of the use and value of pre-interview contacts in connection with a home-interview origin-destination survey. These pre-interview contacts are for the purpose of distributing and explaining the use of travel report cards on which the respondents are requested to record their travel for a specified day.

Although this study does not attempt to measure precisely the value of the pre-interview contact and travel report cards, it points out several advantages and develops certain conclusions regarding the use of this procedure. These conclusions, the reasoning behind them, and the pre-interview techniques used are presented.

● A HOME-INTERVIEW STUDY was set up in Pittsburgh by the Pennsylvania Department of Highways and Bureau of Public Roads (BPR) as a cooperative research project to provide intensive data for testing various travel formulas. One phase of the study was a test of the value of pre-interview contacts and the use of travel report cards furnished to the householders in advance of the day for which travel information was desired.

The Pittsburgh Area Transportation Study (PATS) was selected to supervise this project because of the opportunity for comparison with data compiled from the 1958 study at PATS, and also, because PATS could offer the nucleus of an experienced staff to operate the project. The study was operated in accordance with "PATS Home Interview Manual 1958."

Dwelling places in 13 zones were interviewed in April, May, and June of 1960, following PATS' major study of the complete area in 1958. These zones were picked to give a variety of socio-economic backgrounds to the research project (Table 2 and Fig. 1). The total area of these zones is 19.4 square miles and the total population is 112,107 (1). Home interviews were taken at 4,254 households in the 13 zones with the sampling rate varying from 1 in 3 to 1 in 10. (The 1958 sampling rate was 1 in 25 from all zones.)

The staff of the Pittsburgh Research Project (PRP) consisted of ten interviewers, four editors (two of whom were also substitute interviewers), a clerk-typist, and a supervisor. Of these, the supervisor, three editors, and four interviewers had previous experience in the 1958 interviewing phase at PATS.

A period of nine days was used to train the new interviewers, to familiarize experienced interviewers with several changes in the questions on the schedules, and to train all interviewers in the use of the trip report cards. After interviewing commenced, the same tight controls and checks set up by PATS in 1958 were maintained to insure the highest possible standard of reporting. All questionable information was checked with the respondents by telephone, and each schedule was edited twice by separate editors before a quality control was run on the interviews. Personnel working on the quality control operation checked at least an additional 12.5 percent of all schedules by calling householders and verifying all information given in the interviews. After completing

TABLE 1

ALL INTERVIEWS WITH TRIPS, BY ZONE

	Completed Interviews With Trips									Avg. No. of Trips		
	Households				Persons		Total Trips					
Zone	Number	% Card Users	Avg No Persons Making Trips	Avg No Trips	Number	% Card Users	Number	% of Trips Reported on Cards	% of Trips by Card Users	Reported by Card Users	Recorded for Non-Card Users	Diff Between Card Users and Non-Card Users
010	275	55.3	1.96	6.21	538	47.6	1707	43.9	49.0	3.269	3.085	+0.184
013	332	29.8	1.67	4.70	555	25.0	1560	21.0	27.0	3.036	2.736	+0.300
028	202	42.6	1.90	5.98	383	38.6	1207	38.1	44.3	3.615	2.860	+0.755
037	241	43.1	2.04	6.05	491	35.4	1457	38.2	41.9	3.511	2.669	+0.842
061	266	59.4	2.39	9.20	635	52.1	2448	48.9	56.2	4.160	3.523	+0.637
068	253	65.6	2.37	8.30	599	59.4	2101	53.4	58.7	3.463	3.572	-0.109
073	283	47.0	2.14	6.45	606	35.6	1826	38.1	42.9	3.630	2.672	+0.958
083	247	57.1	2.43	8.40	601	48.4	2076	47.0	51.1	3.649	3.271	+0.378
093	243	58.4	2.36	9.23	574	49.6	2243	48.3	55.7	4.386	3.436	+0.950
149	354	43.8	1.79	5.15	634	36.7	1822	34.2	40.3	3.154	2.711	+0.443
155	253	38.7	2.02	7.16	511	30.9	1812	27.0	32.9	3.778	3.442	+0.336
169	277	35.0	2.27	8.45	630	32.0	2342	32.3	38.3	4.445	3.374	+1.071
187	219	72.1	2.37	8.97	520	64.6	1964	62.6	71.4	4.175	3.049	+1.126
All zones	3,445	49.0	2.11	7.13	7,277	42.9[1]	24565	41.8	47.8	3.758	3.088	+0.670

[1]In addition to the number of persons using cards in this figure, there were 259 persons who used the cards stating that they made no trips. It is reasonable to infer that, had they made trips, they would have used the cards.

the editing and quality controls, the schedules and pre-interview trip cards were coded, punched, and the necessary card work done at PATS. The data was then forwarded to the Washington office of the BPR for analysis.

USE OF PRE-INTERVIEW CARDS

Each interviewer was assigned eight listed households for each travel day. About one week before the "travel day"—the day for which the household was to report its travel—a "Dear Householder" letter was mailed to the sample addresses explaining the general purposes of the survey, the type of information needed, and also telling occupants of the interviewer's impending visit. The day preceding the travel day, the households were contacted and the trip report cards were delivered and their use explained by the interviewer. These cards were picked up the day following the travel day when the interview was being completed. Therefore, after the interviewing began, the interviewer was required to (a) deliver trip report cards to eight households for the next day's travel, and (b) pick up the completed trip report cards and complete the home interviews for the eight samples of the previous travel day with the respondents' help. This was done in an 8-hr period, the interviewers being allowed to work the 8 hours between 9 a.m. and 9 p.m. best suited to their particular zone.

When delivering the trip cards, the interviewer left a sufficient number of cards to cover the trips of each person in the household five years of age or over. A letter of instructions was also left, which detailed the travel information desired, the day for which travel data were needed, and gave specific examples of the proper method of filling out the cards. The interviewer spent, in addition, an average of 10 to 15 minutes explaining the use of the cards. (Figures 2 and 3 show the front and back of the instruction letter. Figures 4 and 5 show the front and back of the travel report card.)

When the occupants of the sample address were not at home on the first call, the interviewers were instructed to make at least one other attempt during the evening hours to deliver the cards in person. Failing to find anyone home on the evening call, the interviewer left the cards and the letter of instruction either in the mailbox or with some responsible neighbor who promised to deliver them. Thus, even when the interviewer delivered the cards without personal contact, the household had two sources of information on filling out the trip report cards—the letter of instruction and the instructions on the back of the trip report cards. The interviewers reported that the cards were delivered directly to a member of the household about 80 percent of the time.

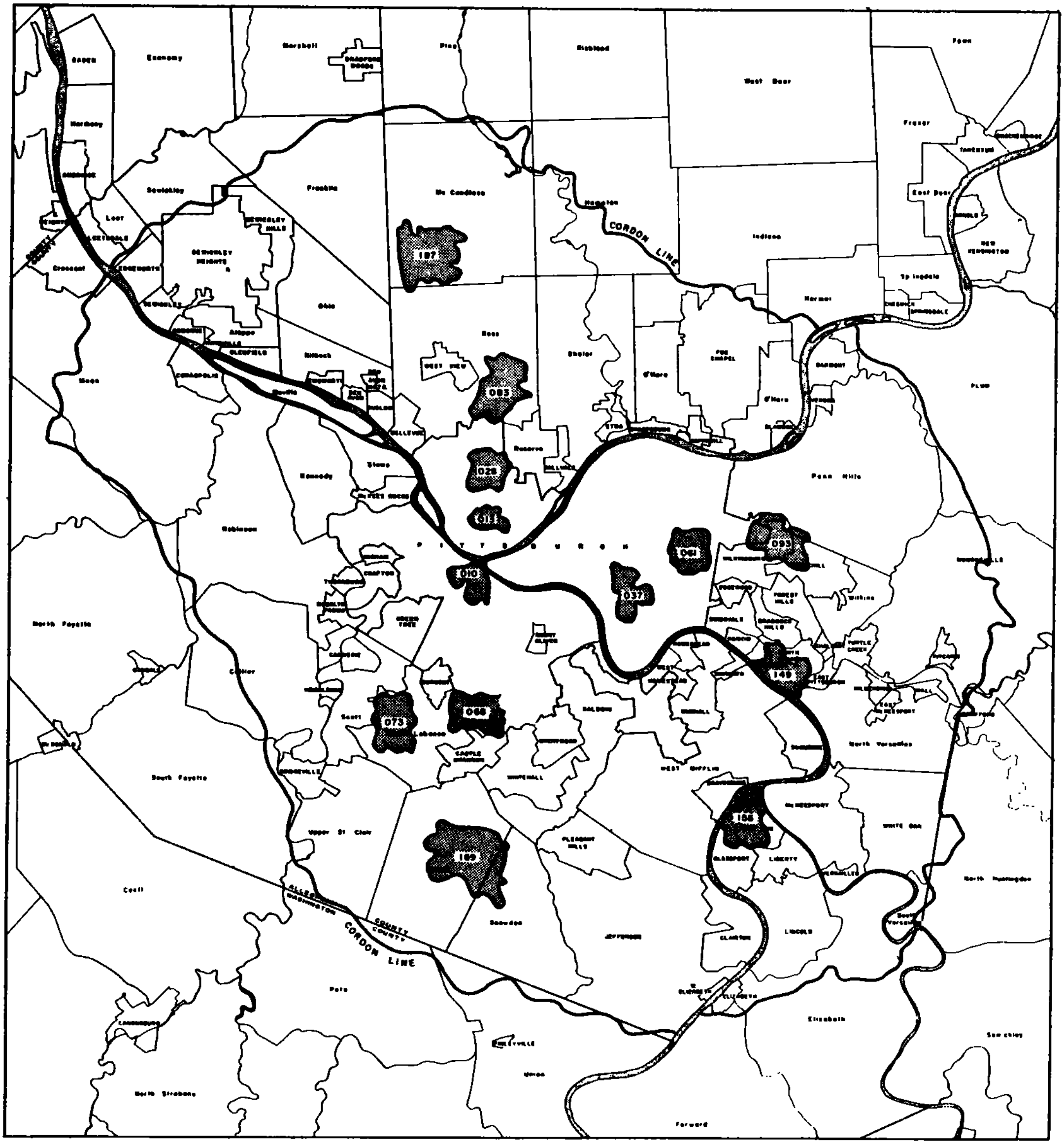

Figure 1. Selected PATS analysis zones for special BPR project.

When completing the home interviews, the interviewers reviewed with the respondent the information on the travel report cards. If this information was complete and accurate, the interview time was cut down by a few minutes to one-half hour or more (depending on the number of trips), because the interviewer could transcribe trip information to the regular interview schedule after the interview. The pre-interview cards and completed interview schedules were then sent in to the office where both were checked for completeness and accuracy of trips reported. After the schedules and cards were checked and rechecked, the pre-interview cards were separated and filed for reference in case of further questions.

COST OF PRE-INTERVIEW PROCEDURE

Scheduling of interviews was arranged to have each interviewer deliver pre-inter-

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U. S Bureau of Public Roads

PITTSBURGH AREA TRANSPORTATION STUDY

Sponsored by
PENNSYLVANIA DEPARTMENT OF HIGHWAYS
ALLEGHENY COUNTY and CITY OF PITTSBURGH
IN COOPERATION WITH U S BUREAU OF PUBLIC ROADS
Survey Office 14 Wood Street Pittsburgh 22, Pa
Telephone EXpress 1-3850

SUPERVISING CONSULTANT
J. DOUGLAS CARROLL JR
STUDY DIRECTOR
LOUIS E. KEEFER

Dear Householder

As explained in the letter recently sent you, your household is one of a number selected from which to obtain vitally needed travel information in connection with the Pittsburgh Area Transportation Study.

Each member of your family is being asked to record, on the attached forms, the trips which he or she makes during the day of ______________________________ Our interviewer will return to your home on the following day to collect the information contained on these trip records We realize that this is an inconvenience, but so is the traffic problem. It is only with your complete cooperation that your State and local government can take effective action toward solving this difficult problem.

The requested information is completely confidential and will be used for statistical purposes only

Thank you in advance for your contribution of time and information

Very truly yours,

Louis E. Keefer

Study Director

(See General Instructions and example on back of this letter.)

Figure 2. Letter of instructions.

view trip cards to eight samples and obtain an average of eight interviews for each day worked. This schedule was maintained without difficulty. When one of the regular interviewers could not work because of sickness or personal reasons, one of the editors would take his place so that there would be no gap in the interviewing schedule.

At the beginning of the study it was necessary to deliver pre-interview cards for the first two travel days, and this time was charged to interviewing. The final report showed that an average of 0.96 completed interview per interviewing hour was maintained for the study, contrasted with the 1958 study in which the cards were not used and an average of 1.01 completed interviews per interviewing hour was obtained.

Inasmuch as the interviewers were able to deliver the pre-interview cards and to

GENERAL INSTRUCTIONS

1. Each person in this household 5 years of age or older, including maids, roomers, and out-of-town guests, should keep a separate record of his or her trips.
2. Record all trips for a 24-hour period beginning 4:00 a.m. on ________________.
3. Record no walking trips EXCEPT walking TO work.
4. Identify each person by his or her relationship to the head of the household, such as wife, son, mother-in-law, roomer, etc.
5. PLEASE READ INSTRUCTIONS ON THE BACK OF THE TRIP RECORD FORM.

Example: Refer to Trip Record form and instructions on back.

Mr. Jones drove to the bus stop with his wife. After reaching the city by bus, he walked two blocks to his office. At noon he took a taxi to and from lunch. He was driven home by a friend. Mrs. Jones rode with her husband to the bus stop in order that she could have the car during the day, driving the car home from the bus stop. Later she took her 4-year old son to the barber shop, waited for him, then drove to her daughter's home. From her daughter's home she drove to the grocery store and then home, her son accompanying her on these trips.

PATS 2-168 ZONE 010 ; SAMPLE 008 ; PERSON MR JONES (HEAD) SEE BACK FOR INSTRUCTIONS

Beginning of Trip (Origin)	End of Trip (Destination)	Purpose of Trip	Establishment at Destination	Time of		Blocks Walked		Mode of Travel	Auto Drivers Only		
				Start	End	Origin	Dest		Persons in Car	Parking Type	Parking Rate
Home	800 Washington Rd Mt Lebanon	Catch Bus	Bus Stop	AM 7:21	AM 7:30	0	0	A.Dr	2	NP	–
800 Washington Rd Mt Lebanon	14 Wood St Pitts	Go To Work	Law Office	AM 7:32	AM 8:10	0	2	Bus			
14 Wood. St Pitts	Wm Penn Hotel	Lunch	Hotel	PM 12.05	PM 12:12	0	0	Taxi			
Wm. Penn Hotel	14 Wood St Pitts	Back To Work	Law Office	PM 1:05	PM 1:10	0	0	Taxi			
14 Wood St	Home	Home From Work	Home	PM 5:15	PM 6:00	0	0	A. Pass			

PATS 2-168 ZONE 010 ; SAMPLE 008 ; PERSON MRS JONES (WIFE) SEE BACK FOR INSTRUCTIONS

Beginning of Trip (Origin)	End of Trip (Destination)	Purpose of Trip	Establishment at Destination	Time of		Blocks Walked		Mode of Travel	Auto Drivers Only		
				Start	End	Origin	Dest		Persons in Car	Parking Type	Parking Rate
Home	800 Washington Rd Mt Lebanon	Went With Husband To Bus Stop	Bus Stop	AM 7.21	AM 7:30	0	0	A. Pass			
800 Washington Rd Mt Lebanon	Home	Return Home	Home	AM 7:30	AM 7:39	0	0	A Dr.	1	Res	Free
Home	328 Beverly Rd Mt. Lebanon	Take Son To Barber	Barber Shop	AM 9.35	AM 9:40	0	0	A Dr	2	St.	Meter
328 Beverly Rd Mt. Lebanon	978 Andover St Mt Lebanon	Visit Daughter	Residence	AM 10:10	AM 10.16	0	0	A Dr.	2	St	Free
978 Andover St Mt Lebanon	Banksville Rd at Dormont Ave	Shop at Krogers	Grocery Store	AM 11:40	AM 11:46	0	0	A Dr	2	Lot	Free
Krogers Store	Home	Return Home	Home	PM 12:20	PM 12:26	0	0	A Dr	2	Res	Free

Figure 3. Letter of instructions (reverse side).

average eight completed interviews per 8-hr day, it is reasonable to say that very little, if any, extra cost resulted from the use of the pre-interview cards in the field.

Compared with a district office having a similar work load in the 1958 study, an additional editor was the only difference in the staff of this project. It might be stated then, that the difference in cost in the two office staffs was the salary of this one editor, and this is probably attributable to the additional work imposed by the use of the cards.

PATS 1-16B ZONE__________ SAMPLE__________ PERSON____________________ SEE BACK FOR INSTRUCTIONS

BEGINNING OF TRIP (ORIGIN)	END OF TRIP (DESTINATION)	PURPOSE OF TRIP	ESTABLISHMENT AT DESTINATION	TIME OF		BLOCKS WALKED		MODE OF TRAVEL	AUTO DRIVERS ONLY		
										PARKING	
				START	END	ORIGIN	DEST		PERSONS IN CAR	TYPE	RATE

Figure 4. Trip card.

INSTRUCTIONS

A TRIP IS THE ONE-WAY MOVEMENT OF A PERSON BETWEEN TWO POINTS BY A SINGLE MODE OF TRAVEL. IF YOU ARE EMPLOYED AS AN OPERATOR OF A VEHICLE (bus, taxi, truck driver) DO NOT INCLUDE TRIPS MADE WHILE ON DUTY.

TRIP ORIGINS AND DESTINATIONS: Record actual street address, for example, 1120 Keller Drive. Names of prominent buildings are satisfactory. The word "home" is sufficient when the trip begins or ends at your place of residence.

PURPOSE OF TRIP: Describe why you made the trip; for example, to go to work, return home, buy a box of candy, catch bus, pay a bill, to eat lunch, go to doctor, pick up son.

ESTABLISHMENT AT DESTINATION: Give a description of the type of establishment at the destination end of the trip; for example, high school, grocery store, department store, park, insurance office, bank, steel mill, fabricating plant, gas station, house or dwelling. Note whether the store is a wholesale or retail store and the kind of office or plant.

TIME OF START AND END: Record to the nearest minute the time you begin and end a trip. INCLUDE THE TIME IT TAKES TO PARK CAR AND WALK TO YOUR ACTUAL DESTINATION.

BLOCKS WALKED: Record the number of blocks walked at each end of the trip (such as home to bus or auto, at origin of trip, and from the location parked to your destination at the end of the trip).

MODE OF TRAVEL: Use the abbreviation for one of the following classifications:

Auto Driver (A. Dr.)	Railroad Passenger (R. R.)	Taxi Passenger (Taxi)	Walked to Work (W. W.)
Auto Passenger (A. Pas.)	Bus, Streetcar, Pass. (Bus)	Truck Passenger (Tr. Pass.)	Truck Driver (Tr. Dr.)

PERSONS IN CAR: If you drove, give the total number of people in the car, including yourself.

PARKING TYPE: Use the abbreviation for one of the following classifications:

Street (St.)	Garage (Gar.)	Residential Property (Res.)	Not parked (N. P.)
Lot	Service and repair (Serv.)	Cruised (Cr.)	

PARKING RATE: Use the abbreviation for one of the following classifications:

Hour (Hr.)	Day (D)	Month (Mo.)	Meter (Met.)	Free (F)

IF YOU HAVE DIFFICULTIES IN RECORDING A PARTICULAR TRIP OR SEQUENCE OF TRIPS, MAKE A NOTE ON THE FACE OF THIS FORM DESCRIBING THE SITUATION. THE INTERVIEWER WILL ASSIST YOU IN PREPARING THE FORM WHEN HE RETURNS TO COLLECT THE TRIP INFORMATION.

LEAVE THIS FORM HOME THE DAY FOLLOWING THE 24 HOUR PERIOD DURING WHICH YOU RECORDED YOUR TRIPS.

Figure 5. Trip card (reverse side).

RESULT OF USE OF CARDS

The information contained in Table 1 summarizes the results obtained in the use of the trip report cards. In 12 of the 13 zones, the average number of trips reported by persons using the cards was greater than that recorded for persons not using the cards; the differences ranging from 0.18 to 1.13 trips per person. The over-all average shows that card users report two-thirds of a trip per person more than did the noncard users.

It will be noted that Table 1 gives both the percent of trips reported on the trip report cards and the percent of trips made by the persons using the cards. The difference between these figures (41.8 to 47.8 for all zones combined) represents additional trips obtained by the interviewers and editors when reviewing with the respondent the information they had recorded on the trip report cards. The value of having the trip report card as a lead in conducting the interview is discussed later.

Finally, it was found that the average number of trips per household obtained by this special survey was 0.5 trips per household higher than that obtained for these same zones by the 1958 origin-destination study conducted by PATS. This is an increase of about 9 percent.

Card use, that is the percent of persons using the cards, varied considerably from zone to zone. Table 2 shows that, in general, the higher income zones had the higher percentage of card users. Inasmuch as family income was obtained by this study (of all completed interviews, 86 percent of the household reported their annual gross income) it was possible to examine card use as related to family income. The results of this examination show that the proportion of card users increases as income increases and that in the lower income ranges card use was very low (Fig. 6).

OPINIONS OF INTERVIEWERS AND EDITORS ON USE OF TRIP CARDS

The interviewers were asked to give their opinion of the advantages and disadvantages of using the pre-interview card. Their answers are summarized as follows:

Advantages of Pre-Interview Trip Card

1. Interviewer was able to set up appointments for call-backs when delivering the cards, thus eliminating repeated calls.
2. Broke the ice for the regular interview.
3. When the cards were used correctly, they not only shortened the time spent on the interview, but prevented taxing the patience of the respondent.
4. When the household letter was not delivered by the post office for some reason, the delivery of the pre-interview card set up the interview.
5. Because of the way the trip card and instructions were set up, the wording of

TABLE 2

RATE OF CARD USE BY ZONAL CHARACTERISTICS

Zone	Sample Rate	Household Data: Persons 5 Years & Over: No.	Household Data: Persons 5 Years & Over: % Mkg. Trips	Household Data: % of Car Owners	Household Data: *% of Multi. Car Owners	Average Earnings, Family Income ($)	% of Persons Using Cards	Total Area in Acres	Net Residential Density (persons per acre)	Distance from CBD (mi)
010	1- 7	983	55	68	11	4,900	47.6	607.4	46.39	1 1
013	1-10	1169	48	52	5	3,400	25.0	304.6	142 87	1 1
028	1-10	612	63	65	14	5,500	38.6	688.5	48 22	2 5
037	1- 9	784	63	75	10	6,700	35.4	648.9	50 83	3.1
061	1-10	869	73	81	24	9,000	52.1	644 0	34 84	5.0
068	1-10	820	73	81	19	6,700	59.4	917.1	23.78	4.1
073	1- 8	918	66	94	33	7,600	35.6	991.3	17 90	5.4
083	1- 3	755	80	96	22	8,600	48.4	1,100.9	15.76	4.5
093	1-10	752	76	95	24	8,600	49.6	953 5	24.08	7 0
149	1-10	1326	48	55	9	4,300	36.7	912.1	99 53	7 6
155	1- 8	869	59	82	15	5,500	30.9	991 2	38.63	9.5
169	1- 5	886	71	92	19	6,700	32.0	2,168.5	10.10	8.0
187	1- 3	663	78	100	41	7,700	64.6	1,484 9	7 97	8.3
All (avg.)		877	64	75	17	6,100	42.9	954 8	31.05	

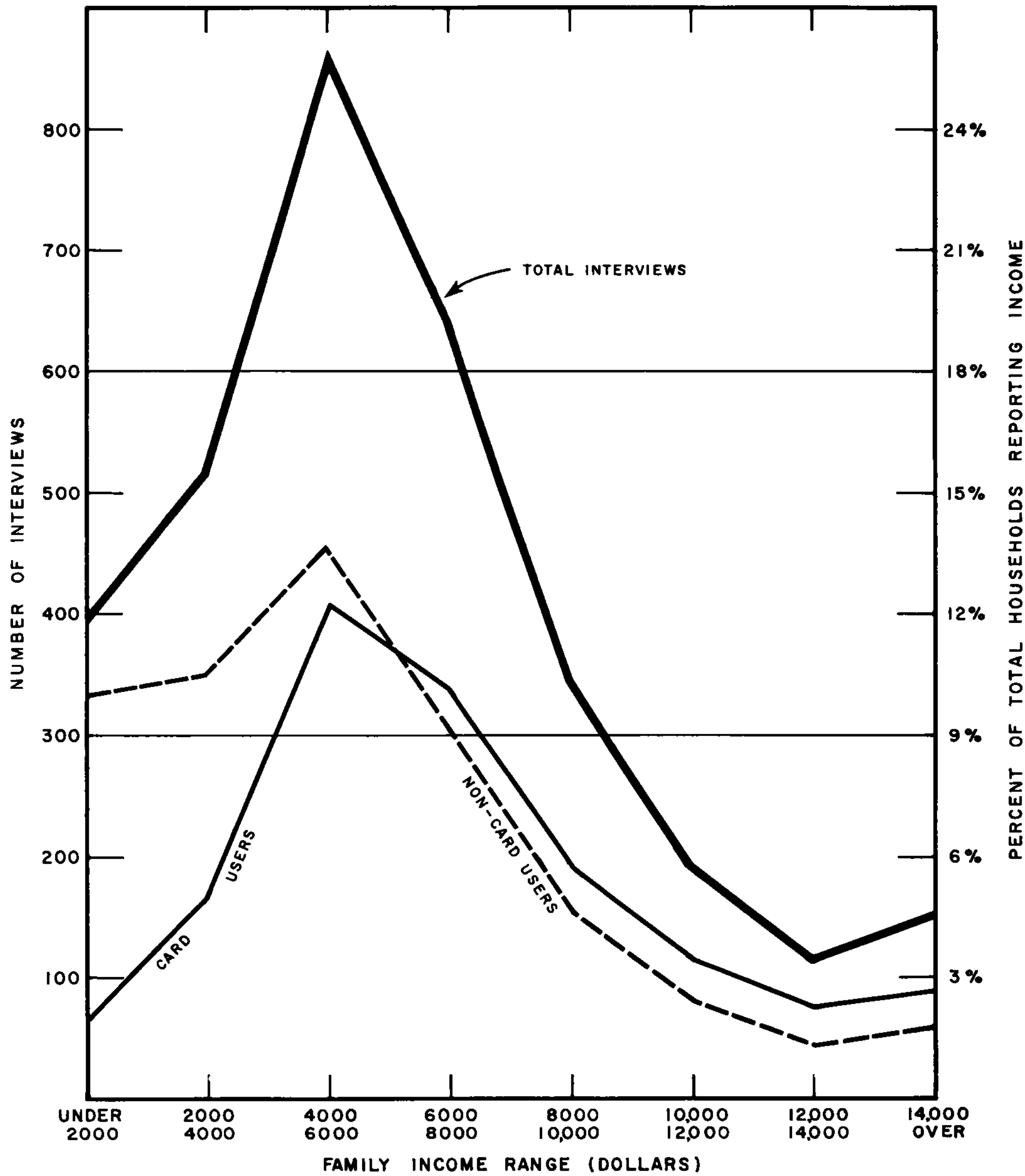

Figure 6. Trip card use by households reporting income.

the trip purpose, stated in the respondent's own terms, became more explicit; that is, to school for P.T.A. meeting.

6. Filling out the card in advance of interview enabled the respondent to reflect on his answers and to remember travel both during and after filling out the card.

7. Even if the cards were not used, they made the respondent aware of the information needed.

8. When an interview was made without the cards, very often the information was taken from only one person. This person might not have been aware of all the trips of everyone else in the household; whereas, with the cards, each household member had the opportunity to record his own trips.

9. The cards were particularly effective in households where one or more persons made a great number of trips (that is, doctors, salesmen, etc.).

10. The cards stressed the importance of the project to the householders and gave them a feeling of personal participation in the study.

Disadvantages of Pre-Interview Card

1. Some people could not understand the card and became suspicious, making an interview more difficult to obtain. This condition occurred infrequently, however, and mostly in low-income areas.

2. Some people would consider the interview complete after filling out trip cards, and would therefore be hard to contact a second time; this was probably due to lack of explanation by the interviewer.

3. Some people objected to filling out the pre-interview trip card because they felt it would require too much time.

The opinions of the editors on how the pre-interview trip card affected their work could be summarized as follows:

1. The clues provided on the trip cards, when checked against the information on the schedules, enabled the editors to find and correct trips on the schedules. For example, sometimes the trip card of a driver showed passengers on trips, with no mention of these passengers' trips on the cards of other members of the family or on the schedules. Very often these trips were made by members of the family or car pool passengers, and because of the trip cards, quite a large number of these were picked up by the editors. The type of trip missed on the card to the greatest extent seemed to be (a) returning home after listing a trip to some destination, and (b) "serve passenger" trips.

2. When checks were being made by telephone, the people whose information was being checked could remember the information on the cards, if nothing else.

3. When the trip cards and completed schedules agreed or were corrected to agree, the cards furnished documentation of the schedules.

CONCLUSIONS

The advantages in using the pre-interview cards in the Pittsburgh Research Project were numerous. Although the additional number of trips obtained over a like number of samples from the same zones in PATS 1958 study was considerable, this does not represent the total value of the pre-interview contacts.

There can be no doubt that the use of the pre-interview cards was responsible for obtaining a greater number of trips. Table 1 shows that the reported trip average of trip card users exceeded the trip average of noncard users by better than one-half trip per person. If the trip average of the card user in each zone is applied to all persons making trips in the zone, a net gain of 2,517 trips, or 10.24 percent, results. By the same token, if the trip average of the noncard user in each zone is applied to all tripmakers in the zone, a net loss of 1,859 trips, or 7.57 percent, results. This represents an over-all difference of 4,376 trips, or 16.16 percent. Here is strong evidence that the pre-interview card was a potent instrument to use toward the goal of obtaining an accurate and complete record of trips.

However, there were other advantages to the use of the cards. These were intangibles that do not show up in the cold light of tables, summaries, and statistics, and these factors played an important role in strengthening the study as a whole. The fact that each household member responded for himself when using the card was an improvement over the situation where a wife, for instance, possibly unaware of all of her husband's trips, reported for him without using the cards. That additional trips were obtained when the schedules were edited from clues furnished by the cards, that respondents were more likely to record all of their trips when using the cards, that they were more responsive and more aware of the information needed as a result of the pre-interview visit—these were all intangible factors that cannot be measured by conventional means.

Also, interviewers' travel time and interview time were reduced by the ability to make appointments when delivering the cards; and time was saved by completing interviews from the cards after checking them out with the respondents.

It was felt by the staff that a greater degree of data accuracy was obtained through the ability to check out items of information from the schedules with the information recorded on the cards by householders. The members of the staff who had participated in the 1958 PATS study agreed that, despite the extra work involved in delivering the trip cards, they would prefer to interview with the cards rather than without them.

One suggestion for future use of the pre-interview cards would be that the interviewer make a note of whether cards were delivered in person or were simply left with the letter of instruction. This factor probably has an effect on the percentage of card users and degree of completeness of those cards that were filled out without personal instructions.

Another suggestion is that the letter of instruction, which shows examples of the use of the card and therefore is a valuable tool, should be left for each person in the house, rather than one letter per household.

REFERENCE

1. "Interim Technical Report Number III: Home Interview Summary Data." PATS (1959).

Cartographic and Design Work for a Comprehensive Origin-Destination Survey

GEORGE A. LUSTER and WADE G. FOX, Pittsburgh Area Transportation Study

●COMPREHENSIVE origin and destination (O-D) studies such as the Pittsburgh Area Transportation Study (PATS) are still relatively new; consequently many of the problems confronting these studies are new also. Maps, charts and related items required for the collection, processing, analysis and presentation of the Study's data have a direct bearing on many of these problems. Although one study's requirements may differ slightly from those of another, the experience gained at PATS may prove generally helpful toward a solution to many difficult situations.

This paper is presented, then, in a twofold manner. First, an account is given of the methods and procedures found suitable for the Cartography and Design (C&D) Division of the Pittsburgh Area Transportation Study. Second, there are suggestions throughout the paper on additional procedures for perfecting the methods used at PATS.

At PATS, it is the responsibility of the C&D Division to: provide maps, manuals, visual aids, and forms for data collection and to assist in the land-use measurement; establish a complete system of geographic identification, to be used for the collection, coding and analysis of study data; prepare a series of maps for the arterial and mass transit inventories and assignments; visually present the data collected and projected; illustrate, edit, collate, have printed and distribute all study publications; and establish and maintain a technical library.

The organization of the C&D division and each of these general responsibilites is discussed and the total contribution that can be made to an O&D study by an effective C&D division is summarized.

ORGANIZING AND ESTABLISHING THE C&D DIVISION

The number of personnel needed in the C&D division will vary according to the size and scope of the study. However, basically, the organization of most comprehensive O&D studies is similar. For example, no matter how large a study's area is, the methods and procedures followed in the division are fundamentally the same. Consequently, the basic personnel requirements of the C&D division do not change to a great extent in any given study.

There are three key positions that make up the nucleus of the PATS C&D Division. They are: the cartographer, a graphic designer, and an editor-librarian. It is the cartographer's responsibility to set up and supervise the drafting of all maps required by the study. The cartographer should also be familiar with photogrammetry so that he can give technical assistance for the land-use measurements and highway location planning. The job of the graphic-designer is to lay out and prepare all forms, displays, illustrations and publications needed for the proper functioning of the study. Both of the aforementioned positions are of equal importance and the selection of personnel to fill the jobs is very important. It would be a great asset to the division and the study if experienced O&D personnel could be recruited for any of these key positions. Although neither must be a college graduate, extensive training and experience in each of the fields is essential. There are some experience requirements that would be helpful to either or both of the persons filling the positions. They are: experience in supervision, technical writing, photocopy work, printing, negative stripping and other related procedures. The C&D supervisior should be selected from either the cartographer or the graphic designer, depending on schooling, experience and ability. The editor-librarian is responsible for the editing of all publications turned out by the study.

The editor-librarian must also be familiar with basic printing procedures and must be capable of setting up and typing originals for printing by xerox or other direct methods. Also, it will be his (or her) responsibility to build up and maintain a technical library for the study's use. In a small study, the public relations may also be handled by the editor-librarian. (In a larger study, the public relations may have to be handled as a separate operation.) The editor-librarian must have a college background with a major in English or the equivalent in editorial experience.

Because the tasks assigned the C&D division vary greatly, personnel versatility is very important. For this reason, care must be taken when selecting employees. It is far better to select a person with a well-rounded background than a "specialist" in any of the fields.

All three of these positions should be filled early in the study. The cartographer should be the first of the three hired and must begin his job before field work starts. This is necessary for preparation of the required data collection maps. Soon after, so that forms and manuals may be prepared, the graphic designer and the editor-librarian positions must be filled.

The division's supporting personnel should consist of cartographic draftsmen, illustrators, and clerical help. Where feasible, it would be to a study's advantage to have its own photographer (copy camera), printer, and related equipment.

After recruiting the personnel necessary for proper function of the C&D division, a brief but intensive training program must be conducted. The instructions should include a thorough explanation of the purpose and procedures of an O&D study. A review of manuals and reports on similar studies could be helpful. Also, to enable a better understanding of reproduction and printing procedures, a tour of at least one local printing house is encouraged. Time should also be taken to familiarize the division's personnel with the topography of the area under study. In addition, training must cover all phases of the study's internal procedures, inasmuch as, the C&D division is a supporting unit for all other sections.

In conclusiion, it may be said that the more familiar the division's personnel are with the goal of the study and the methods necessary to attain this goal the more efficiently the C&D section will operate.

PREPARATION FOR DATA COLLECTION

The most important pre-field duty of the C&D division is to obtain a complete set of maps covering the area under study. The scale of the maps should be a minimum of 1 in. = 800 ft, to allow completeness of detail without cluttering the maps to any great extent. Due to the large map scale required for adequate coverage, a series of maps will generally be necessary to represent the complete study area. The maps should distinguish and name: (a) existing expressways, roads, streets, and alleys; (b) streams, rivers, and lakes; (c) railroad lines; (d) civil divisions; (e) cemeteries and major parks; (f) bridges, tunnels, etc.; and (g) local place names (other than civil divisions). The following details are also worth mentioning: (a) A map numbering system should be incorporated for control purposes. (b) The map sheets should be standardized at a good workable size. (c) A geographic identification system (grid coordinate system) should be included. (d) Contour lines, representing relief, are not necessary for the purpose of O&D work.

Although streets are not drawn at scale, it is helpful to the field listers and home interviewers to show alley widths at a smaller scale than major streets.

Field listers, as referred to in this paper, are the persons who manually account for all parcels of land within the study area, and classify each parcel into its particular land use. The field lister also obtains the street address of each building within the area. The data is collected by block and geographically identified by the block's grid coordinate values. From this list, samples are selected for home interviewing.

Home interviewers are the persons who make personal contact with the sample households and obtain the trip information required for the O&D study. Another aid in the interpretation of map detail is the representation of hard surface roads by solid lines and dirt roads by broken lines.

In addition to the study's map coverage there is a definite need for complete aerial coverage at a minimum scale of 1 in. = 800 ft. These aerials are necessary for proper land-use measurements. If insurance maps are used for these measurements, in all probability there will not be complete study area coverage. Therefore, the aerial photos may be used to supplement these measurements. The aerials are also useful as an aid in highway location planning, as well as for use in updating, checking, and/or drafting the series of maps required for the study's field work. When obtaining these enlarged aerials, it would be helpful to acquire a set of stereo matched prints and a complete set of single-weight photographs to be used in making an aerial mosaic of the study area.

The major circumstance influencing the procedure to be followed in acquiring maps and aerial photographs is availability from local sources. If satisfactory materials cannot be obtained locally, other courses of action must be taken. (It is unlikely that the survey will have at its disposal the equipment necessary for adequate aerial coverage. Therefore, it will be taken for granted that the aerials must be acquired from their government sources or a private concern.)

The first alternative is for the C&D division to draft the maps needed. Due to the detail required for adequate mapping of the study area, a great amount of drafting work is necessary, creating a need for additional draftsmen prior to the study's field work. But, inasmuch as a tighter control can be maintained when the mapping is done internally, a very good series of maps can be produced. Following is a suggested procedure for preparing a series of maps suitable for the work of an O&D study.

The first step is to obtain the black color separations for the USGS 7½- by 7½-ft quadrangles covering the area under study. (Also, a complete set of colored USGS topographic quadrangles at the same scale should be acquired.) Using the black separations, reproduce a Cronaflex print of each of the quadrangles. (Cronaflex is a trade name for a polyester base material which has the following desirable characteristics: sensitized for photographic process; durable, matte surface for ink work; very stable, thus very important in the mapping field.) Next draft onto the Cronaflex prints (using the colored topographic quadrangles as a base) all of the drainage within each quadrangle. (For clarity use the standard stream symbol.) This procedure will be followed on each quadrangle throughout the study area.

Then, add onto the Cronaflex prints a grid coordinate system to be used for geographic identification. After determining the axis of the grid system (usually at the area's central business district), the north-south line should run parallel to the nearest set of longitude marks on the Cronaflex prints. The east-west axis line should then be drawn perpendicular to the north-south line. From these axis lines plot out, in ½-mi increments, a complete grid coordinate system. Great care must be taken when plotting these grid lines from one sheet to another so that a uniform coordinate system may be realized.

An exception to this method is a study area with a predominantly "checkerboard" street network. The grid system in this case may be orientated to correspond with the street pattern. A slight deviation of the grid system from north will not affect the accuracy of the geographic identification. However, the degree of deviation from north must be noted.

The foregoing will result in a complete set of maps (1in. = 2,000ft USGS quadrangles) on Cronaflex film containing much of the detail needed for the data collection map series. Before proceeding any further, the drafting scale must be determined. This scale is governed by the aerial photograph enlargements. If, for instance, the enlarged aerials are at the scale of 1in. = 400 ft, then the Cronaflex prints would be photographically enlarged to that scale. A similar scale for both the aerials and the maps is necessary so that the photographs may be used for updating purposes. Also, because the maps, and not the aerials, will contain the geographic identification system, the maps must be used for control purposes when measuring the land uses from the aerial photographs. To facilitate this correlation between map and aerial, the Cronaflex prints are laid out for sheet size comparable to the aerial enlargements. (There is a five time enlargment required to obtain the map's desired scale 1 in. = 2,000 ft to 1 in. = 400 ft.)

Because the line weight of the map's detail at this enlarged scale is distorted to some extent, redrafting is necessary. Before the tracing can begin, a considerable amount of detail must be added to the enlarged maps. First, the maps should be overlaid on the aerials and the street network updated. Besides the addition of streets to the maps, a vast amount of supporting information must also be obtained. For instance, all available street maps from throughout the study area should be used to identify the streets represented on the maps. Also, all civil division boundary changes must be noted and made on the enlarged maps. When this updating is completed and thoroughly checked, the maps may be drafted in final form. The maps should contain all of the map detail as listed in the beginning of this section. (PATS required 60 maps at the scale of 1 in. = 400 ft for complete coverage of the study's 450-sq mi area.)

If the C&D division is not in a position to prepare the map series itself, a second alternative is to let the preparation of the maps out on bid. It is essential, when the contract is drawn up, that the person responsible for the C&D division assist in the writing of the required specifications. In most cases the company preparing the maps will also be in a position to supply the aerial photographs required by the study. If the preparation of the maps is contracted out, the C&D supervisor should have the prime responsibility for establishing liaison as well as insuring that adequate maps are prepared.

Whichever procedure is followed in obtaining the map series, it is imperative that the maps be as complete and accurate as possible and contain all of the data necessary for proper geographic orientation. Obtaining these maps and aerial photographs must be one of the first activities of the study. It is imperative that ample time be given for completion of the map series before the study begins field operations.

An additional check on the accuracy of the map series can be carried out during the field listing process. The field personnel should be instructed to verify all streets and street names. Any corrections or additions found by the field listers should be noted and forwarded to the C&D division for entry on the map originals. By following this procedure, the study can insure a more accurate map to be distributed for land-use measurement and home interviewing.

Geographic Identification

Before any of the study's data collection phases can begin, a complete system of geographic identification must be incorporated into the map. There are two major requirements of this system: first, it must express an easily understood relationship between the data obtained and its geographic location; and second, it must permit the application of data processing for rapid geographic summarization.

As previously stated, a plane-coordinate grid system is superimposed onto the Cronaflex prints (USGS quandrangles) and subsequently enlarged and drafted at 1 in. = 400 ft. This ½-mi grid system is the basis of all geographic identification. That is, all of the units of area used for data collection and summarization are related directly or indirectly ½-mi grid network. Following is a brief outline of a geographic identification system suitable for a comprehensive O&D study (Fig. 1).

The Block

The smallest unit of area used for data collection is the block, similar in size and shape to the common census block. It is identified by the coordinate values of the block's geographic center. The blocks are determined first on the 1 in. = 400 ft base maps. Their size is determined, somewhat by the development of the area. For example, where population is dense, the blocks are small; in the more rural areas, the block's area is generally larger. Where feasible, the block is bounded by actual on-the-ground features, such as roads, streams, railroads, paths, power line rights-of-way, or other terrain features. During the block layout procedure, the 1 in. = 400 ft aerials must be referred to constantly. Where terrain features are absent, an imaginary line must be drawn to limit the block size. These arbitrary lines must begin and end at a definite spot on the map and be easily identifiable on the ground (such as road intersections, sharp bends, etc.).

When practical, an attempt to relate census blocks with the study's blocks is recommended. This possibility should be kept in mind and the census blocks referred to

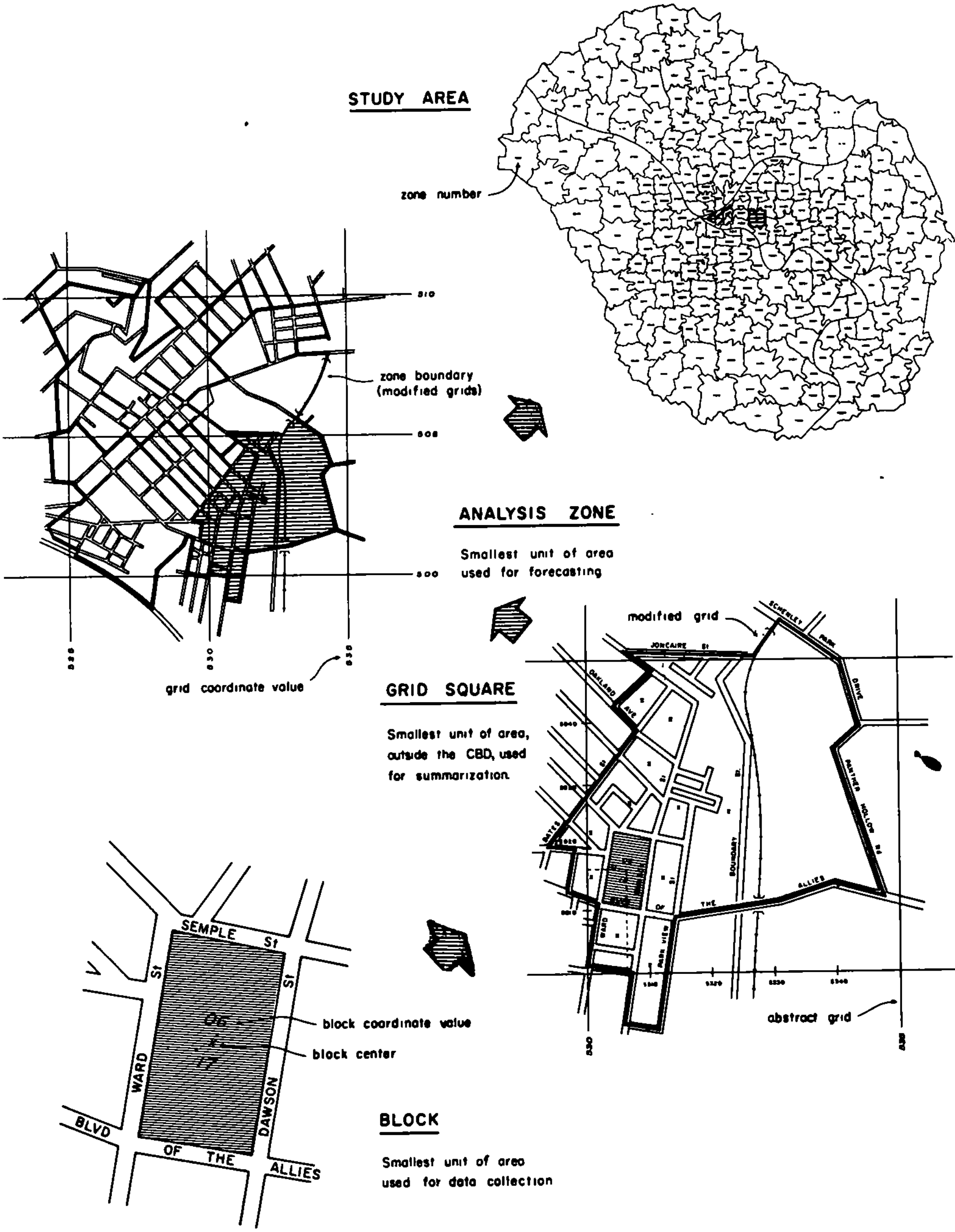

Figure 1. PATS' geographic identification progression.

when determining the study's block boundaries. By following this procedure an easy correlation can be made between study findings and census information. This method will necessitate an additional master deck of machine processing cards containing the study's block geographic identification and its census block counterpart. (This master deck will not interfere with the normal function of the block as used by the study, but will be used for the checking and updating of population, dwelling unit and related information.)

The Grid Square (Superimposed Grid)

To summarize the data collected during the study, a larger unit of area should be used. For this purpose the "grid square" is incorporated. The grid square is formed by the intersection of the ½-mi grid network, resulting in uniform ¼-sq mi areas. The grids are identifiable by assigned numerical "X" and "Y" grid coordinate values. As previously stated, the block is identified by its geographic center. Assigned to each grid square are all of the blocks whose centers fall within the superimposed grid's lines. Due to the dissimilarity between the superimposed grid and the block boundaries, a "modified grid" is required for reconciliation of areas. The modified grid is bounded by the perimeter of the block grouping and is geographically identified by the coordinate value of the superimposed grid from which it was formed (Fig. 1).

At PATS (with the exception of the central business district, where data is summarized by block) all information obtained during the data collection phase was summarized by grid square (modified grid). Thus, it was imperative that an adequate geographic identification system be used. For all intents and purposes, the system outlined was found satisfactory.

Forms

Another major function of the C&D division, particularly in the early stages of the O&D study, is the designing, drafting, and printing of forms. Although this may seem rather trivial contrasted with many of the division's other duties, it is of great importance to the collection, processing and controlling of the study's data that the forms be prepared correctly. It is a good practice for the person requesting the form to prepare a sketch of its contents, after which the actual designing is accomplished in conjunction with the C&D division's personnel. (A source used many times as a guide in the preparation of forms is the Bureau of Public Roads standard home interview form.) This cooperation is essential to insure that the maximum amount of usefulness be obtained from a form. With a thorough understanding of its purpose, the graphic designer can prepare a form suitable to the study's needs. Following are some suggestions for preparing the study's forms (especially adaptable to the home-interview-type forms).

1. Design form to minimize the amount of writing that must be done by the interviewer. That is, where possible, design the form so that a check or circle may be used to answer questions, rather than written answers.
2. Where writing is essential, allow adequate room so that the words need not be cramped.
3. On forms that contain areas for coding, as well as the recording of data, the coding block can be made more prominent by shading the block's area. This is accomplished during the photographic process with a 10 or 15 percent of black screen.
4. Shade areas in the body of the form that do not require the recording of any written data.
5. Draft form at a scale larger than that intended for the finished printed form, to insure a neater looking form.

Although the actual content of a form is the responsibility of the person or division requesting its preparation, there are some details that are many times overlooked. Following are some suggested methods of improving the efficiency of the form.

1. Where practical, squares should be provided on interviewing forms so that all of the coding required may be done directly on the form. That is, the coders (a coder is the person responsible for translating the written information obtained from the interview into a code suitable for machine processing) should work on the same forms used by the interviewer.
2. When the code used for an answer to a form's question is the same as the answer itself, the form should be designed so that the interviewers can enter the answer directly into the coding block. This will eliminate unnecessary work by the coder. (Example: "Number of cars owned?" Answer: "2". The "2" should then be placed by the interviewers directly into the coding block provided for that question.)

3. Much of the information obtained during interviewing has only a limited number of possible replies; for example, "mode of travel," "type of parking," and "trip purpose." The possible answers to each of these questions should be listed in a convenient place on the form along with their assigned codes. The interviewer may then use this listing as a guide for recording answers to the question.

Manuals

Manuals covering office procedure, field listing, home interviewing, roadside interviewing, and land-use measurements must be prepared before the field work begins. The coding manual, although not needed for field work, should be prepared as soon as possible following the other manuals. It is not the C&D division's responsibility to write these manuals, although they may assist in some of the technical sections concerning map reading or related information. The division should set up a standard format to be followed in preparing the manuals and should prepare the required illustrations.

Miscellaneous

Along with the particular projects mentioned, there are numerous minor duties that must be completed by the C&D section. First, the division must acquire all available maps of minor civil divisions within the study area. Also, if possible, postal route maps should be obtained from post offices throughout the area. These maps can be used as an aid in preparing the map series needed for data collection, and can be used as reference for local zoning ordinances and land use. In addition, during the early stages of the study, local agencies can be approached for maps containing information pertinent to the study area.

Also included during this phase of the study is the setting up of the library. Reference material useful to all phases of the study should be obtained, indexed and filed.

PREPARATION FOR CODING AND ANALYSIS

Coding Requirements

After the data collection phase of the study is under way, the C&D division duties include the preparation of source data for the coding procedures. A study's analysis will be inadequate unless trip ends can be precisely located. Therefore, there is a great need for accurate coding guides which geographically locate the trip end possibilities. It should be the duty of the C&D division to assist in the preparation and checking of all such guides.

At PATS, there were five coding guides: the trip generator file, local place name guide, street guide, intersection guide, and adjacent area guide. The procedures followed in obtaining the required guides were found satisfactory; therefore, these methods are described. First, to compile the trip generator file and local place name list, the study's grid coordinate system was plotted on a set of USGS topographic quadrangles of the study area. (Local place names as referred to here pertain to those areas other than civil divisions known by school districts, predominant geographic feature, old "stand-by" names, etc.) Next, for the generator file, the names of as many large trip generators as possible were obtained. Each generator was then located on the USGS sheets and assigned its grid coordinate value. A similar method was used for the geographic identification of the local place name coding guide. When these lists were completed, they were then turned over to the machine processing division and an alphabetical listing of each guide was then printed.

The street guide was initially processed from field lists by the machine methods division of PATS. These lists contained all street names by the lowest-highest address in each block within the study area. It should be the C&D section's duty to verify all streets from the data collection map series.

The street intersection guide was prepared in an effort to pinpoint trips in rural areas. For example, if the interviewer could not obtain a suitable address or location for a trip, he was instructed to get the road names of the nearest intersection. Therefore, to code trip ends such as this, a street intersection guide was prepared. The guide geographically identified all street intersections by both streets involved. Although the list is prepared by the machine processing division, the C&D section must verify each intersection, thus insuring an accurate means of assigning trip ends that might otherwise be lost.

In order to allow adequate accountability of trip information beyond the immediate study area and to create a buffer zone for future predictions, an adjacent area surrounding the study's cordon line was plotted. Detailed maps, such as the 1 in. = 400 ft data collection maps, were not needed in this area. Instead, the 1 in. = 2, 000 ft USGS quadrangles were used for adjacent areas coverage, and the grid coordinate system was extended to take in this area. In this way, a means of geographic identification was possible. An adjacent area coding guide was then prepared. In this guide, each civil division was assigned the grid coordinate values of the "superimposed grid" located at its geographic center. Also, to assist coding, all place names within each civil division in the adjacent area were assigned the grid coordinates for that civil division. (For coding purposes, all trip ends in the adjacent area were coded to these civil divisions.)

The C&D division may also help the coding procedure by preparing coding conversion tables and large coding charts, (for example, small tables converting normal time to the military numerical system—5:30 PM to 1730; also, coding progress charts).

Analysis Requirements

The block, the superimposed grid and the modified grid have been described. The block is the unit of area used for the collection of data, the modified grid is used for summarization (being formed from blocks and identified by its superimposed grid counterpart). Now for more general analysis, it becomes necessary to enlarge the units of area.

The system used at PATS to define "zones" and the reasoning behind this system will be described, because the criteria followed could be used as a guide for any given area.

The analysis zones within the study area were set up to provide workable units of area for the anlaysis of collected data and the forecast of future population and land use. Zones are composed of one or more modified grids and vary in size from approximately ¼-sq mi in the CBD to 4½ sq mi in the more rural areas. The variation in zone size is, in part, an attempt to equalize trip ends. Other factors pertinent to the selection of zone boundaries are: the extent of the arterial network, the degree of urbanization, continuity of the area, and the existence of topographic barriers.

The zones were first plotted on boards containing PATS' arterial street new-work system on an overlay of the 7½- x 7½-ft USGS quadrangles. (The making of the USGS boards and plotting of the arterial system on them are explained in the next section.) Clear acetate was placed over the USGS topographic maps which, in addition to the arterial system overlay, also contained the superimposed grid and a modified grid overlay. Because the grouping of the modified grids into analysis zones is somewhat of a trial and error procedure, the initial plotting of the zones was done with grease pencil on the clear acetate. As stated, there are certain factors that control the zone size and these factors must be taken into consideration when plotting the zones. Some of the factors previously mentioned may be found in part or in whole on the USGS 7½- x 7½-ft quadrangles themselves. For example, the topographic barriers are quite evident on these maps. When additional base data are used in conjunction with the USGS maps, some of the other factors, such as the degree of urbanization and the continuity of the area, are apparent. The extent of the arterial system, which is already plotted on the maps, is readily accessible. Another point to take into consideration is the zonal loading node. (The zone loading node is the single point at which trips to and from the zone enter or leave the arterial network in the traffic assignment process.) All major arterial intersections are considered potential loading nodes; therefore zones to some degree are so constructed that their centroids are located near a major intersection. The remaining factor, and one of the most important, is the problem of equalizing trip ends. A valuable asset to have when considering this important point is a "tab map" (to be explained in detail later) containing the number of trip ends in each modified grid (grid square).

Although satisfying all of these criteria is generally impossible, each must be taken into consideration when selecting the grouping of modified grids which make up the zones. In Figure 1 the growth of a zone from block to modified grid and finally to analysis zone can be seen. When a satisfactory series of analysis zones had been set up at PATS, the modified grids' coordinate values within each zone were listed and punched into cards for machine processing. A tabulation was prepared and checked back against the original zone layout for completeness. The zones were then numbered consecutively from the CBD in a clockwise manner within ring and sector.

Analysis zones were also carried out beyond the study area and into the adjacent area but were formed on the basis of less detailed inspection. These zone boundaries were formed by incorporating the Pennsylvania Department of Highways' statewide coding system. However, because the civil divisions were used for assigning trip data in the adjacent area, the zone boundaries could have been formed to correspond with the civil division boundaries. (Because the adjacent area zones were large at PATS, grouping of the civil divisions would have been necessary in most cases.) By using these civil division boundaries, a tighter control of the trip data would have been possible. Also, estimates of population distribution and land use would have been simplified a great deal.

For broader and more general analysis, there was prepared a system of "rings," concentric about the central business district, and "sectors," or wedges with the small ends focused at the CBD. Generally speaking, where two ring lines and two sector lines encompass an area, a "district" is created.

Rings are plotted in time-distance increments starting at the CBD and ending at the study's cordon line. Primary rings are first plotted in uniform progression from the CBD. But, since all units of area used for analysis must be related to allow machine summarization, the zone boundaries nearest the plotted ring lines are followed. At PATS there were eight such rings within the study area, numbered from 0, in the CBD, to 7 at the perimeter of the study area. All of the adjacent area surrounding the cordon line was considered ring 8, everything beyond was assigned to ring 9.

The sectors at PATS were first plotted in roughly at a 45-deg angle from the CBD and aligned so that each of the three river valleys was straddled by the sector's boundaries. This procedure was followed in an attempt to group types of land uses and environments into sectors. Again, the zones nearest the plotted sector lines were used for the actual sector boundaries. The PATS study area is split up into a total of eight sectors. These sectors are continued beyond the study's and adjacent area's extremities and carried throughout the United States, Canada and Mexico.

And analysis district is created by the intersection of two ring and two sector lines. Due to the construction of the rings and sectors, it is only reasonable that the area of the districts will enlarge as the distance from the CBD increases. Since the requirements for the district are similar to that of the analysis zone, great care must be exercised in plotting each ring and sector. When these controls (for the forming of zones) are considered during the selection of the ring and sector, the initial uniformity of trip ends and land use (urban and otherwise) is not lost.

PREPARATION OF ARTERIAL AND MASS TRANSIT ASSIGNMENT MAPS

As the trip maps needed for the highway and mass transit trip assignments are virtually the same, only the procedures followed in preparing adequate maps for the highway assignments is described. In the following paragraphs, the methods used at PATS to prepare this map series will be explained, beginning with the origin of the highway system.

For the purpose of selecting an adequate highway network, a complete set of 7½- x 7½-ft USGS topographic quadrangles covering the study area and the adjacent area was obtained. These USGS maps were then mounted in pairs on heavy-duty cardboard and the predetermined superimposed grid was plotted onto the maps exactly as it is on the data collection map. Each board was then numbered for indexing and covered with matte acetate and protective clear acetate overlays. (The clear acetate was also used for preliminary layouts in grease pencil.) The matte acetate was used for a more permanent record of the arterial network plotted. Although these boards were primarily used for the network layout, they had many other uses, as for example, the plotting of the analysis zones described in the preceding section.

The USGS boards were, at this stage, then turned over to the traffic engineering division for plotting of the highway network. While the arterial system was being laid out by the traffic engineering division, the C&D division began preparing the maps needed for the assignment series. First, the black separations of the 7½- x 7½-ft quadrangles were acquired from the United States Geological Survey, after which a film negative print of each of the sheets was reproduced. The negatives were then matched together (east to west) forming three strips covering the study area. (Strips, as referred to in this part, are the USGS 7½- x 7½-ft quadrangles matched side by side, covering the study area from east to west with one 7½-ft quadrangle north to south. Three such strips covered the PATS area.) The negative strips were then screened and a contract Cronaflex print reproduced from each of the strips. The screening procedure subdues the image of the USGS map's detail so that the more pertinent information, such as the arterial street network and the study's analysis zones (added later by the C&D division personnel), stands out on the finished product. This subdued area is referred to as the supporting detail of the assignment maps.

When the arterial street network was examined, it was decided that the area surrounding the CBD was much too congested for an adequate posting of assignment results. Therefore, this portion of the study area was photographically enlarged and placed on a separate Cronaflex print. Although this enlargement was sufficient for the area surrounding the CBD, it still was not detailed sufficiently for the CBD itself. Consequently, a still larger scale map was required for the area. In all, three separate map scales were used for the PATS traffic assignment series: first, basic USGS strips at the scale of 1 in. = 2, 000 ft; second, the enlarged area surrounding the CBD at the scale of 1 in. = 1, 000 ft; and third, the CBD itself at the scale of 1 in. = 500 ft. A separate Cronaflex strip was also prepared with line diagrams of the expressway interchanges to illustrate the complex coding of the interchanges required for traffic assignment problems.

When the aforementioned procedures were completed, the C&D division had five map strips showing the supporting detail within the study area. Three contained the USGS black plate at scale, one consisted of both the enlarged maps of the central portion of the study area, and one contained the expressway interchanges.

A point worth emphasizing is that the supporting detail should be printed on the reverse side of the Cronaflex strips. This allows changes and additions to be made on the first side without distorting the supporting detail on the back. Also, when contacting additional Cronaflex prints, a sharper image is achieved. The importance of this method will become more evident in later parts of the discussion.

When all of the maps containing the supporting detail were completed, the arterial network was added to the Cronaflex strips, using the prepared USGS boards as a guide. When plotting of the arterials was finished, black and white prints were reproduced and delivered to the traffic engineering division to be used in making the arterial street inventory. On completion of the inventory, all additions and corrections to this highway network were noted and submitted to the C&D division for revision of the Cronaflex strips. Then reproducible sepia prints were made from the Cronaflex strips. Pertinent arterial inventory data could be added to the sepias, and black and white prints reproduced when needed. This completed the mapping needed for the arterial inventory; however, there is additional information that must be posted on the Cronaflex strips before the set of assignment maps is adequate.

Sometime between the selection of the arterial network and the completion of the network's inventory, the analysis zones should be defined. (For the method followed, see the section on, "Preparation for Coding and Analysis.")

At this point, all of the basic detail needed to set up the assignment maps was available. There is a complete set of Cronaflex strips (with the USGS map information screened and printed on the back) of the study area, including the existing highway network (drawn in ink on the front side). Also, the analysis zones were completed and posted on USGS board overlays. These zones were then added to Cronaflex strips for use in the assignment coding. Inasmuch as the zones, like the USGS map detail, will not change with each new assignment, they were drafted on the back of the Cronaflex prints and black and white prints made. The traffic engineering division devised a numerical identification system (node numbers) for all arterial intersections on these prints which were then returned to the C&D division. After editing, the node number and symbol for each intersection were added to the Cronaflex strips.

Although a major portion of the Study's planning effort concentrates on traffic movement within the study area, consideration was also given to the adjacent area. A simplification of the type of map needed for traffic assignments was used. All that was required was a single line drawing, showing the arterial network, the arterial intersection identifications, and analysis zones. The scale of this adjacent area map was much smaller than the study area map, thus enabling the complete adjacent area to be shown on one map.

Before future traffic assignments can be made, there is a trial and error period used to test different methods of assigning traffic on the original arterial street system (revising the computer program as necessary). Using this procedure, the results of the different methods may be checked back against known ground counts, as obtained by the arterial inventory (or, if interchanges have been calculated by computer, checking back against known interchanges). Once an adequate program is devised, there is a need for additional sets of assignments to test various arterial and expressway proposals. To eliminate the need for preparing a new set of maps for each assignment, the following procedure is recommended: reproduce auto-positives (on Cronaflex prints) of the complete set of assignment maps containing the existing highway network. These should then be filed. The original Cronaflex strips (containing the arterials and their intersection identification on the front side in ink, and the zones and USGS maps' detail on the back) were used for the next assignment and each additional assignment thereafter. On black and white prints of the original strips, the traffic engineering division can make the necessary highway changes and highway proposals. The new arterial intersections formed may then be identified, checked, and coded into the highway system. These changes can be made on the original Cronaflex prints and a sepia print reproduced. The sepia print may then be labeled and filed as a permanent record of that particular assignment. Also, black and white prints can be made for posting the assignment results.

For the next assignment and each assignment thereafter, until an adequate highway system is decided on, the mapping procedures will be the same as the ones previously outlined. That is, the highway changes required for each new assignment should be made on prints of the previous assignment, and the change made on the original Cronaflex prints. Each time the original Cronaflex prints are changed, a sepia print should be made and filed as a record of the highway system used for that assignment.

The great difference in cost is the reason for using sepia prints in place of Cronaflex prints for immediate assignments. However, the sepia prints are not very durable. Therefore, for the definite arterial networks (first and last assignments) the Cronaflex prints are preferable. Also, the Cronaflex prints are much more suitable for corrections and additions, because the initial arterial roads set up by the study can be altered and added to without any distortion or mutilation of the zones and supporting data on the back.

From time to time there is a need to display the assignment results. This need is most evident in the early stages and for the late stages of the trip assignment phase. While the maps described fulfill the purpose for which they are intended, any attempt to display the entire study area at one time would prove very difficult. To overcome this difficulty, the strips were photographically reduced to a desirable scale and joined into a composite map. From this, a Cronaflex map was reproduced (and subsequently black and white prints), on which a color coding system was used to display the assignment results.

A properly prepared series of assignment maps is of the utmost importance to a comprehensive O&D study. Assigned trips to proposed plans represent the culmination of many months of data collection, forecasting, and planning. These results are therefore of vital interest to both study staff and sponsoring agencies and deserve the best presentation possible. It is felt, at PATS, that the method outlined will satisfy all the requirements of an adequate series of assignment maps.

PRESENTATION OF STUDY DATA

During the life of a comprehensive O&D study, a vast amount of information is obtained. It is the C&D division's duty to graphically present this data in an accurate and concise manner. Not only is the pictorial representation of data an aid to the study's planners, but it is also an important public relations factor. In many cases, a person's initial opinion of the study (gained through personal contact or through publications) is the most lasting. People, although they will not admit it, do attempt to tell a book by its cover. Consequently, to favorably impress the visitor or reader, graphic illustrations must be presented in an attractive manner. Along with attractiveness, the information must be accurately displayed by the simplest method possible.

There are two primary means of presenting the study's data. One is the permanent display housed at the study's office. These displays may be used for presentation at lectures, conventions, and the like. They are also used by study personnel and other interested agencies for analytical purposes. The second method of graphically presenting information is through written technical reports, monthly publications, and the study's final report.

The following sections outline the procedures followed by the PATS' C&D division in completing some of the more important displays. Also noted is the use of these displays as illustrations in publications.

Base Map

The PATS' base map can be defined as a picture of the study area, showing selected study data and geographic features necessary for orientation. On this base, all data collected and all future predictions may be visually presented. In this way, there is formed a clear and definite pattern to assist in final analysis.

The base map is composed of ten separate overlays, five of which represent the following major geographical features: the PATS' arterial road network; civil divisions; civil division names; drainage; and major railroads and airports. The remaining overlays present the imaginary boundaries that were set up for the collection and analysis of data and include: ½-mi grid coordinate system; modified grid; analysis zones; districts; and cordon and screenline stations.

Although these two types of detail had different origins, the process of compilation was similar. Each item was laid out on a suitable reference map. A preliminary check was made for completeness and accuracy. The next step was to trace the items separately on overlays registered to one another. Each overlay was then reduced photographically to the working scale of 1 in. = 1 mi. The reductions were drafted in ink on a polyester base drafting film. After the drafting work was finished, each item was thoroughly checked for completeness, accuracy, and neatness. As work was concluded on the individual features, they were compared to one another for perfect registration of detail.

For most analysis and display purposes PATS used the base map at a scale of 1 in. = 2 mi. To facilitate the availability of the required base map combination, all overlays were reduced to this scale and filed in negative form. Each overlay was reproduced in line and screened form, so that the item of importance to the user would stand out (line) on a background (screened) of related information. Also a few composites were prepared in anticipation of maps needed for analysis. From this pool of overlays and composites, most of the study's reference maps could be prepared without any additional drafting.

To explain further, an example would be a user interested primarily in the arterial road network. He would want to associate the network with the ½-mi grid, the civil divisions, and the drainage. The arterial road network would be printed in line form, the ½-mi grid in line form, and the civil divisions and drainage in halftone. This would give the user the arterial road network, with which he is working, and the ½-mi grid; the background, providing orientation, would be the civil divisions and the drainage.

To accomplish this, each of the four overlays must be combined photographically to a single reproducible from which prints can be made.

In addition to the overlays, specialized overlays were also prepared as requested. For example, an index of the aerial photograph coverage was drafted as well as a mass transit system overlay.

For presentation of data in the PATS' final report, a simplification of the base map was required. The map is a composite of many of the base map overlays and contains the minimum amount of detail required for proper orientation.

Another phase of the base map series at PATS was the preparation of a CBD map. This map contains all streets within the CBD with overlays defining its arterial streets, blocks, analysis zones, and census blocks.

Tab Map Display

Tab Map.—A tab map, as prepared by PATS, may be defined as a geographic table. In reality, it is a gridded roll of tabulation paper containing data collected or projected by the study, originating in the machine processing division. The grids printed on the tabulation paper are set up to correspond with the superimposed grid coordinate system

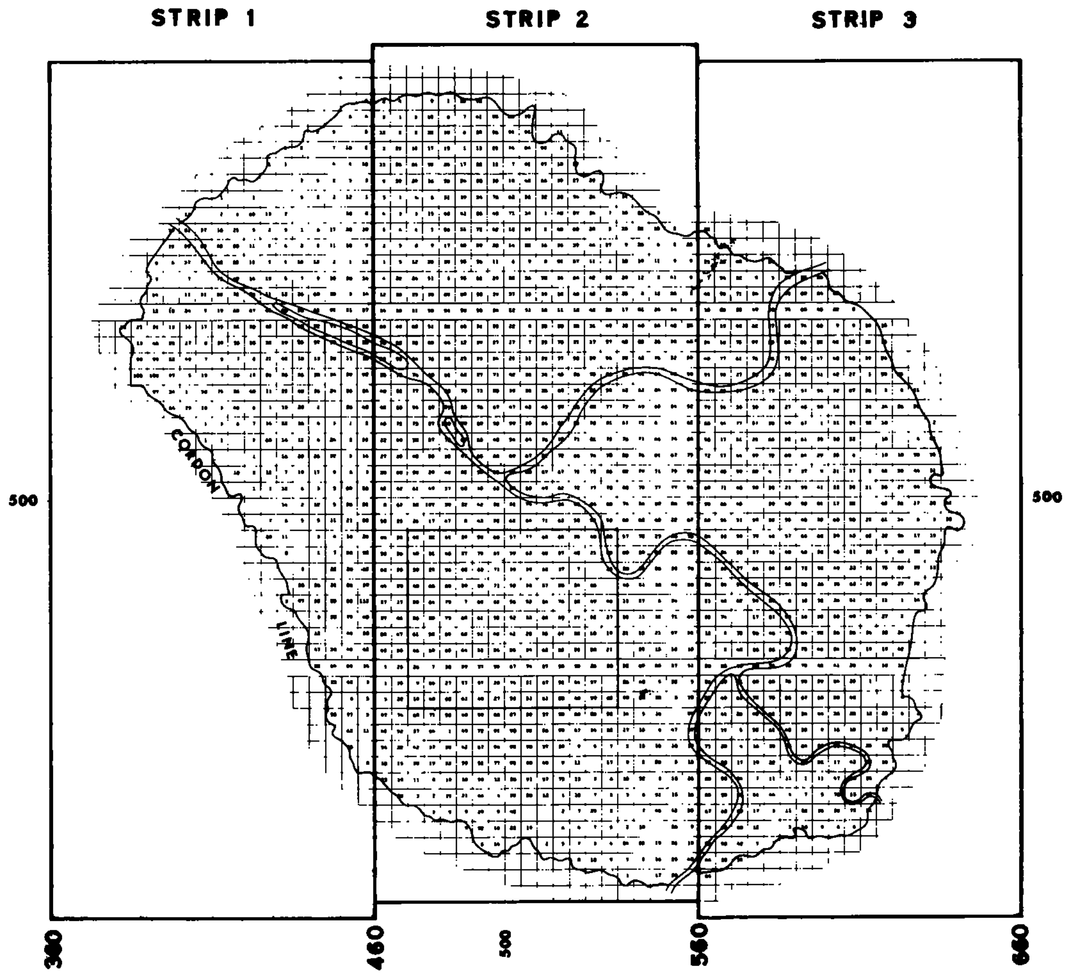

Figure 2. Layout of machine-printed tab map. The Study's cordon line and rivers were added to this reduction to clarify the relationship between the study area and the tab map.

used for geographic identification. The information to be printed on the maps is on punched cards and arranged in such order that the data pertaining to a particular grid square (modified grid) is printed in a ½ in. square representing that grid on the tab map. The ½-mi grid is the smallest unit of area summarized for the printing of the tab map. These maps break the study area's 1,692 grids into three strips (Fig. 2) at the scale of 1 in. = 1 mi.

Although the grid square is the basic unit of area used for presenting data collected, it becomes necessary to decrease the number of geographic units for the study's forecasting, therefore, the analysis zones are used. To present this projected data in tab map form, the same machine procedure is used, with the exception that only one grid out of each zone is used for printing information pertaining to the whole zone, this grid being the geographic center of the zone, whenever possible. (For a description of how analysis zones are formed, see the section on "Analysis".)

When the three strips making up the maps, either the zone or grid type have been printed and checked for accuracy by the machine processing division, they are turned over to the C&D division. After the three sections have been stripped together and all of the X and Y coordinates labeled, an appropriate title is put on each map, and the data is then reviewed (Fig. 2).

Although all the tab maps printed at PATS are important as reference material, the tab maps thought to be most useful were reduced from 1 in. = 1 mi to 1 in = 2 mi and prints reproduced. To facilitate reading of the grided tabulations, they are used with transparent overlays of the PATS' base map. In this way pertinent information may be readily correlated with civil divisions, the PATS' arterial system, or the PATS' analysis zones.

Presenting the data on tab maps with different overlays is sufficient for reference purposes, but is ineffective for over-all effect and legibility. It is practically impossible to look at a group of maps, each containing hundreds of grids, with anywhere from one to five digits printed in each grid, and try to form a complete picture. This is the major factor that necessitated the presentation of PATS' data in display form. Here the old saying "One picture is worth a thousand words" (or digits in this case) was never more true.

In choosing the data to be presented, several factors are to be considered. First, the data should be comprehensive enough to contribute to the general idea the study wishes to convey. Another consideration is the analytical value and appearance of the finished display weighed against the cost of producing it. With a decision based on these two points, the process used for data presentation was the problem next at hand.

At PATS two methods of displaying the data printed on the tab map were employed. By the first method, a model was built with the values in each ¼- sq mi area (grid square) represented by the height of wooden sticks. The data best presented in this manner was trip information. The second method used was the isoline map. This type of display is compiled by enclosing areas (grid squares) of similar values. Both of these methods are explained in detail in the following paragraphs.

Trip Models.—Inasmuch as the data to be shown was reduced to the standard display scale of 1 in. = 2 mi, each ½-in. grid became ¼-in. square. Consequently, wooden sticks ¼-in. square were used. From these strips, 7,000 wooden blocks were cut in ⅛-in. increments, in sizes ranging to 4 in. in height.

The procedure followed in making all models whose data are summarized by grid square is exactly the same. For this reason, the process used in preparing the model shown in Figure 3 will be explained.

The reduced tab map, "Mass Transit Trip Destinations" (by ¼ sq mi), was scanned to set up a suitable scale that would best point out the concentration of mass transit trip destinations within the study area. The vertical scale decided on was 1,500 trips per ⅛ in. of vertical height. A conversion table was then prepared using this increment range. For example, all grids with values between 1,000 and 2,249 were rated 1,500 trips (⅛ in.); likewise, all grids with trips ranging from 2,250 to 3,750 were rated 3,000 trips (¼ in.), etc. With the conversion table as a guide, the reduced tab map was gone over very carefully and each grid that fell within one of the values was

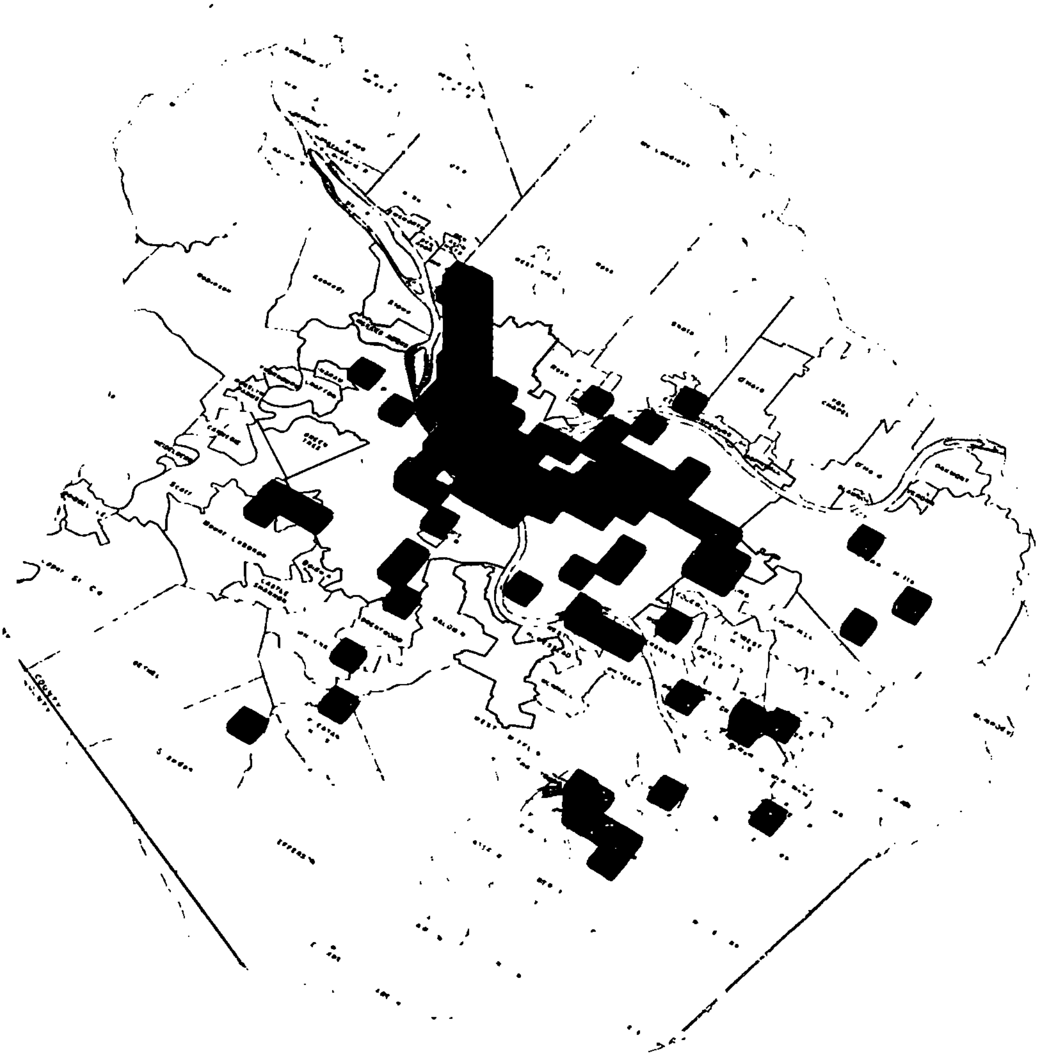

Figure 3. Typical model depicting mass transit trip destinations, by $\frac{1}{4}$-sq mi grid.

marked. When this step was completed, a transparent base map overlay (the same kind that will be used in the final display) was aligned on the tab map and the proper size wooden blocks were placed on the grids they represented. For example, all ¼-in. blocks were placed on the grids that fell within the range of the 3,000 trip value. Whenever the blocks were adjacent to one another, they were glued together, but not to the overlay. On completion of the positioning of the blocks, a very careful check was made to asure that each grid was represented by the proper size block. After all adjustments were made, the blocks were painted and varnished. (If the models are to be photographed, do not varnish the sticks until after the photographs have been taken.)

A photoprint of the same type of map that was used to set the wooden blocks on was then mounted on an 18-in square board, and the study area was tinted in. Next, the blocks were transferred from the overlay to the photoprint and glued down. It was necessary to exercise great care in this process, so that there would be no geographic distortion of the work trips represented by the blocks. This was the major reason for using the same map for both the tab map overlay and the photoprint used for the display. To complete the model, the title, legend, and border were then added, and as a protective measure, the model was covered with a plastic dome.

At PATS, the preparation of the models used to represent the study's trip forecasting is similar to the method previously described. There is, however, one major difference between these two models. The difference lies in the preparation of the base map on which wooden sticks are positioned for display. The base map contains, in addition to the civil divisions, all of the analysis zone boundaries. This is necessary because the wooden sticks, in most cases, represent an area much larger than the stick is square. (In the case of the models summarized by grid, the wooden sticks, which are ¼ in. square, are exactly the same size as the grid square they represent.) Also, because the area being defined is larger, a stick may be used to represent current trip data in the same zone with a stick representing the projected trips; thus the relationship between present and forecasted trips may be better compared.

Besides these displays representing data pertaining to the study area as a whole, models were also constructed representing Pittsburgh's CBD trip destinations and floor area data. In the CBD, data was summarized by block in place of grid, therefore, the models were prepared directly from table print-outs and not from tab maps. The preparation of the wooden sticks was similar to that of the study area models.

The completed trip models at PATS are used by the study for three different purposes. First, they are used by the study personnel and other interested agencies for general reference and analysis. Second, the models are photographed and presented as illustrations for the final report. The third way the models are used at PATS is for public relations purposes. They are displayed at conventions and meetings outside the study to familiarize other agencies and public with the study's functions and findings.

Isoline Maps.—In the case of the isoline maps, as with the trip models, the data to be displayed are printed out on a tab map and reduced to 1 in. = 2 mi. (The word "isoline" simply means a line of equal value and the compilation of an isoline map may be described as similar to the "logical contouring" of relief features. The isoline map as used here, however, is compiled by enclosing areas of similar values rather than connecting an infinite number of equal-value points.) The information printed in the tab map's grid square (or superimposed grid) is first "color coded" by grouping the data on the map into logical value ranges. Then the color given each abstract grid is transferred to its modified grid counterpart on another map. This transformation is necessary because of the variation between the superimposed and modified grids and results in better orientation of the information and the area which it represents. After checking, the color-coded modified grid map is overlaid with a drafting film containing a base map for final drafting. The perimeter of each color grouping is then traced. This type of isoline is used at PATS to represent the percentage of a modified grid used for a particular land use.

For presentation of data relating directly to population, another step is incorporated. By visual reference to actual population concentrations, the perimeter of each grouping is shaped somewhat, instead of simply following the modified grid boundary. (Similar shaping is done at the major rivers and prominent terrain features on all isoline maps.) This method conveys a more realistic picture of the distribution of population, car ownership, residential density, etc.

This type of isolining requires individual interpolation; therefore, it is doubtful that two persons would ever draw the same isoline map. However, the difference in interpretation may be lessened somewhat by the addition of more reference matter. At PATS, to attain greater accuracy and a more realistic picture, an overlay containing all large plots of used land (other than residential) and the vacant unusable areas was prepared. This overlay was used in conjunction with each of the color-coded modified grid maps for forming the isolines representing data relating to population.

A properly prepared isoline map is a valuable contribution to a study's analytical ability. Also, it provides an excellent means by which an area's land use and population characteristics may be defined.

Trip Desire Line Maps

A complex problem in every O&D survey has always been the presentation of trip desire data. For the data to be a useful tool to the analyst, it must be presented in such a manner that it can be read and understood. One graphic method of displaying trip desire data would be to plot every trip by hand. This method requires many man-hours of labor and the finished product would not be easy to read and understand. Several methods have been used to reduce this problem to manageable terms. Probably the most commonly used method has been to group trip ends by zones and display the volume of interzonal trips by varying width bands. This method shows grouped trip desire lines. Another method which has been developed and is used by several agencies is to compute the direction each trip moves on a grid, punch a card, for each grid square traversed by the trip as it moves from origin to destination, summarize the cards, and make a tab print-out (tab map). This print-out can then be taken to the drafting table and isolined, producing a trip desire density chart.

All of these methods have one bad characteristic—the amount of man-hours and machine time necessary to complete the display. Early in 1958, the Chicago Area Transportation Study, in conjunction with the Armour Research Foundation of Chicago, developed a machine that will help to solve the problems associated with the presentation of trip desire data. Called the Cartographatron, (1), this machine is an unbelievably swift X-Y plotter.

The Cartographatron process involves three steps. Step one involves converting the original punched card deck for each survey to magnetic tapes. Step two is the actual operation of the machine in which the records taken from the tapes are converted to light traces, and recorded on a photographic plate. This plate acts as a memory or summarizing device. Step three involves the photographic plate, which is removed from the camera and developed. The negative can, by use of a densitometer, be electronically split to find the range of densities depicted by the data. This information can then be used by the photo lab to "slice" the negative into high contrast prints of different densities, which, in turn, can be drafted to form an isoline map. This method produces possibly the truest trip isoline that can be made, because the density patterns depicted in this manner are products of a mechanical application and not of human judgment.

If isoline maps are not desired, the negative is simply combined photographically with an overlay of the civil division map (for orientation) and printed to form a display. The machine can also be wired to show only origin of trips or destination of trips for particular trip purposes.

To estimate the amount of man-hours necessary to plot each origin and destination for an entire study area is next to impossible; to group trip ends by zones and plot them that way would take several months. However, the Cartographatron can, after the tapes are made, run a complete display in less than four hours. Thus, with approximately 4,000,000 combinations from one complete trip file and because of the speed at which they can be put in readable form, the analyst has many more desire line maps in highly selective forms.

Growth Map

A growth map may be described as a pictorial way of expressing progressive development in a certain area. Still another description might be that, in essence, it is much like looking at a cross-section of a large tree that shows its growth pattern in the annual rings. The growth map compiled by PATS, for example, shows the development of the Pittsburgh area from 1760 to 1958.

The major source of historical maps required for plotting the growth map was the Carnegie Library of Pittsburgh. Any source that might contain information on the placement of population for a particular year was closely examined. All maps that were found and thought to be of value were then traced exactly as printed in the source. Showing as much detail as possible at this stage proved to be a great help later when the different maps were collated. There was an abundance of material available on the growth of Pittsburgh proper; however, very little data were to be found on the area now known as metropolitan Pittsburgh.

Other sources were then sought for more recent maps showing population trends.

The United States Geological Survey (USGS) quadrangle, dated 1904, and a map showing development, dated 1930, were obtained—the latter from the Allegheny County Planning Commission. For the most recent information on development, the PATS' aerial mosaic was used. This was made from photos dated 1958.

After the basic data was compiled, it was analyzed so that an accurate picture of growth could be presented. Certain maps were discarded due to insufficient information or because they were dated too close together to show a noticeable difference in growth. After analysis, the following maps were chosen for final use: 1760, 1795, 1830, 1875, 1910, 1930, and 1958.

The 1904 USGS map was used as a basis for compiling the collected data inasmuch as much of the street network at that time corresponds with that of today. Roads, along with rivers, streams, railroads, and general contour of the land, constituted very good reference points for the plotting of the newer developments. At the same time, the 1904 base map helped in the location and plotting of the older settlements.

The 1904 map was then overlaid and, starting with the earliest date, each growth year was drawn in isoline form. After the growth map was drafted in final form, it was photographically reduced for use in PATS' final report. The original was used as a permanent display.

The growth map, besides being a display and illustration in the final report, will serve other functions. It may be helpful, for instance, in the prediction of future development in commercial, industrial, and residential areas. The map may also be used for analysis in conjunction with the area's economic status. Aside from these reasons, there will be even more uses for the growth map, because knowledge of what has happened in the past is a great factor in predicting what is to happen in the future.

Aerial Mosaic

An aerial mosaic provides a more complete and concise picture of a study's area than any other means of visual presentation. Although it cannot be used for exacting measurements, it is an excellent source for general references during all phases of the study. The mosaic will contain all existing topography at the beginning of the study. This is important for two reasons: First, it is very doubtful that there will be any map available containing all recent developments throughout the study area. This is extremely important for pin-pointing locations for land use and large trip generators. The mosaic will also afford a permanent record of the study area as it existed during, or immediately before, the data collection phase. Besides being valuable as a reference tool, the aerial mosaic is a very impressive permanent display.

Terrain Model

A terrain model (a three-dimensional map) of the study area is definitely an interesting display. The value of the terrain model as an aid in the study's planning procedure is dependent on the terrain features dominant in the area. In Pittsburgh, where the terrain is quite irregular, a model of this type was found necessary to properly grasp the actual lay of the land for traffic planning.

If the terrain model is decided to be an asset to the study, a method of obtaining it must be decided on. There are two procedures that might be followed. First, the model could be made by study personnel; second, the preparation of the model can be contracted. The construction of an accurate model is a very tedious operation requiring tools not common to a drafting room. For this reason, it is very unlikely that the C&D division would attempt to build the terrain model. Therefore, the second method is more desirable. If the building of the model is let out on contract, the amount of detail shown on the map is dependent directly on the amount of money allotted for construction. Regardless of the amount of detail on the model, there are certain basics that are common to any model that might be made. For instance, the model should be constructed of a lightweight durable material that is capable of maintaining its shape. Also, consideration should be given to the possibility of updating the model's detail (new roads, developments, etc.). That is, the model's original detail should be set up so that additions can be made by the study's personnel or, if done outside the study, at a minimum of expense.

Miscellaneous Displays

At PATS, it is felt that by varying the method of displaying study data a more effective over-all result may be achieved. For this reason, in addition to the displays mentioned in the preceding sections, numerous other displays will be constructed by the C&D division. To date, PATS has prepared approximately twenty displays by methods other than those previously described. These include such items as "Data Collection Stations," "Rapid Transit Proposals in the Pittsburgh Area," "Centroids of Selected PATS Data," "Station to Station Thru Trips," "CBD Accumulations of Persons and Vehicles," "Study Progress Chart," "Study Organization Chart," "Traffic Flow Map," and many more.

Illustrations for Publications

Due to the complicated nature of the data and the constant use of statistics, graphic illustrations are necessary to support the text of study publications. Well-planned illustrations assist the author in telling his story and provide additional interest for the reader.

At PATS the type of illustrations used in publications, except the final report, consist namely of charts, graphs and simple maps. Due to the expense involved most of these illustrations are printed in black and white. However, if the information or area defected appears to be congested, then a colored overlay is added to clarify the situation. When overlays are used, extreme care must be taken to insure proper registration during the drafting and printing process.

Although neatness and accuracy are essential for all illustrations, a little more effort should be exerted when preparing the final report's maps and figures. Each illustration should be thought out carefully and the end product visualized before it is drafted. Where possible, especially for the final reports graphs, a standard base is desirable. For example, at PATS most of the graphs are to be printed at a 3- x 3.3-in. size. To standardize the line weights of each of these illustrations, a base graph containing the borders and three horizontal lines was drafted at 10 in. x 11 in. (to arrive at the desirable printing size, a reduction of 30 percent of the original's size is needed). This base graph (containing five equal spaces from top to bottom) was then overlaid and the required lines representing given information were drafted. The overlay was then registered to the base graph. When an additional color was necessary, another overlay was drafted and registered to the first two. In the next step, all of the overlays and base graph were photographically reduced to the printing size on film negative prints. The original base graph was then used for all similar illustrations and the same procedure was followed, except that only the overlays were reduced. The one reduced base graph will be used with all illustrations of this type.

Also, to facilitate orientation of the isoline maps, the same base map is used for all illustrations depicting information by the isoline method.

The previously described trip models are also used as illustrations for the PATS' final report as well as in this publication. The models selected are photographed and a halftoned film negative reproduced at the desired size. The halftoned negative is then used for printing the model.

In general, a good rule to follow when preparing illustrations for any publications is that a completed illustration with suitable caption should be self-explanatory. In other words, it should not be necessary to describe the figures in the text. Each illustration must be an aid to the author and not another point to be explained.

Summary

Certain displays have been described in detail, whereas others have only been mentioned. It is the opinion at PATS that the displays described in detail are of the type that will probably be used by other agencies conducting a comprehensive O&D study. The displays mentioned as "other displays," are equally important, but methods and procedures used to produce them may vary greatly from one study to another. Usefulness versus cost is a major factor in determining what data will be displayed. The decision on the method of display that would best present a particular type of data should be the responsibility of the C&D division, subject to approval of the study director.

Space necessary for display purposes was acquired by using the PATS' conference room. This served a dual purpose. First, the displays are readily available for committee discussions and, second, when the committees are not meeting, the room is used to receive visitors.

The importance of good displays and illustrations cannot be over-emphasized. Collecting, coding, summarizing and analyzing data requires the expenditure of a vast amount of money and labor. Attractive, well-planned and prepared displays and illustrations lend themselves to the justification of these expenditures. They also compliment the efficiency of the study organization.

PUBLICATIONS AND LIBRARY

The publications prepared by the Pittsburgh Area Transportation Study are the only contact many persons or organizations have with the Study; therefore, their preparation is a vital part of the Study's operation. A great amount of interest is created by PATS' procedures, as they represent a relatively new approach to the O&D study. PATS' findings have also been found useful by local agencies because of their application to the surrounding area. By reporting the Study's facts and figures through publications, it is hoped that the method suggested and the data presented may aid other interested agencies.

The printed matter will fall into one of the following two categories: that information which assists the study personnel in the completion of their duties; and that information which reports the findings of the study. In preparing publications for the first category, the main concern is to present the information clearly, as these are manuals of procedure. Manuals used at PATS were the Land Use, the Home Interview, the Truck and Taxi Interview, the Home Interview Office Procedures, the Coding and Roadside Interview. The text should be prepared by the division requiring the manual. The C&D section must then edit, prepare illustrations, collate, and prepare the text for printing. Although manuals need not be elaborately printed, they should have a durable cover, so that they will hold up under the constant use they will receive. The second category consists of publications designed to report the study's findings, as well as the procedure followed to arrive at these conclusions. At PATS there were four types of publications prepared for this purpose: the Research Letter, Interim Technical Reports, Technical Papers, and the Study's Final Report. Following is a description of each publication.

Research Letter

This is a publication of general Study information prepared and distributed monthly to interested agencies. Because most of the articles are written by Study personnel soon after completion of that phase of the study described, an excellent, simplified account of the methods followed is recorded. (For more detailed accounts of individual phases, the Study prepares Technical Papers.)

At PATS the C&D division set up style specifications to insure the uniformity of each Research Letter. The division's editor-librarian was responsible for editing and preparing the copy for printing and on completion of the printing, the editor-librarian also handled distribution. All illustrations required for the articles were prepared by the C&D section in cooperation with the author.

The Research Letters prepared by PATS have met with favorable response and, at the present time, approximately 250 copies are distributed monthly.

Interim Technical Reports

When information was considered (by the Study) important enough to warrant special attention, the data was presented in an Interim Technical Report. The content of these reports was less general than the Researvh Letter; therefore, the distribution was limited to persons interested in the particular subject covered.

The C&D division is responsible for editing, illustrating, printing, and distribution of these reports. At the present time, PATS has prepared four Interim Technical Reports, with about as many more in sight.

Technical Papers

The Technical Papers, as prepared by PATS, are used as background for the Study's Final Report, and to record many of the Study's more complicated methods and procedures for analysis. Distributing these papers before or with the Final Report eliminates a considerable amount of explanation that would otherwise be necessary in the text of the report.

There are a total of thirteen Technical Papers, to date, and more to come as needed.

Final Report

The Final Report will consist of two volumes. The first volume is concerned only with conditions as they were during the data collection phase of the Study. The second volume will present the Study's 1980 forecast of Study conditions as well as its recommendations for an integrated transportation system (transit and highways).

In the latter part of the Study, the preparation of the Final Report is the C&D division's most important function.

Due to its importance, a considerable amount of planning is required. Technical problems concerning the Final Report should be taken into consideration early in the study.

Prior to the printing of the Final Report, a proof copy of each chapter is distributed to the Study's supporting agencies for approval. This proof copy is prepared by the Study before a printer is contacted, to eliminate the need for distributing galley proofs (which are run for editing purposes by the printer preparing the report). Moreover, if a proof copy is prepared as each chapter is completed, one part can be written while another is distributed for approval. If galley proofs were used, the writing of the report would have to be finished (due to contract difficulties) before it could go to the printer. The printer then would set the type and run galley proofs, after which the completed report would have to be distributed for approval and rewrite. In all probability the whole report would then have to be typeset again; consuming a great amount of time and money.

Library

A technical library was established at PATS soon after the start of the Study. The books and periodicals collected by the library are to be used by staff members as reference material and also as a means of keeping up to date on current developments in fields related to the O&D study.

The editor-librarian is responsible for ordering the publications requested by PATS' staff and for cataloguing this material when it is received. At PATS, library material is grouped on shelves, alphabetically, according to general subject classification. A card file is also kept, containing the appropriate information for each publication, and cross-indexed by author, title and subject. Reports ordered for staff members included results of other O&D studies, procedural manuals, statistical compilations, economic studies, planning reports, and technical periodicals. The librarian also requests that PATS' name be placed on the mailing list of agencies related to the transportation and planning fields.

To save the typing time that would be required if a separate order were prepared for all new acquisitions, an order letter and a thank-you card were printed, with a copy of the order being kept on file for control and reference.

An additional library function is a newspaper clipping service. Articles on traffic plans or changes, mass transit, land use, and area development are put into scrapbooks and circulated among members of the Study staff. New publications are also routed to interested Study employees and, at intervals, library acquisition lists are compiled and distributed.

CONCLUSION

This report has described the organization and the methods used to discharge the duties and responsibilities of the C&D division at the Pittsburgh Area Transportation Study. Also included throughout the text are suggestions which the authors feel would improve some of the methods and procedures. Although some point or points may not be applicable to every study area and study group, generally the contents of this paper could be used as a reference by those agencies about to engage in O&D work.

During the study phases of data collection, coding and analysis, the C&D division aids and assists all other study divisions by supplying the "graphic tools" necessary for the completion of their tasks. These tools must be designed to cause or allow the data to be recorded with accuracy and dispatch.

After data is collected, coded, summarized and analyzed, it becomes the duty of the C&D division to transform this data so that the findings of the study can be clearly and explicitly conveyed to the study's sponsoring agencies and other interested parties.

So that these duties and responsibilities can be performed in the best interest of all concerned and the objectives of the study prosper thereby, thoughtful consideration must be given to the establishment and organization of the C&D division when the study is being formed. Lack of proper planning and foresight can seriously hamper the effectiveness of this division. The role of the C&D division in a comprehensive O&D study must not be underestimated or slighted. A well-organized division, adequately staffed with qualified, responsible personnel is a definite and necessary asset to the study.

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Holiday and Summer Weekend Traffic Survey

ANDREW V. PLUMMER, LEO G. WILKIE, and ROBERT F. GRAN, respectively, Administrative Engineer, Traffic Engineer, and Statistician, Cook County Highway Department, Chicago, Illinois

● CONSIDERABLE information both quantitative and qualitative related to weekday automobile travel habits has been generally available for planning and improving the highway system. During the past several years the Cook County Highway Department has gathered quantitative data in the form of machine volume counts during the Memorial Day, July 4th, and Labor Day holiday periods.

However, there has been little qualitative traffic data for summer weekends and extended holidays.

To provide such data the staff of the Traffic Engineering Division of the Cook County Highway Department designed and conducted a series of roadside interview surveys. During these several surveys more than 12,000 motorists were interviewed.

DESIGN OF STUDY

Two sites were selected for conducting roadside interviews (Fig. 1). These study sites were chosen to represent holiday and non-holiday characteristics for northern Cook County. Site 1, on Rand Road, US 12, is approximately 35 miles northwest of the Chicago CBD and site 2 on Edens Expressway is 14 miles east of site 1.

Rand Road, near the Cook County line, was selected because it is one of the better routes used in going into the northern Illinois and southern Wisconsin lake areas. Interviewing was scheduled for the hours between 2 PM and 8 PM on Friday, July 1 and between 7 AM and 1 PM on Saturday, July 2 for the outbound (northwest) traffic only. These hours were selected because it was felt they would carry a large portion of the outbound holiday traffic. As a criterion for typical non-holiday summer weekend travel, a similar survey was planned at the same location for the corresponding hours two weeks later, July 15 and 16. Enough interviewers were provided to assure a 20 percent sample.

In drawing the sample a flagman directed traffic into an interview lane to provide each interviewer with one vehicle. The flagman then directed traffic into a bypass lane until such time as the interviewers were ready for another set of vehicles.

Randomness in sampling was strived for by channeling all traffic into a single lane and then either selecting a charge of vehicles for interview or allowing traffic to bypass until the interview lane was ready for a complete recharge.

Manual and machine counts were made of all traffic passing through the station so that the data could be factored up to the total ground count. No trucks or commercial vehicles were interviewed because the primary purpose was to determine the nature of holiday travel.

The second site was surveyed in mid-August prior to the Labor Day weekend. The location of this site was on Edens Expressway just north of the Dundee Road interchange.

This location differed markedly from the first. It is located on a six-lane expressway coming north from the Chicago CBD. The particular site selected is just south of an entrance to the Northern Illinois Tollway going north toward Milwaukee. It was known that a substantial portion of the total traffic entered the Tollway at this point. The physical set-up of this station differed slightly from the first to allow for the tremendous difference in traffic volume (Fig. 2).

Lane 1 was used for interviewing. Lane 2 was blocked off for interviewers. Lanes 3 and 4 were used for by-pass. A study on the Saturday before Labor Day was done at

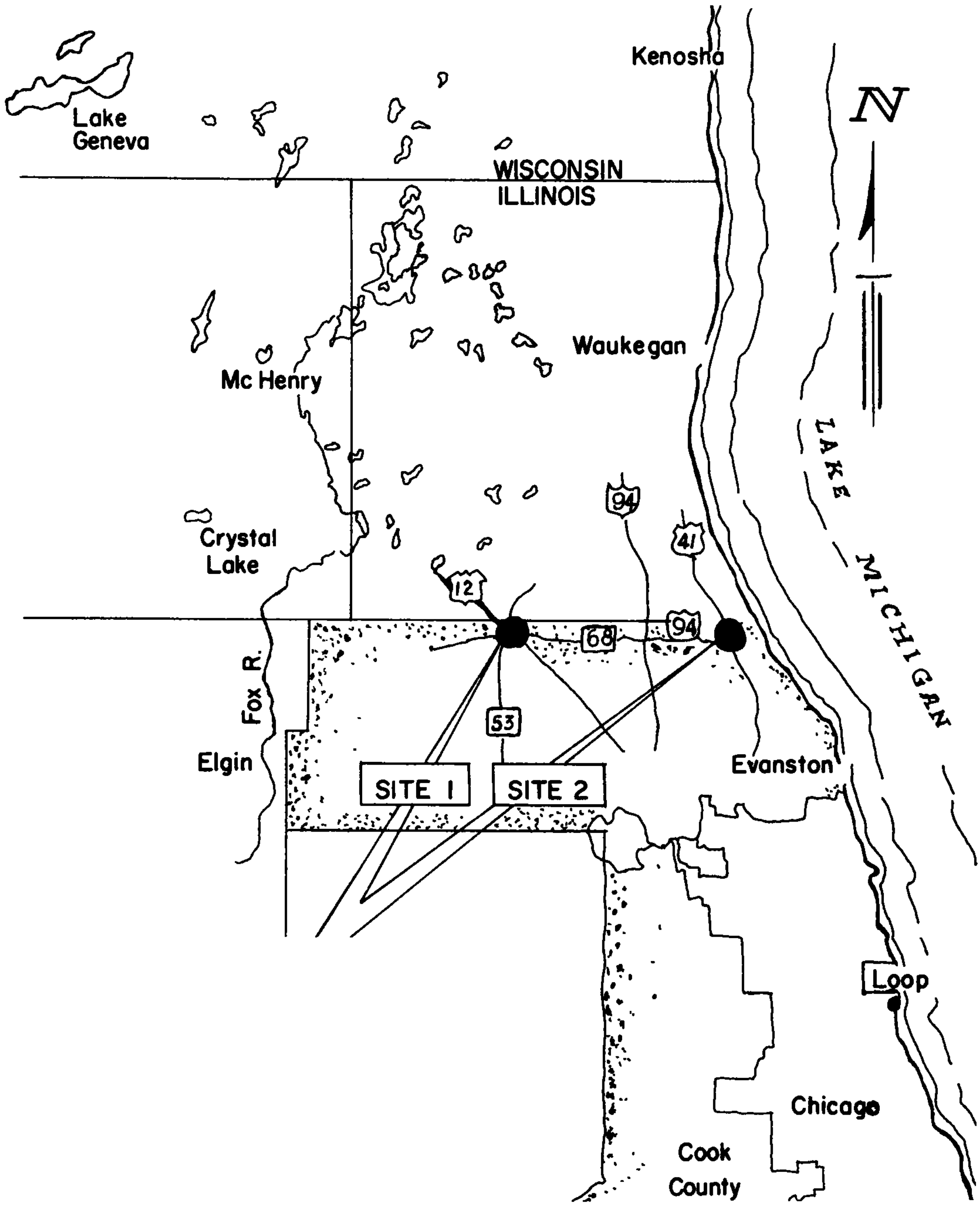


Figure 1. Survey site locations.

Rand Road site for the inbound (southeast) direction. It was felt that this would give some qualitative data on holiday trips into the Chicago area.

INTERVIEW FORM

The basic questions on the interview schedule were those pertaining to origin, desti-

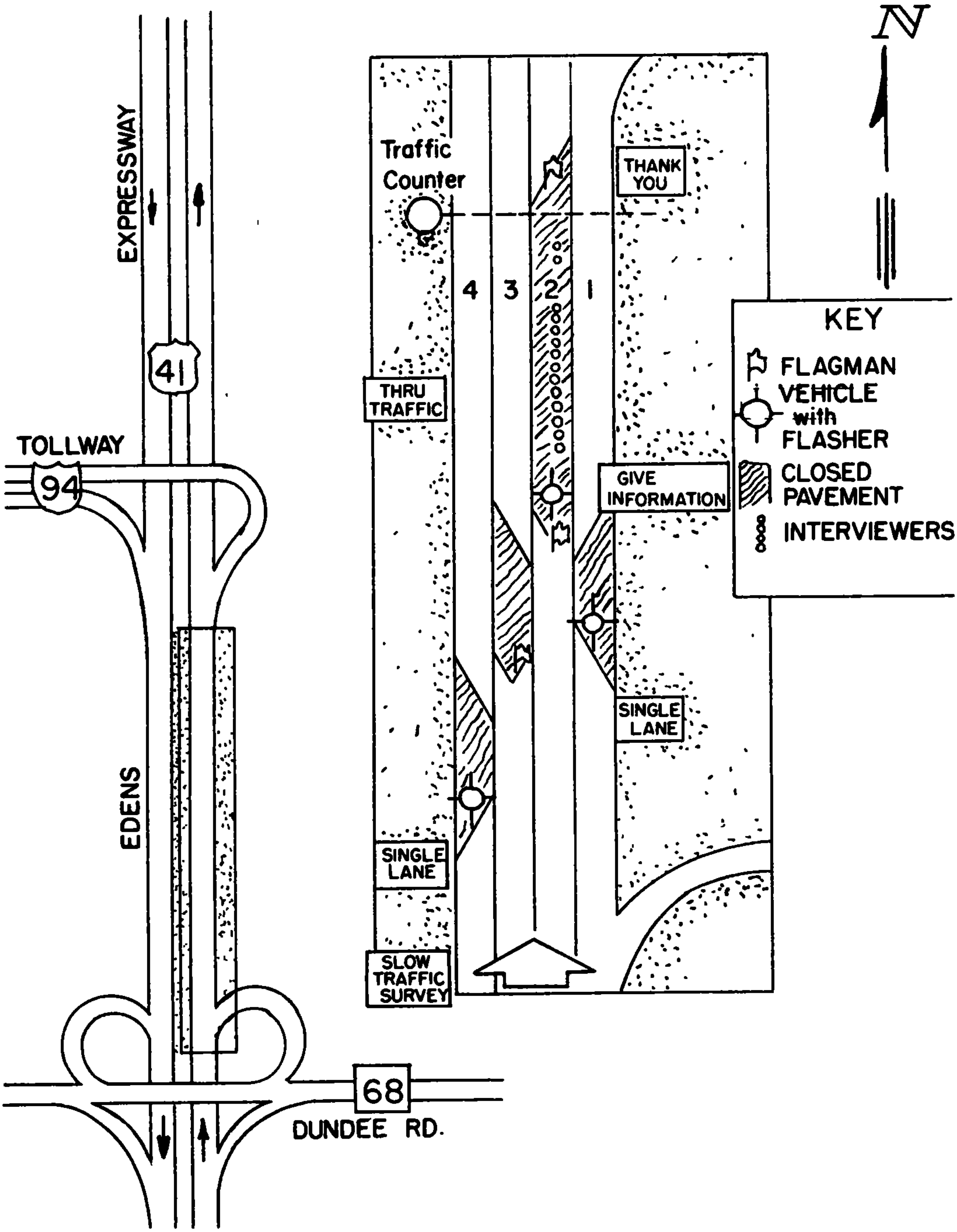


Figure 2. Interview station—site 2.

nation and trip purpose. For recreational trips, additional questions as to the frequency of trip and return date were also included. In addition, there were several questions relative to occupation and quitting time.

The site 2 schedule also included a question regarding tollroad use.

FIELD PORTION OF STUDY

The station requirements varied from site to site depending on the physical nature of the site and the traffic volumes expected during the survey hours. No attempt was made to obtain a constant sample size. Rather, a charge of vehicles was channeled into the interview lane so as to provide each interviewer with one vehicle. When the last of this group of vehicles left the station after being interviewed, another group of vehicles was immediately channeled into the interview lane.

This method maximized the sample size while maintaining randomness and minimizing motorist delay time. Because of the fact that the sample size was a variable percentage of the total traffic, it was necessary to factor all data up to the total passenger traffic volume. This was accomplished by computing factors for each 15-min intervals.

Figures 3 through 10 portray some of the initial findings. A considerable portion of the analysis remains to be done. Figure 3 shows the holiday weekend travel beginning

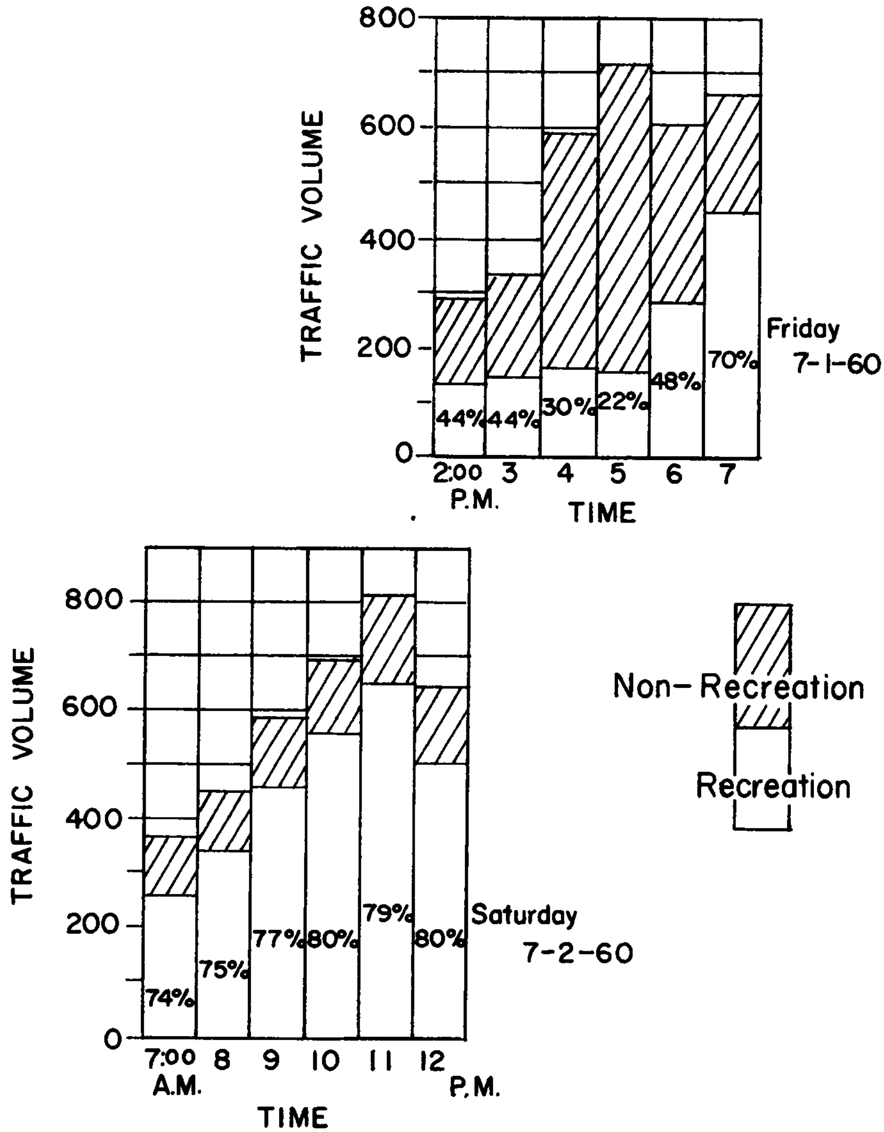
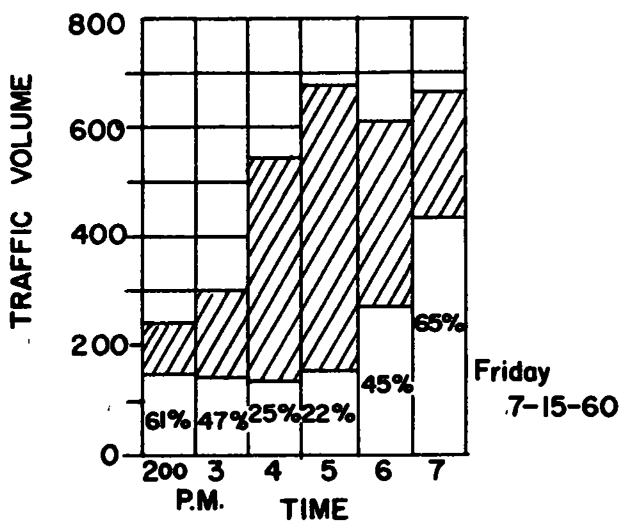


Figure 3. Recreation trips in relation to total traffic volume by time of day on holiday weekend; outbound, site 1.

at 2 PM on Friday preceding the three-day 4th of July weekend. The lower portions of the bar graphs indicate the number and percent of recreational trips for each of the survey hours. Between 2 and 6 PM the number or recreational trips was fairly constant but the percentage ranged from 22 percent to 44 percent. However, after 6 PM the number and percentage of recreational trips increased significantly to a maximum of 70 percent.

The percentage of recreational trips for the next day, Saturday, ranged from 74 percent to 80 percent. The peak hour for the number of recreational trips was between 11 AM and 12 noon. The average percent of recreational trips for Friday was 42 percent and for Saturday was 78 percent while the number of trips was slightly more than double on Saturday.

The hourly pattern for trips on the non-holiday portion of the survey are shown in Figure 4. The absolute number as well as the percentage of recreational trips were both significantly less for the non-holiday weekend.



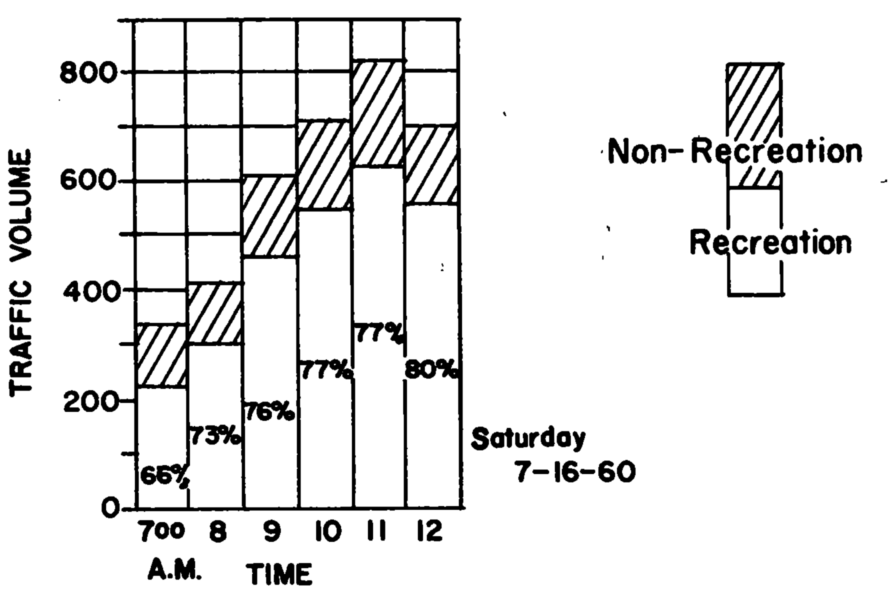


Figure 4. Recreation trips in relation to total traffic volume by time of day on non-holiday weekend; outbound, site 1.

RECREATIONAL TRIPS FOR A NON-HOLIDAY SUMMER WEEKEND BY TIME OF DAY

Figure 5 shows the Friday portion of the site study and shows that the percentage of recreational trips ranges from 25 to 48. In absolute number the peak for recreational trips was between 6 and 7 PM. This represents a significant difference from the characteristics found at site 1, Rand Road, during a non-holiday summer weekend. Another difference is in the relative percentage of recreational trips, site 2 carrying a larger percentage of non-recreational trips.

Figure 6 shows the Saturday portion of the non-holiday summer weekend study, and shows that the general recreational trip characteristics are quite similar to that for site 1. Again, however, site 2, on Edens Expressway carries substantially larger percentages of non-recreational trips for each survey hour, compared to site 1, Rand Road.

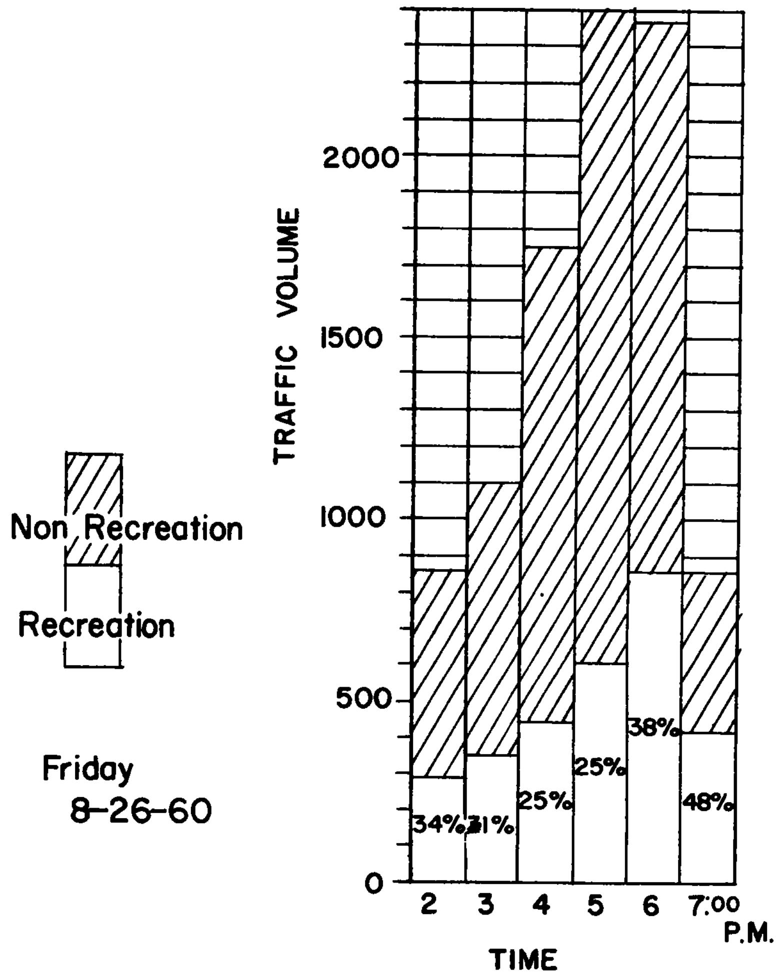


Figure 5. Recreation trips in relation to total traffic volume by time of day on non-holiday weekend; outbound, site 2.

RECREATIONAL TRIPS AS A FUNCTION OF DAY OF RETURN TRIP FOR HOLIDAY AND NON-HOLIDAY SUMMER WEEKENDS; SITE 1, OUTBOUND

The two sets of bar graphs on the left side of Figure 7 indicate the number and percentage of recreational trips by return day. The lower portion of each graph represents same day return. The left portion is for holiday trips and the right for non-holiday. On Friday at Rand Road, for the holiday portion, 20 percent of the recreational trips indicated a return on the same day and 80 percent a longer recreational stay. The corresponding non-holiday, Friday, showed 36 percent with same day return trip and a 64 percent longer stay.

On Saturday similar differences were observed between holiday and non-holiday weekends, although for each a much larger percentage indicated same day returns.

Statistically, the differences between holiday and non-holiday recreational trips with respect to return date were highly significant.

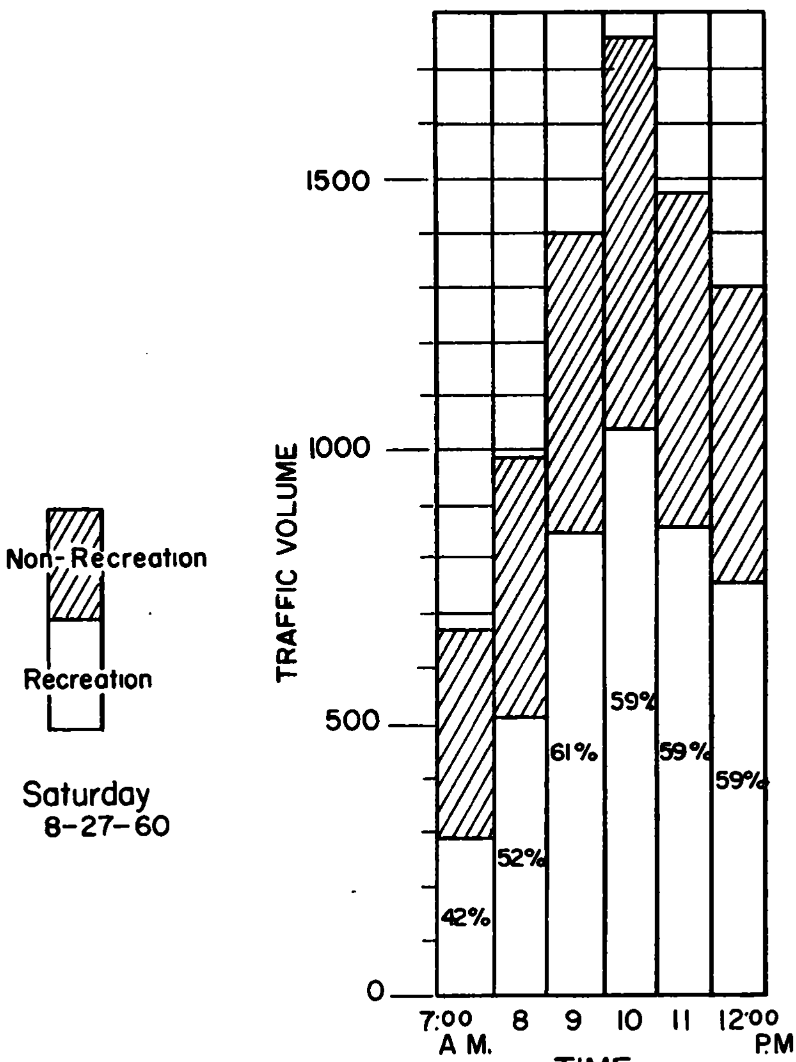


Figure 6. Recreation trips in relation to total traffic volume by time of day on non-holiday weekend; outbound, site 2.

RECREATIONAL AND NON-RECREATIONAL TRIPS BY DESTINATION FOR TOLL ROAD AND NON-TOLL ROAD USERS; SITE 2, OUTBOUND

Figures 8 and 9 pertain to toll road selection. Figure 8 relates toll road selection to destination of trip and breaks each indicated destination into recreational and non-recreational trips.

The left portion of each set of bar graphs is for recreational trips and the right for non-recreational.

Of the outbound recreational trips to the Chicago suburban area, 37 percent used the toll road while 63 percent did not. Of the non-recreational outbound trips only 19 percent used the toll road.

Of the recreational trips to the Illinois resort areas beyond suburban Chicago, 77 percent used the toll road. Only 58 percent of the non-recreational trips to the Illinois resort areas used the toll road.

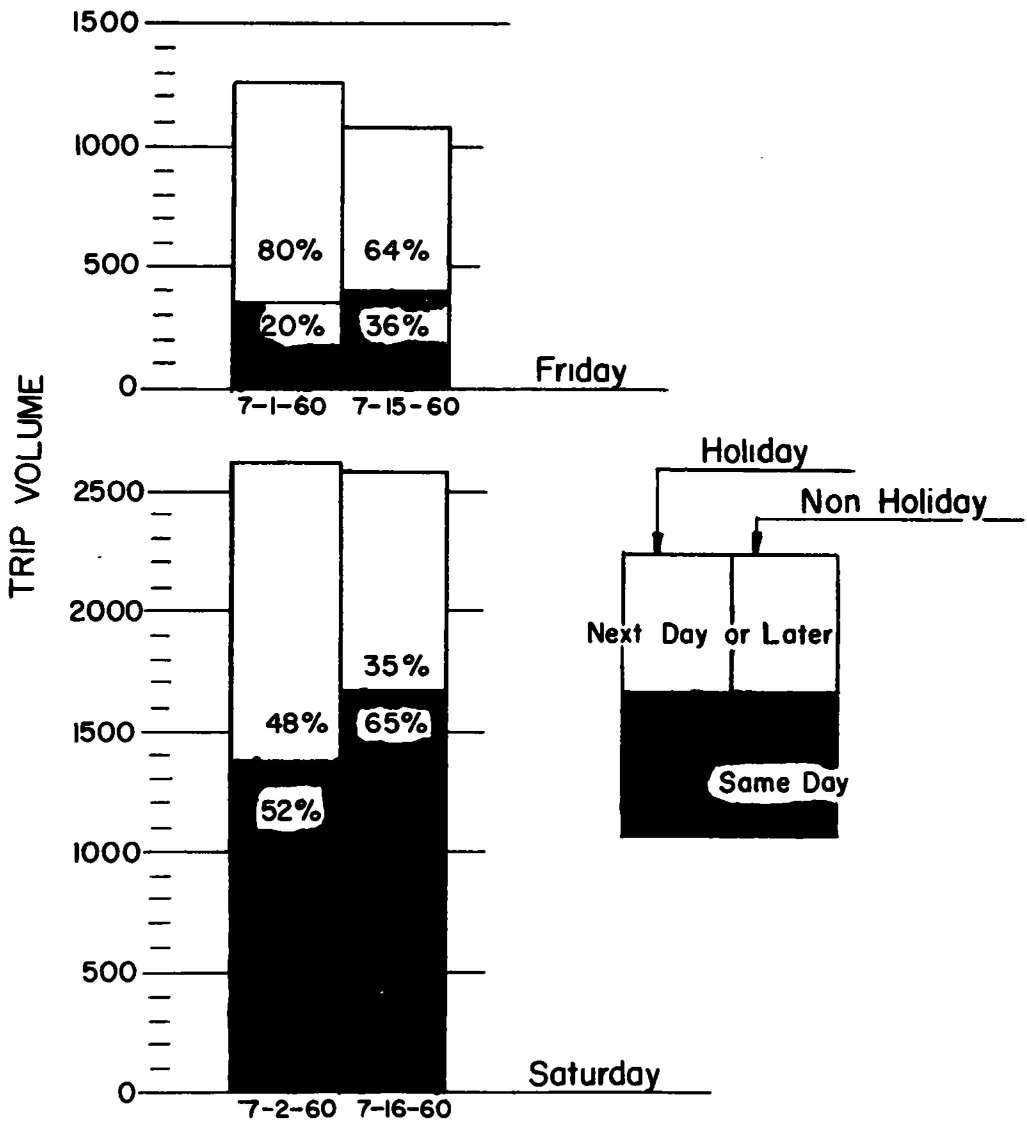


Figure 7. Return day for recreational trips.

trip drivers. This percentage on Friday was 85 percent of the frequent trip users to 64 percent of the occassional trip drivers. On Saturday the percentage was 65 for the frequent toll road recreational trip users to 54 for the occassional toll road trip users.

The data shown in both of these figures were found to be highly significant.

RECREATIONAL TRIP FOR A HOLIDAY SUMMER WEEKEND BY TIME OF DAY; SITE 1, INBOUND

It is generally believed that there is a substantial exchange of population between city and country for recreational purposes on a holiday weekend. To ascertain the degree of this exchange, a study was made of inbound traffic at site 1 on the Saturday preceding Labor Day.

Figure 10 shows that this exchange is not nearly as marked as had been expected; for instance, the total recreational trips passing through this station was only about one-third as large as the number leaving during comparable hours of the July 4th weekend. The percentage of recreational trips for the total of the five survey hours was 48 percent as compared to 78 percent for the outbound study during the Saturday portion of the July 4th weekend.

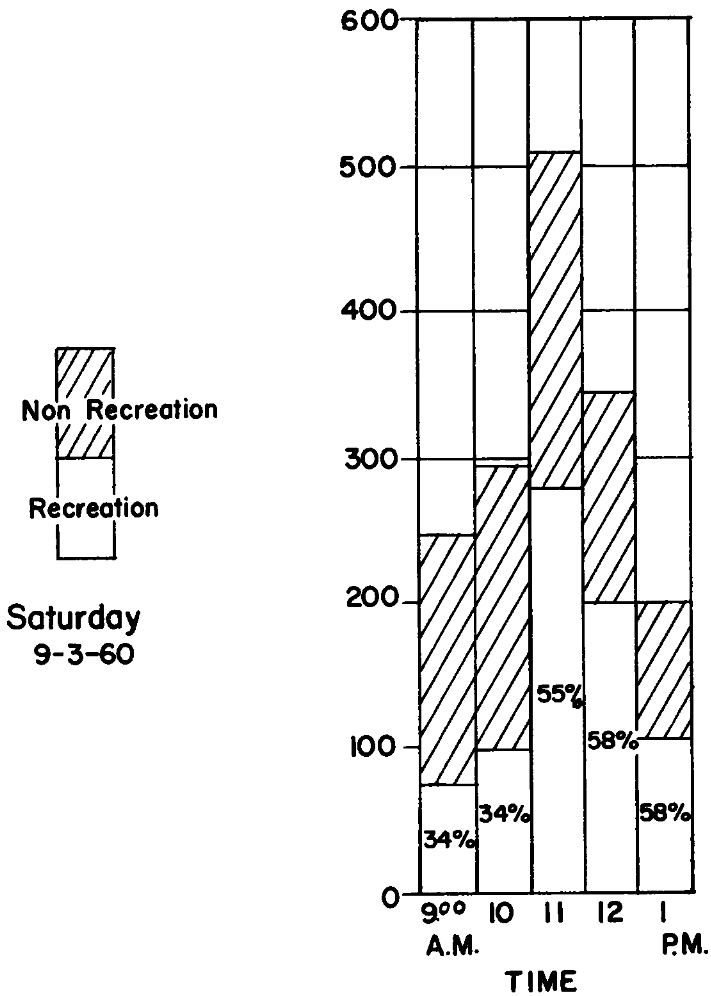


Figure 10. Recreation trips in relation to total traffic volume by time of day on Labor Day holiday weekend; inbound, site 1.

Although there is no direct trip comparison for both directions of flow at a given station for the same day, an examination of traffic volumes during the survey hours shows that there was more than twice as much traffic outbound than there was inbound and that the peak volumes both inbound and outbound occurred between 11 and 12. The actual peak hour for the 24-hr day was between 11 AM and 12 noon for the outbound traffic and between 7 PM and 8 PM for the inbound. This inbound peak can be largely accounted for by the recreational trip returns from Friday and Saturday trips.

Further analysis of these studies is in progress and a report is expected to be completed shortly.

Forecasting Traffic with a Modified Growth Factor Procedure

W.S. POLLARD, Jr., Partner, Harland Bartholomew and Associates, Memphis, Tenn.

● THIS paper presents a comparison of three methods of traffic projection and reduction to 1975-level desire lines. The basic origin-destination (O&D) data which were used were obtained in 1944; supplemental O&D data were obtained in 1950 from which the earlier information was up-dated to 1950. This adjusted 1950 O&D data are those which have been used in all traffic projection and assignment work in the Memphis Metropolitan Area. During the course of the last seven years there has been occasion to work with the basic O&D data in preparing a major street and highway plan, in preparing interstate route location studies, in preparing the 108(d) and 104(b) 5 cost estimates, and in preparing final construction plans. As this data has been processed, varying techniques of projection and of assignment have been used intentionally to give a cross-check of the one method against another. By virtue of their inconsistencies it has been found both proper and necessary to apply considerable engineering judgment in the use of this material.

This paper presents a comparison of total trip-end desires for each O&D zone in 1975 (Table 1), a comparison of a random selection of zone-to-zone travel desires for 1975 (Table 2), a comparison of the semi-assigned 1975 desires by corridors in 1975 (Table 3), a graphic comparison of the trip-ends by zones and physical location within the metropolitan area (Fig. 1), and semi-assigned cardinal corridor design hour traffic vs capacity (Figs. 2 and 3). The assigned desires by cardinal corridors are the desires as obtained by the judgment-applied factors method.

This presentation does not purport to be a learned discourse on the relative merits of the three projective techniques. It is the sincere belief of the writer that, among the several projective techniques which are now in existence, some light needs to be shed. It is felt that this light can best be shed by a comparison among all of the techniques for a selected group of large, medium and small urban areas wherein, using the same basic data, the several techniques are applied, their end products carefully compared, and the significance of their differences explored and resolved to ultimate meaning. It is felt that such an approach could well lead to a demonstrably valid and grossly simplified and more economical approach to determining reasonable future traffic desires for planning and design use. It is maintained that the final test of necessary level of accuracy of the final projected product is that level which will always clearly establish the individual lane call. Working upward from peaking percentages and directional distribution percentages to the equivalent average daily desire served by the capacity of a lane, it may be seen that a reasonably sizeable variation in average daily desire will, when reduced to corridor orientation for analysis, not necessarily be unusually significant. The likelihood of this significance being unusually great is also minimized by the fact that the semi-assignment to corridors of the individual zone-to-zone trip values results in a necessary grouping of a number of separate values, some of which are high and some of which are low—hence a further dampening effect.

As work continues with O&D data and its projection in various parts of the nation, incorporation of as much research as possible in this matter of the most intelligent and logical use of O&D data is attempted. A demonstrably sound rationale has been obtained which allows forward movement from traditionally obtained O&D data to a reasonably valid projected set of desires with trip-end balance, to the assignment of these desires to corridors for reduction to peak period desires, to the comparison with

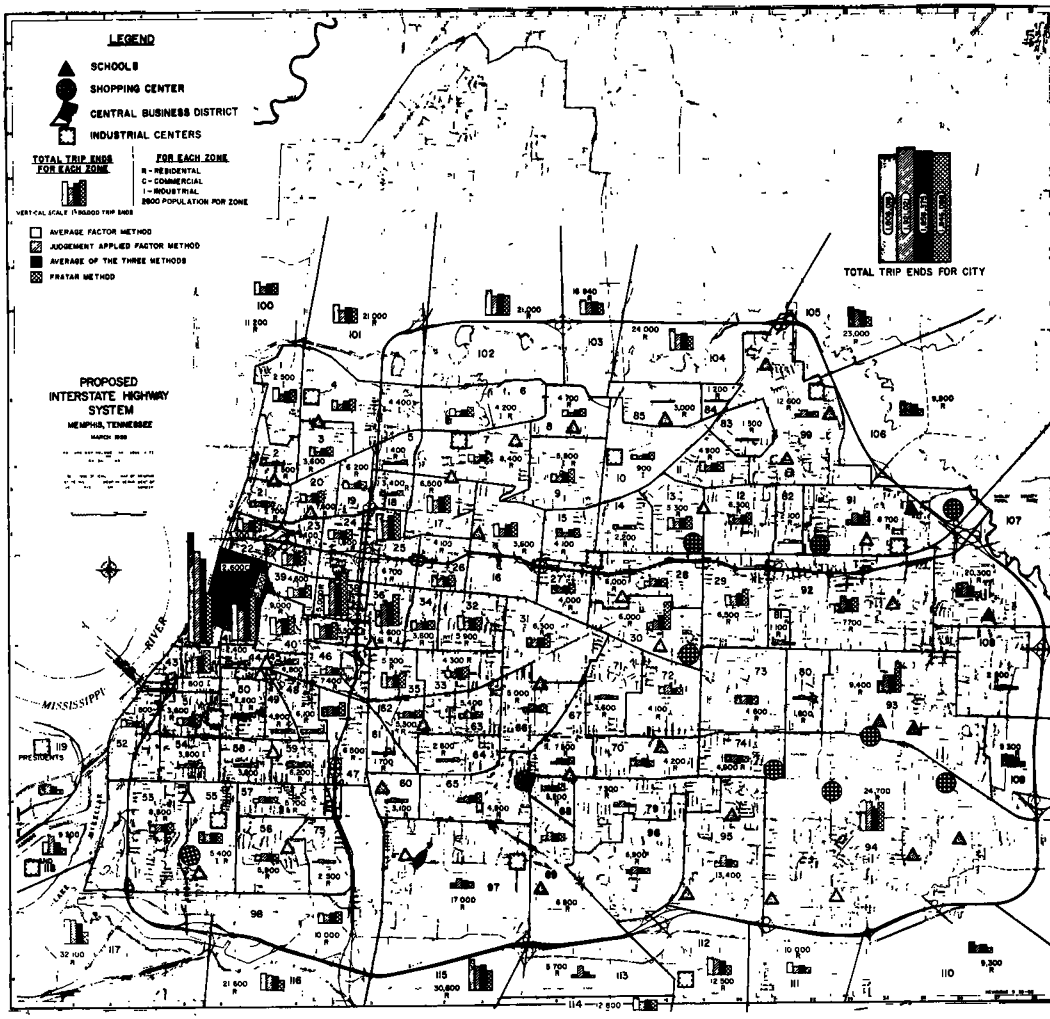


Figure 1.

existing capacity availability, and hence to the final guide to area-wide street and highway planning—a capacity-deficiency determination by location and orientation within the community. It is believed and hoped that traditional approaches from further analyses of these procedures will be simplified. It is admitted that these procedures are somewhat cumbersome and more time consuming than some of the techniques which are now in existence. However, it is believed that the basic validity of these more cumbersome techniques warrants their continued application to a satisfactory point of proof and to an ultimate reduction to a greatly simplified technique which is machine applicable. A corollary benefit in using these cumbersome techniques is that of being able to inculcate into young traffic engineers and planners a true understanding of relationships which bear on the entire matter of traffic generation.

This brief paper does not set forth the detailed step-by-step procedure which is currently being used because it would not seem to be germane to the action which this paper hopes to seek. This area of traffic projection, assignment, and ultimate analytical use is an area which constantly seems to become more complicated as each investigator applies himself to this area of thought and investigation. The basic question of whether the theorists are indeed making significant contributions or whether

TABLE 1

COMPARISON OF TOTAL TRIP-END DESIRES FOR EACH ZONE IN 1975

Zone	Average of Three Methods	Fratar Method	Average Factor Method	Judgment-Applied Factor Method
1	18,781	21,669	23,212	11,463
2	6,191	5,751	9,388	3,435
3	11,986	14,465	14,546	6,948
4	14,425	18,295	16,018	8,963
5	4,631	6,195	4,270	3,430
6	8,819	14,919	11,982	8,524
7	10,945	13,867	11,320	7,649
8	9,805	12,429	10,158	6,827
9	15,183	21,241	13,736	10,571
10	8,409	11,941	7,318	5,968
11	13,800	15,795	16,376	9,229
12	14,979	18,937	16,206	9,793
13	17,666	20,019	19,892	13,088
14	5,223	5,527	6,454	3,689
15	11,388	12,707	14,764	6,693
16	20,384	23,967	22,912	14,273
17	26,219	27,755	29,142	21,761
18	5,861	7,277	6,214	4,093
19	10,817	12,687	11,604	8,160
20	14,841	18,165	14,844	11,514
21	9,151	9,233	10,792	7,428
22	18,568	19,553	22,718	13,433
23	19,727	23,331	20,396	15,454
24	13,236	15,105	14,540	10,063
25	39,775	44,869	43,258	31,205
26	16,420	18,553	18,240	12,466
27	12,786	15,357	13,092	9,908
28	11,781	13,591	8,978	12,775
29	19,703	25,807	15,700	17,602
30	24,754	47,725	12,000	14,536
31	16,232	19,513	16,046	13,138
32	19,380	19,957	23,774	14,408
33	14,299	16,583	16,560	9,755
34	13,481	15,241	15,408	10,874
35	21,816	24,297	25,744	15,408
36	38,934	52,905	25,996	37,900
37	24,539	27,253	25,210	21,153
38	53,918	71,103	34,334	56,316
39	16,945	19,773	16,908	14,154
40	27,833	30,419	29,982	23,099
41	63,372	74,677	63,836	51,603
42	140,875	83,847	185,562	153,215
43	28,117	37,009	21,218	26,123
44	5,410	6,359	5,836	4,035
45	5,377	6,415	4,930	4,787
46	11,434	9,911	10,006	14,385
47	14,665	16,605	13,362	14,029
48	5,589	6,251	5,510	5,006
49	5,420	5,769	5,430	5,062
50	6,067	6,589	5,756	5,855
51	14,439	16,767	13,422	13,129
52	9,300	9,347	12,128	6,427
53	12,808	14,957	10,686	12,781
54	6,512	6,547	6,040	6,949
55	17,882	16,963	20,496	16,186
56	10.652	10.061	9,876	12,020

they are, conversely, "straining at nits" is the next most significant determination to be made in this area of exploration.

DESCRIPTION OF THREE METHODS OF TRAFFIC PROJECTION USED

Judgment-Applied Factor Method

Expansion Method.—This procedure uses the best of the averaging method and the Fratar Method. The method does not adapt directly to machine methods which are purely mechanical; however, a computer program is being worked on to apply a close approximation of the method. The adjustment to create trip-end balance requires time and study, letting sound judgment (guided by intimate local planning and engineering information) be the basis for the addition or subtraction of trips from the movements. The method is as follows:

1. Apply an increase factor to the 1950 trip ends for each zone-to-zone movement. This increase factor is an average of the increase factors for each of the two zones unless one of the zones in question possesses a strong bond of attraction. This strong bond should be recognized and adjustments made to give a more realistic presentation of the future desires between the two zones.

57	8,738	8,981	7,548	9,684
58	5,914	6,149	5,300	6,293
59	7,374	7,689	6,242	8,190
60	5,108	5,139	3,446	6,738
61	3,753	4,169	3,918	3,172
62	10,773	11,701	8,842	11,777
63	7,167	10,343	7,430	10,894
64	4,871	5,405	4,352	4,857
65	10,567	14,785	6,934	9,981
66	11,699	12,827	8,642	13,627
67	8,623	10,701	4,094	11,073
68	9,142	11,995	6,640	8,790
69	12,623	13,025	9,692	15,151
70	11,329	9,409	13,840	10,737
71	6,068	5,369	5,282	7,554
72	12,665	9,637	12,962	15,397
73	14,135	13,579	14,628	14,198
74	10,630	8,321	12,534	11,035
75	3,866	3,185	2,660	5,752
79	5,688	3,563	4,138	9,363
80	4,616	4,323	3,858	5,667
81	3,860	2,651	2,626	6,305
82	4,823	4,335	2,972	7,162
83	2,767	2,375	2,882	3,043
84	1,371	1,091	1,486	1,535
85	1,603	1,661	1,556	1,593
91	17,448	23,043	8,560	20,740
92	20,460	23,289	11,438	26,655
93	34,755	50,941	19,016	34,308
94	36,176	48,739	10,737	49,053
95	12,227	9,565	7,316	19,801
96	8,548	8,885	6,506	10,252
97	12,135	11,889	8,216	16,300
98	17,022	19,227	16,900	14,938
99	8,459	8,863	5,306	11,207
100	17,742	18,447	21,004	13,776
101	25,790	24,209	31,634	21,527
102	35,853	33,527	42,032	32,001
103	20,155	17,955	23,364	19,145
104	28,791	23,365	36,020	26,988
105	26,282	16,787	33,714	28,344
106	18,370	10,389	24,234	20,486
107	17,978	7,771	22,262	23,901
108	4,788	2,803	5,226	6,336
109	13,419	5,503	17,518	17,235
110	13,592	8,909	18,280	13,586
111	12,729	9,243	17,162	11,783
112	23,210	14,601	28,990	26,039
113	9,805	4,289	4,554	20,573
114	16,769	16,227	19,406	14,673
115	43,306	33,175	53,756	42,986
116	23,434	16,245	28,972	25,085
117	34,627	19,667	42,890	41,324
118	20,848	9,515	21,730	31,299
119	12,470	7,083	13,654	16,672
Adjusted totals	1,858,375	1,858,375	1,858,375	1,858,375
Unadjusted totals		1,846,088	1,808,016	1,921,021
Percent variation from average		+1	+3	-3

2. Prepare the trip-end projections obtained by applying the appropriate expansion factors for each zone with the trip ends totaled from the expansion of each zone-to-zone movement.

3. Adjust the total trip ends for each zone to meet the desired total. This can be accomplished by studying each zone-to-zone movement—with respect to the growth expected in each zone, the proximity to each other, the land use, and location within the city. In most cases the high growth areas will be the outlying areas of the city. These areas are spotty as far as 1950 O&D information is concerned. There are many zone-to-zone movements which did not have any movements in the 1950 O&D survey, but due to the land use, proximity, development, etc., there should be trips between them. In most cases this will help both zones in achieving trip balance. The zones which require some reduction in trips are studied in the same manner and the reductions made in light of these factors. It may take two or three run-throughs to balance the system.

Expansion Factors.—(a) vehicle ownership, 1.58 (city wide); (b) vehicle use, 1.10 (city wide); (c) population, computed for each zone (1.76 city-wide average); and (d) CBD, 1.25.

TABLE 2

COMPARISON OF SELECTED ZONE-TO-ZONE TRAVEL DESIRES FOR 1975

Zone From	Zone To	Average of Three Methods	Fratar Method	(%)[1]	Average Factor Method	(%)	Judgment-Applied Factor Method	(%)	Land Use
42	4	357	164	-59	468	+31	440	+23	C-1
42	14	272	109	-60	388	+43	320	+18	C-R
42	109	1088	564	-48	1350	+24	1350	+24	C-R
42	72	716	338	-53	905	+26	906	+26	C-R
42	94	841	1654	+97	445	-47	1646	+96	C-R
42	46	651	245	-62	855	+31	854	+31	C-R
42	96	279	325	+16	205	-26	306	+10	C-R
42	114	1115	586	-47	1380	+24	1378	+24	C-R
42	31	1004	607	-40	1155	+15	1250	+25	C-R
42	55	436	298	-31	505	+16	506	+16	C-(I-R)
42	99	319	356	+12	264	-17	336	+ 5	C-R
113	27	94	100	+ 6	91	- 3	92	- 2	R-R
113	38	582	564	- 3	316	-45	866	+49	R-R
113	12	64	72	+12	59	- 8	60	- 6	R-R
113	94	280	315	+13	62	-78	462	+65	R-R
97	24	180	218	+21	161	-10	160	-10	R-R
94	41	932	1962	+110	267	-71	566	-40	R-I
55	32	53	44	-17	75	+42	40	-25	(I-R) -R
1	70	0	0	0	0	0	0	0	I-R
67	106	13	40	+200	0	-100	0	-100	R-R
104	10	244	377	+55	174	-29	180	-26	R-I
106	41	566	802	+42	448	-21	448	-21	R-I
101	33	9	29	+200	0	-100	0	-100	R-R
56	60	0	0	0	0	0	0	0	R-R
56	115	966	1202	+24	696	-28	1000	+ 4	R-R
7	25	840	876	+ 4	795	- 5	850	+ 1	R-R
73	35	0	0	0	0	0	0	0	R-R
47	92	8	0	-100	0	-100	25	+200	R-R
70	36	134	171	+28	92	-31	140	+ 4	R-R
69	91	39	53	+36	32	-18	32	-18	R-R
119	117	872	914	+ 5	987	+12	724	-17	I-R
53	75	107	123	+15	84	-22	114	+ 6	(I-R) -R
18	98	97	110	+13	82	-15	100	+ 3	R-R
50	98	8	9	+12	7	-12	8	0	(I-R) -R
101	3	63	189	+200	0	-100	0	-100	R-R
102	17	28	84	+200	0	-100	0	-100	R-R
2	23	113	107	- 5	123	+ 9	110	- 3	R-R
104	9	182	231	+27	174	+ 4	140	-23	R-(I-R)
106	109	134	228	+70	87	-35	88	-35	R-R
45	75	84	90	+ 7	75	-11	86	+ 2	R-R
6	10	130	147	+13	96	-26	146	+13	(I-R) -I
20	12	88	98	+11	77	-13	90	+ 2	R-R
17	7	779	855	+10	702	-10	780	0	R-R
33	34	373	443	+19	257	-31	420	+13	R-R
29	92	156	75	-51	38	-76	355	+128	R-R
Average variation				+20		-20		+ 4	

[1]Percentage variation from the average of the three methods.

Average Factor Method

Expansion Method.—The 1950 O&D desires between zones were expanded to 1975 by applying an increase factor that was the average of the two individual increase factors for each zone. Undeveloped zones in 1950 were compared with developed zones having similar land use and orientation to obtain the 1975 desires. In this expansion no attempt was made to attain trip-end balance.

Expansion Factors.—(a) vehicular registration, 1.58 (city wide); (b) gasoline consumption, 1.10 (city wide); (c) population growth computed for each zone (1.76 city-wide average); and (d) CBD, 1.26.

TABLE 3

CORRIDOR ANALYSIS COMPARISON

Corridor	1 Judgment-Applied Factor Method Assignment	Average Percent Variation of 1 With Fratar Method Within Corridor	Average Percent Variation of 1 With Average Factor Method Within Corridor
E-W-"E"	30,000	+10	-10
N-S-"O"	17,100	- 2	- 3

<u>Fratar Method</u>

The Fratar Method of traffic projection has been described elsewhere (1). The basic elements are as follows:

1. For each zone the estimated future traffic volume is distributed to the movements to and from it and within it, in proportion to the relative attractiveness of those movements.

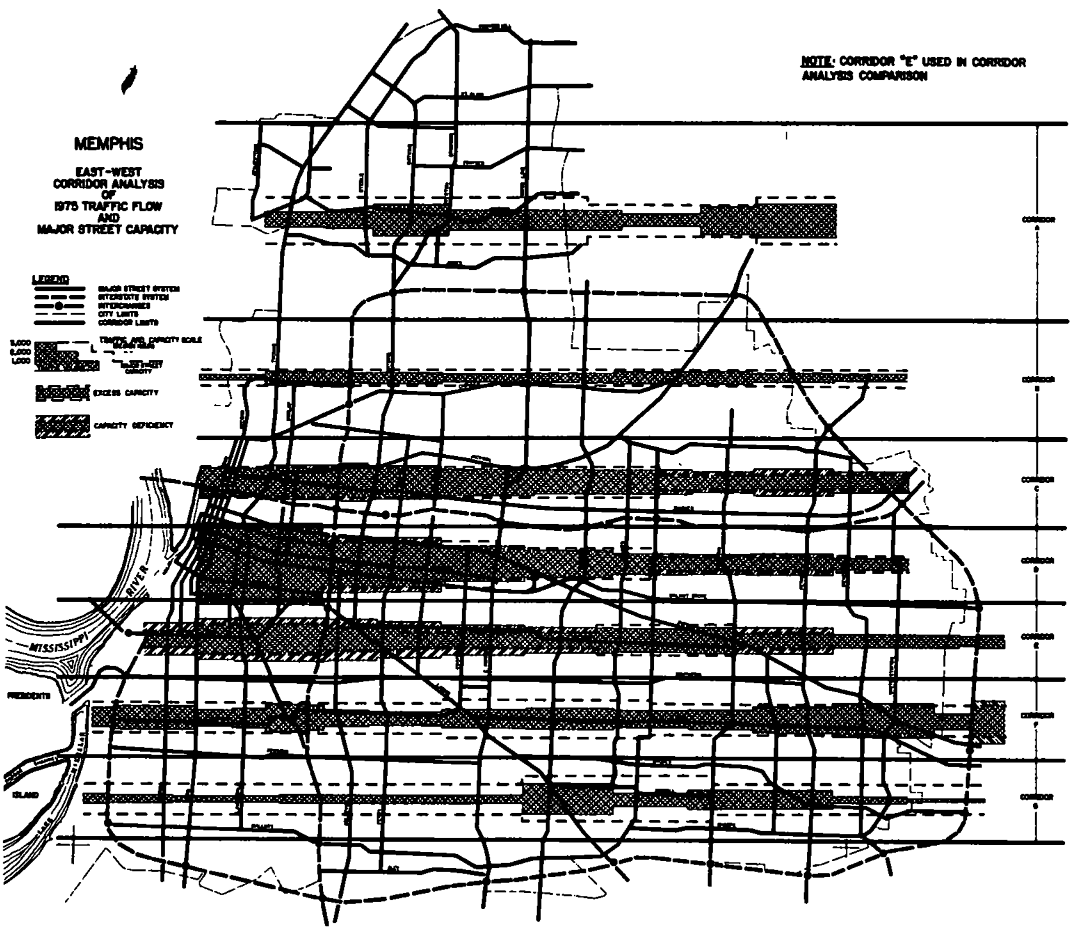


Figure 2.

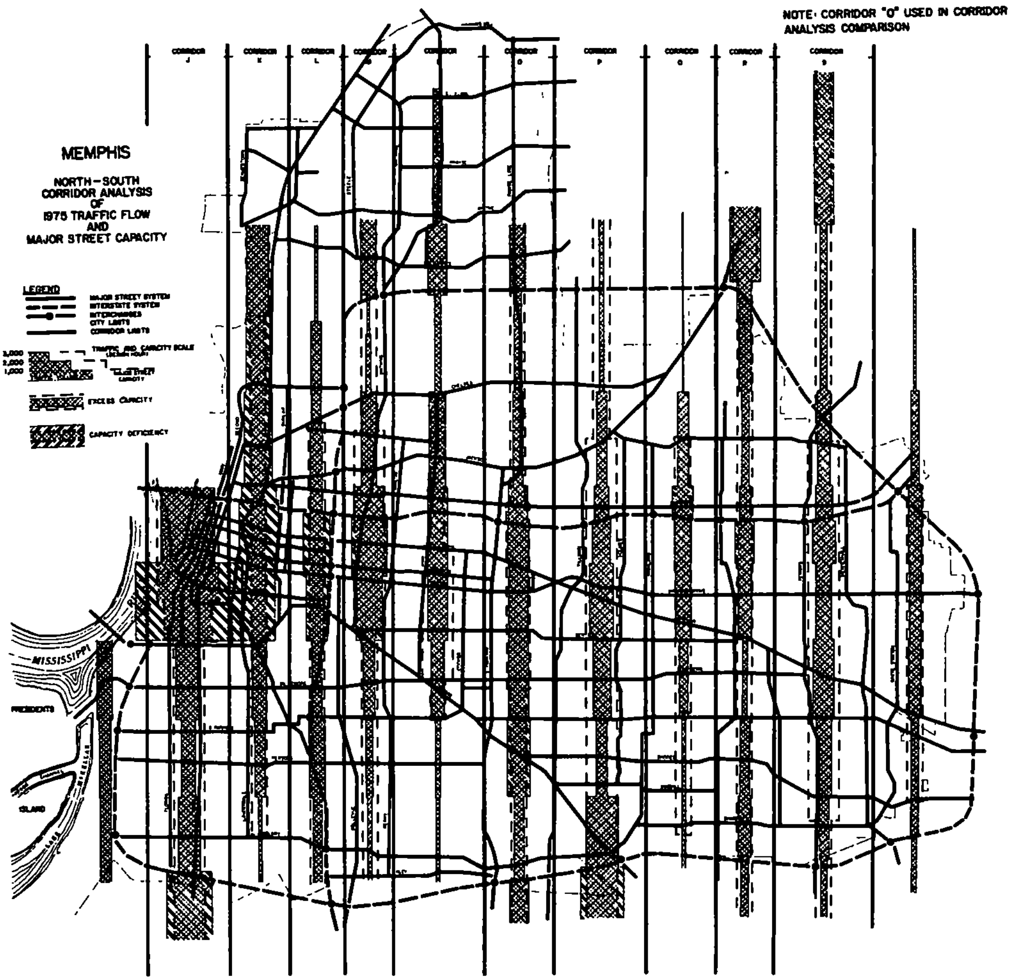


Figure 3.

Reasonable indicators of relative attractiveness are existing traffic movements and estimated zonal traffic growth factors.

As a practical matter, the intrazonal movement of the zone may be treated in the same way as an interzonal movement, with due regard to the difference between a trip and a trip end.

2. At the end of the first distribution, each movement—except intrazonal movements—has two volumes resulting from the zonal distributions at each end of the movement. The pairs of volumes are averaged to obtain a first approximation of zone-to-zone movements and intrazonal movements.

3. The averages for the interzonal pairs of trips radiating from each zone and the first approximation of intrazonal volume are summarized to determine adjustment factors for the zones to be used in the second approximation.

4. For each zone the originally estimated trips are again distributed to interzonal movements and to movements within the zone in proportion to the volumes and adjustment factors obtained by the first approximation. The pairs of tentative volumes obtained for interzonal movements by this distribution are averaged as before, and the process repeated until the desired conformity is obtained.

It was found that for the procedure outlined, the convergence was very rapid and otherwise satisfactory. With punched cards and IBM equipment the mechanics of the procedure are relatively simple.

The successive approximations method, with some refinements, was used for the traffic study recently completed for Detroit under J.D. Carroll's direction.

A computer program was borrowed from the IBM Library by the State of Tennessee for use in this analysis. Three iterations were accomplished with this program to attain trip-end balance. The expansion factors used in this program were: (a) vehicle ownership, 1.58 (city wide); (b) vehicle use, 1.10 (city wide) (c) population, computed for each zone (1.76 city-wide average); and (d) CBD, 1.25.

ACKNOWLEDGMENT

The cooperative attitude of the cities and states that supplied information is appreciated as is the willingness of the U.S. Bureau of Public Roads for permitting the authors to experiment with variations of technique in projecting and analyzing traffic data.

REFERENCE

1. Fratar, T.J., "Comprehensive Arterial Highway Plan for the Cleveland Metropolitan Area." HRB Bull. 153 (1957).

Review and Evaluation of Electronic Computer Traffic Assignment Programs

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● THE automation of traffic assignment procedures began, of course, with punched card tabulating equipment for which some very sophisticated techniques were developed (1).

As electronic computers began coming into use in the highway field, developments in the areas of structural design, roadway design, surveying, hydraulics and related fields progressed rapidly. Traffic assignment programs were also developed but they were modest improvements on earlier punched card tabulating procedures. They were limited to an analysis of segments of isolated freeway routes. They were for the most part tabulating programs that summarized the data that the engineer prepared. The interzonal movements had to be routed through the highway system visually by using a map and such elements as distance, time, etc., had to be coded and punched for each movement. The computers merely aggregated the parts for a final result. In one such program, the engineer furnished the routings in terms of map inches at various speeds along with a map scale factor. The program converted from map scale to miles and time, determined the percent diversion to the freeway route by consulting a stored table that represented a time-ratio diversion curve. It then accumulated the diverted volumes on the various elements of the freeway that were also stored as a table. At the conclusion, the accumulated volumes were summarized in various ways and punched into cards for further processing. Such developments were significant steps forward in relieving the engineer of burdensome work and in speeding up the assignment process but much manual labor and judgment was still required. The selection of the routings still had to be done by hand. This could rarely be delegated to clerical help so the horsepower of the analysis staff was severely limited.

The American Association of State Highway Officials' Policy Manual states that the travel time ratio is the travel time via the freeway divided by the travel time for the quickest alternate routing. This statement clearly indicates that the criterion for route selection shall be minimum time. Usually the development of a computer program to solve any particular problem can proceed in an orderly fashion once the criterion for solution of the problem has been clearly stated. The route selection problem languished, however. Fortunately, others working in a field quite unrelated to highways had the same problem. The telephone people were faced with the problem of route selection for direct-dialing long distance telephone calls. It is not obvious how the circuit is selected without human intervention for a call from Washington to St. Louis, for example, when one considers that the most direct circuit may be busy. The number of possible circuit routings to St. Louis is practically unlimited if the imagination is given free rein.

The breakthrough came in 1957 with the presentation of two papers. One was by Edward F. Moore, titled "The Shortest Path Through a Maze," presented at the International Symposium on the Theory of Switching at Harvard University. The other was by George B. Dantzig, titled "The Shortest Route Problem," in Operation Research 5:270-3. About this time, J. Douglas Carroll, Jr., was searching for a solution to the problem to help in the assignment of the Chicago Area Transportation Study. The services of the Armour Research Foundation were retained and J.G. Haynes and F. C. Bock were assigned to work on the problem (2).

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.

Morton Schneider and others on 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 of the Chicago Metropolitan Area. These efforts were still in the research and development category. 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. The writer had the good fortune to be associated with the project in a minor consulting capacity. 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.

About this time, Albert Mayer and his staff of the Detroit Area Transportation Study took up the development along slightly different and independent lines, but using what has come to be universally known as "The Moore Minimum Path Algorithm". Their development was also successful but for a smaller but equally speedy machine.

The Washington Regional Highway Planning Committee, whom the writer now represents, was also searching for a solution for their assignment problems. A joint development project was undertaken involving G. E. Brokke of the Division of Highway Planning, Office of Research, Bureau of Public Roads; William F. Boardman, Acting Technical Director, of the Washington Regional Highway Planning Committee, The General Electric Computation Laboratory, Phoenix, Arizona; and the writer, who was then representing the Division of Development, Office of Operations, Bureau of Public Roads. Paul Jennings of the General Electric Company deserves much credit for his unflagging efforts in bringing the computer programming to a successful conclusion. Many assignments have been made for the Washington area with this system.

The Washington system was further developed by the Minnesota Highway Department, the Bureau of Public Roads, and the General Electric Company to provide greater flexibility.

Many developments have followed in quick succession with many technical ramifications and for different types of computers. Interest in the electronic computer approach to traffic assignment is now widespread.

The Division of Development, Electronics Branch of the Bureau of Public Roads has prepared a non-machine language computer program manual for traffic assignment patterned after the Washington and Minnesota developments. Its purpose is to aid those who wish to develop their own programs. The principles of the Moore Algorithm are clearly set forth.

Very little has been published, however, concerning the technical details of the assignment programs now in existence that use the Moore Minimum Path Algorithm. This led the Origin and Destination Surveys Committee of the Highway Research Board to initiate the preparation of this report. To aid in the gathering of the necessary information, a questionnaire was sent to each of the known developers for their consideration. All graciously replied. Each of the developments are briefly discussed.

DEFINITION OF TERMS

The following terms have become quite standard among developers and users of traffic assignment programs that use the Moore Minimum Path Algorithm:

Node—A node is defined as a point of intersection in the highway network.

Link—A link is the one-way portion of the highway network connecting two nodes.

Centroid or Loading Point—A node in the network that is considered to be the point of origin or destination of trips for a geographical area or zone. Often centroids are connected to the highway network by hypothetical links that do not represent segments of real highway facilities. In other developments, the centroids are considered to be at intersections of the highway network.

Tree—A tree is the aggregate of all the minimum path routings from a node to all other nodes in the network. Usually the interest is in the trees from centroids to all other nodes in the system.

Routing or Trace—A routing is a part of a tree. It is the minimum path through the network from one node to another.

Tree Building—The use of the Moore Algorithm for computing minimum paths is generally referred to as tree building.

Network Description—The network description is the highway network under consideration described in tabular form as nodes, directional links, link impedances, link distances, turn restrictions, etc.

Loading the Network—The process of assigning the interzonal volumes to the network as dictated by the routings determined by tree building has come to be known as loading the network.

Directional Loading—Each one-way link in the network description is loaded with the volumes assigned to it from a so-called square table of directional interzonal movements.

Non-Directional Loading—This is the result when a so-called triangular table of non-directional (sometimes called two-way) interzonal movements is assigned to a network. To prepare such a table, the trips between a pair of zones are added together without regard to direction. For this kind of interzonal movement table, the volumes are usually listed only once, normally from the low-numbered zone to the higher. For example, the trips from zone 1 to zone 50 and those from zone 50 to zone 2 are added together and are listed as being from 1 to 50, there being no movement listed from 50 to 1. When assigning this form of table, the volumes are generally accummulated on only the links whose direction is from low-numbered nodes to high, regardless of the direction indicated in the tree trace. For example, if a trace indicated that a routing passed through a link defined as being from node 500 to 499, the interzonal volume would be accumulated on its complement; that is, links 499 to 500. This system dictates that there can be no one-way streets. At the conclusion of loading, only one-half of the network description has been loaded.

Link Volumes—The total interzonal volumes assigned to a link in the network. These are sometimes referred to as leg volumes. The physical analogy is the traffic volumes occurring at mid-block between intersections.

Non-Directional Turning Movements—The turning movements at the intersections are considered to be two-way. The straight-through movements are also considered to be turning movements in the context that they are part of the movements within the intersection. In this case then there are six possible turning movements within a four-way intersection where all the connecting streets are two-way.

Directional Turning Movements—As explained, there can be a maximum of twelve directional turning movements in a four-way intersection.

Capacity Restraint—Some developments have incorporated what has come to be known as capacity-restraint or capacity feedback. This is a process whereby assigned volumes are related to the capacity of the highway facilities in such a manner that overloaded routes become less attractive as minimum path candidates. This requires that the link impedances in the network description be automatically changed by the program as links become overloaded. This feature is regarded by some as a form of diversion assignment.

Link Impedance—Some impedance value must be assigned to each link in the network description for the minimum path algorithm to select minimum routes. This impedance may be some average value for travel time. It may be distance if minimum distance routes are desired or it may be a combination of the two. It is generally agreed, however, that travel time alone will not give balanced assignments inasmuch as there are many other factors besides travel time that influence the motorist in route selection. Travel time is probably the strongest single factor, however, and thus furnishes a good point of beginning for defining link impedances.

Diversion Assignment—This term is usually reserved for time ratio diversion in the sense that it is defined in the AASHO policy manual on urban design. Some use a combination of time and distance as the criterion for diversion to proposed facilities.

Diversion requires that there be at least two routes through the network found for each interzonal movement and the volume split according to some diversion criterion.

All-Or-Nothing Assignment—This is the term applied to the process of assigning 100 percent of an interzonal movement to the minimum path with no diversion.

Land-Use Feedback—This is a term coming into more frequent use. It is generally recognized that the assignment process cannot be regarded as a separate element of highway planning that is insulated from other variables. When the location of a proposed system of highways has been fixed by virtue of assignment and other considerations, it is recognized that the building of the proposed system will in itself alter land-use patterns which in turn affect the forecasts of interzonal movements. This definition implies then that the whole highway planning process is a continuing iterative system.

CHICAGO AREA TRANSPORTATION STUDY

The Chicago system is programmed for an IBM computer containing 32,000 words of memory storage. The system will accommodate a maximum of 700 centroids (zones) and 4,095 nodes. The total number of directional network links cannot exceed 14,000. Any particular node may have any number of links connected to it.

The program is for directional assignment (a square table of interzonal volumes) by the so-called all-or-nothing method. Turning movements are not computed at a single node representing a street intersection. Turning movements are obtained where desired by describing each turning movement as a link in the network. This procedure requires that more than one node be used to describe each intersection for which turning movements are required.

There are two major options that may be invoked when using this program as follows:

1. The program will forecast the interzonal volumes as an integral part of the assignment process, if desired, by the Chicago method or sometimes called the opportunity model (see HRB Bull. 253). If this option is invoked, the minimum path trees are used in the dual role of forecasting and assignment to the network. If the option is not invoked, the program will accept tables of interzonal movements as input.

2. Capacity restraint is also an optional feature. It functions in the following way: After a tree has been built from one centroid to all other nodes, the forecasted interzonal volumes with an origin at that centroid are accumulated on the links of the network as indicated by the routes in the tree. The accumulated volumes on each link in the network are then compared with the capacity of that link. The impedance of the link is automatically adjusted according to a volume-capacity criterion. After this has been done for the whole network, the next tree is built and the process repeated until all interzonal volumes have been assigned. When the option is not invoked, the link impedances remain constant throughout the process.

Machine running time for one assignment is about 5 hours for a system of 650 centroids, 4,000 nodes and 13,000 links. This is with interzonal volumes being generated internally but without the capacity restraint option functioning. Capacity restraint increases the running time between 5 and 20 percent depending on the system.

The staff requirements are reported as two draftsmen, four coders to prepare the network description and later to post the results, three punched card machine operators, an economist, two traffic engineers and the programmer.

At present the program is not documented in such form that it is ready for distribution to other prospective users. Schneider reports that it could not be run without his help.

From the beginning, a machine installation located in another city has been used. Scheduling, travel, shipment of materials, and communication are considered to be nuisances but not real impediments to the orderly prosecution of the work.

WASHINGTON, D.C., AND MINNESOTA SYSTEM

The Washington and Minnesota developments are discussed together because the Minnesota development is an extension of the Washington system.

There is a total of eighteen programs in the development package. All the programs are stored on a magnetic library tape in such a fashion that any of the programs can be easily called from the library and put into action to do the specific job indicated at any particular phase of the assignment process. The system was programmed by the General Electric Co. to function on any size IBM 704 without any program modification. The size of machine required is dictated only by the size of the network under study. The maximum size, however, is 4,000 nodes, any number of which may be centroids, which requires a 32,000-word 704. There can be a maximum of four links exiting from or entering a particular node. More than one node must be used to describe more complex intersections.

The system will accommodate the following options:

1. Non-directional assignment:
   (a) By the all-or-nothing method.
   (b) By the time-ratio diversion.
2. Directional assignment:
   (a) By the all-or-nothing method.
   (b) By the time-ratio method.
3. Forecasting by the Fratar method either directionally or non-directionally.

All turning movements are obtained at all intersections that the user designates. The system does not incorporate any capacity restraint at this time.

Unique features of the system are:

1. The program library concept.

2. There is a program to update the network description. This program has the ability to add, delete, or change links in the network in such a manner that alternate systems can be analyzed by only changing the affected parts.

3. Any tree or trees may be built separately and also any centroid may be loaded separately.

4. Selected links in the network can be separately loaded. This feature is generally used after an assignment has been completed in situations where particular problems exist. For example, suppose that the assignment shows that a particular section is congested The links in the congested area can be designated as selected links. The output is:

   (a) An assignment to the entire network but only of the volumes that passed through the selected links.
   (b) The origin, the destination, the link of entry, the link of exit and the volume of every movement that passed through each selected link.

There are many other uses such as investigation of interchange spacing, weaving movements, etc.

5. A complete analysis of vehicle hours and vehicle-miles is computed by highway systems and political jurisdictions within the network area.

6. After basic network descriptions and interzonal volume tables are established, card handling is limited to network changes.

Machine running time varies with the options selected but a typical assignment run for a system of 500 centroids and 3,500 nodes is three to five hours. Running time reduces about inversely as the square of the number of nodes.

Washington's staff requirements are one draftsman, three clerks for coding the network and posting results, and two engineers. Minnesota reports essentially the same staff requirements.

The programs are not yet available for general distribution but will be in the not too distant future.

DETROIT AREA TRAFFIC SURVEY

DATS has two traffic assignment programs. Inasmuch as they are quite different, they will be discussed separately.

Expressway Assignment

The expressway assignment program is for the IBM 650 computer with two tape units and an external Ramac disc storage unit. As the title implies, the program assigns only to the expressway system. The maximum capacity is 400 zones (centroids), 75 expressway interchanges and 425 ramps.

The assignment method is non-directional, utilizing minimum distance paths and time ratio diversion. Turning movements are computed at all ramps.

Machine running time for a system of 15 expressway interchanges and 4,300 interzonal movements is about 7 hours. For 30 interchanges and 20,000 interzonal movements, the time is 20 hours.

The staff requirements are one professional and 4 non-professional people to prepare the input and analyze the results.

At present the program is not available for use by others but will be documented shortly.

Arterial Assignment

The arterial assignment program is for the IBM 704. The system has a maximum capacity of 999 nodes, any number of which may be centroids.

The method of assignment divides interzonal volumes over alternate minimum time paths. Non-directional interzonal volumes are assigned. No turning movements are computed.

Machine running time is approximately 4½ hours for a single assignment to the maximum size network. Forecasting is not an integral part of the system.

A unique feature of the program is that after a "Desire Assignment" the volumes are distributed over alternate paths by subsequent assignments with the aim of bringing assigned volumes to within 20 percent of capacity on originally over-assigned links. The alternate paths are computed through networks with link values adjusted according to capacity restraints.

The staff requirements are one professional and four non-professional people in addition to computing center personnel for data preparation and analysis of results.

This program is considered to be still in the development stage. Documentation will begin in 1961.

SERVICE BUREAU CORPORATION

The Service Bureau Corporation assignment programs were written to fulfill the needs of a traffic study for the City of Boston. They were developed for the IBM 704 with 8,000 words of memory storage. The maximum number of nodes is 1,350 of which a maximum of 300 may be used for centroids. Each node may have a maximum of seven outbound links and any number of inbound links. A gravity model forecasting phase is part of the package. It use is optional, however. Directional interzonal movements may be supplied as input. If the gravity model option is invoked, the time function of the gravity model is derived from the minimum path trees.

No turning movements are computed at a single node. Turning movements may be obtained where desired by describing the movements with pseudo nodes and links. The all-or-nothing method (no diversion) is used.

Machine running time for a network consisting of 1,300 nodes, of which 250 are centroids, is slightly over six hours including generation of the interzonal movements by the gravity model. Without the gravity model, the time is reduced by about 20 minutes.

No information concerning the staff requirements for analysis and coding was reported because the Service Bureau supplied only the programming and data processing services. The data coding and analysis was done by outside consultants.

These programs offer three unique features.

1. The gravity model has provision for optionally generating movements for a period that actual ground count traffic volumes are available. The program statistically compares the two sets of data. On the basis of the analysis, changes may be made in the gravity model parameters.

2. This is the only reported development for which the nodes are identified by map coordinates rather than by arbitrarily assigned numbers.

3. The programming was done using the FORTRAN system of automatic programming which allows for rapid program development. Programs written in FORTRAN are usually slower running than the same program written in the conventional manner. They have the advantage however of easy translation to other IBM computers.

The programs are not available for general distribution but inquiries concerning them will be welcomed by the Service Bureau Corporation.

TRAFFIC RESEARCH CORPORATION

The assignment program is presently operational for the IBM 650 equipped with magnetic tape units. The system, as now functioning, will accommodate 100 centroids (zones) and 1,800 nodes for directional assignment. Machine running time for a system of 100 centroids and 250 nodes is 50 to 60 hours.

The development thus far has been considered as a pilot model prior to being programmed for an IBM 7070. It is therefore not available for use by others.

The system has many unique features so it is discussed in some detail.

Trip Generation

Interzonal trips are generated by mode of travel, purpose and time of day using a gravity model developed from basic O-D data.

Route Generation

A highway system composed of nodes and links is first described. Each link is assigned a distance, legal speed limit, number of lanes, turning restrictions, capacity and travel time. The minimum time path principle is then used to find the shortest routes between all pairs of zones or loading centroids.

Trip Assignment

The interzonal trips are first assigned to the minimum paths based on the legal speed limit. The capacity-volume relationship is then evaluated and the route travel times revised accordingly. The system is then "fed back" to the route generation phase and new routes generated. The old routes are kept on record however. The trips are now assigned between the new routes and the old routes in inverse proportion to their travel times. This process is continued until the system stabilizes. As many as four routes are kept on record for any O-D pair. If and when a fifth route is found that is shorter than the longest on record, it replaces the longest.

Gravity Model Feedback

Once the route generation and assignment loop stabilizes, the system may be fed back to the trip generation phase to regenerate and redistribute trips according to the new travel times found due to capacity restraints.

The whole process continues until road user time is optimized within the capacity of a transportation plan. The system can still further be fed back to the land-use plan to take into account changes in land use due to the transportation plan selected. Provision is also made for balancing of auto and transit use due to capacity restraints. The parking function can also be taken into account.

Although still in the development stage, this system is the most comprehensive of all those reported.

CONNECTICUT STATE HIGHWAY DEPARTMENT

The Connecticut assignment programs are written for the Remington Rand File Computer—Model 1, which is classified as an intermediate speed machine, but has large storage capacity. The development was initiated originally for an analysis of a transportation plan for the City of Hartford, but has now been extended to six other cities within the state.

A maximum network size of 10,000 nodes of which 165 may be centroids is reported. It is interesting to note that this is more than twice the maximum number of nodes reported for any other development.

The program is for either directional or non-directional assignment by the all-or-nothing method and has been used primarily with a gravity model program that uses the minimum path trees for the time function in generating the interzonal movements but the system will accept movements from any other forecasting method as input.

Turning movements are calculated at selected intersections or all intersections as desired. Distributions of time and distance versus assigned volumes may be obtained for the whole system or for selected routes within the system. An additional feature provides for obtaining the origin and destination of all movements passing through selected links or all links.

For a system of 120 centroids, 1,400 nodes and 2,500 links, the machine running time is 39 hours, data preparation and analysis is reported as about 180 man-hours.

The programs are not presently available for distribution but are in the process of documentation.

CALIFORNIA DIVISION OF HIGHWAYS

The California assignment program is developed for the IBM 650 computer but will shortly be revised for an IBM 704 with 8,000 words of memory storage. The present development will accommodate a maximum of 699 nodes and 1,000 links. Any node may be either a loading centroid or a street intersection or both. Turning movements are available for all intersections.

Most assignment programs have been developed around the Moore Minimum Path Algorithm. California however developed their assignment program prior to the minimum path development. So-called "by-hand" routings were supplied as input. Now routes are calculated by the minimum path principle and supplied to the original assignment program as input. For small highway system analyses, hand routings are still used.

The system uses the California freeway diversion formula which incorporates both time and distance as the criterion for diversion to the freeway routes. As many as 4 different routes between a pair of centroids may be compared:

1. The existing street system route.
2. The basic route (this is interpreted as being the modification of the existing route caused by the superimposing of a proposed freeway system).
3. The best time freeway route.
4. The second best time freeway route.

The diversion formula assigns 50 percent of the interzonal movement to the freeway portion and 50 percent to the basic route if the two are equal in time and distance. If there is both a best and second best freeway route, the freeway portion is further split between them by a ratio of their time and distance. The percentage assigned to the freeway route is further reduced if the percent assigned is less than 50 percent of the total movement and the difference in distance between the freeway and basic routes is less than two miles. For economic comparisons, 100 percent of the interzonal movements may be assigned to the existing routes. The program accommodates non-directional (so-called two-way) movements only.

Forecasting is not an integral part of the assignment program. California uses a gravity model, the Fratar method or a multiple regression method (which is their own development) for forecasting.

For a network of 699 nodes of which 210 are centroids, the machine running time for a complete analysis is 125 hours. It is estimated that the machine time varies directly as the square of the network size.

The map work and analysis is done by the district offices so staff requirements and time estimates were not reported. The programs are available for distribution through HEEP, an organization of highway users of IBM equipment.

MISSOURI STATE HIGHWAY COMMISSION

The Missouri assignment program is developed for the IBM 650 computer and will accommodate a highway network composed of 791 nodes and 200 centroids. For networks requiring a greater capacity, a technique has been developed such that the network may be divided into two parts. The minimum path trees are developed separately for the two parts and then combined (3).

Another unique feature is what is called a "speed flatterner curve" that optionally distributes tree paths to parallel streets in a grid network. This has the effect of spreading the assigned volumes over all the parallel streets within a corridor movement. The system is non-directional and uses the all-or-nothing method or a time ratio diversion curve. The mimimum path principle of route calculation is used. Forecasting is not an intergral part of the system.

The output is punched cards in the form of minimum path trees or "loaded trees" which may be combined by punched card equipment to accumulate the total link volumes or turning movements.

Machine running time for a system of 1,300 nodes and 270 centroids, which requires the trees to be computed in two parts, requires about 120 hours for the all-or-nothing method. For time ratio diversion, the time is doubled.

The staff requirements are one engineer and two technicians to prepare the input and analyze the results.

The programs are documented in such form that others may use them. Copies may be obtained by writing to the Missouri State Highway Department.

BRITISH ROAD RESEARCH LABORATORY

England is also making excellent progress in the traffic assignment field. Their development is for the Ferranti Pegasus Computer. The system will accommodate a maximum of 44 centroids and 255 links for completely directional assignment by the all-or-nothing minimum time or cost paths. All turning movements are computed.

The English development is unique in two respects in that each link in the system is considered as a centroid or loading point and that travel may be stratified by cost of travel.

Machine running time is one hour for a system of 100 links, each of which is considered as a traffic origin.

The program is available but of course would have to be reprogrammed for use on computers in this country.

DISCUSSION

Program Availability

Only two of the respondents to the questionnaire stated without any qualification that their programs were available for general distribution. This is not because any of them wish to maintain any proprietary rights in their developments. It would be most difficult, therefore, for any prospective user to acquire and use any of these programs without a great deal of consultation with the developer. The reasons for this situation are many and not generally understood. To discuss the problem, there must be a clear definition of what constitutes a computer program in its finished form. Such a program consists of three major parts, as follows:

1. A carefully written user's manual which describes the programs in detail from the engineer's point of view including such items as data preparation, staffing requirements, suggested sequence of program utilization, interpretation and analysis of results, common pitfalls, experience of prior users, etc., so that the prospective user may decide whether the program is applicable to his particular needs, and, if it is, to proceed to use it without undue study and delay.
2. A programmer's manual which describes the programs from a programmer's point of view. Such a manual includes general and detail flow charts, copiously annotated program listings accompanied by symbolic program cards. The test of the completeness of the programmer's manual is that any competent programmer exper-

ienced with the machine in question should be able to very quickly understand in detail any part of any of the programs so that he could modify them for special needs without a great deal of study. Without adequate documentation, it often takes longer to understand someone else's program than it took to write it originally.

3. A machine operator's manual should contain all that an experienced machine operator needs to know to successfully operate the programs and to deal with unusual operational problems without a programmer being present. The operator's manual is accompanied by the actual machine language program cards.

Programs documented in this fashion would be almost ready for distribution, but not quite. There must be facilities for reproduction and program maintenance. Program maintenance is something that hasn't received much publicity in the highway field but we will hear more about it as computers become more commonly used. No program is perfect. Most of them are not completely de-bugged. It is not unusual for "latent bugs" to be discovered in a program even after it has been in heavy use for months and even years. Programs are constantly being improved and modified. Large computer installations have a staff devoted exclusively to program maintenance. For programs to be successfully distributed, then, there must be adequate documentation and provision for the issuance of errata sheets and the latest changes and modifications. The programmers are not to blame for the lack of documentation. Most programs are developed under a great deal of pressure, usually with a deadline to be met. Usually, at the time of development, no thought is given to sharing the programs with others. When the programs do become operational, the sponsor usually assumes that because they are running, they are complete, and the programmer is assigned another job just as urgent as the first. Probably only the programmer is aware of the "patches" and modifications that had to be made to get the programs to run. Six months later even he has trouble in remembering what was done. Program development is an expensive business. The Washington and Minnesota developments came to more than $50, 000 before they became completely operational. Minor troubles still are being discovered. The writer believes that these developments must be shared, but it would be unfair to burden the original developer with the job of distribution, reproduction and follow-up. The Highway Engineering Exchange of Programs (HEEP), an organization of highway users of IBM computers, is doing a good job in this field, but only one assignment program is reported as having been submitted to them. Perhaps there is a need for a central exchange of programs used only in the highway planning field without regard to the manufacturer of the machine. No central distributing agency can function, however, unless the programs are documented according to clearly set forth rules. It is the responsibility of the sponsor of the development to state clearly to the programmer that documentation will be required and to give him the time to do it after the development is operational.

Large Versus Small or Intermediate Machines

The larger the machine, the less it costs to operate for a particular assignment job. This assumes of course that the user is being charged for the machine only for the actual running time. Two of the respondents reported about 125 hours of intermediate size machine time for an assignment to a system of about 250 zones and about 800 nodes (these are average figures). Forty dollars an hour is a fair charge for the machine involved. This is neither the lowest nor the highest figure for the machine. At this rate, the cost is about $5000 for machine time for an assignment. The large high-speed machines will handle much larger networks with a machine running time of about 3 to 5 hours for a complete assignment at a cost of about $1, 000 to $2, 000. Here again, these are median figures. Even with no adjustment for network size, the cost is less than one-half. This is not to imply that the users of intermediate size machines should abandon their developments in favor of the larger machines. There are many advantages to being able to work locally. But to those who are considering entering this field, the following facts are pertinent. There is already pressure for assignment systems to accommodate larger networks than the largest now available. The so-called second generation of faster all-transistor machines is now here. When assignment systems become available for them, the machine costs will probably be cut to one-half of the best now operating. Even larger and faster machines are just over the horizon. Programming for the larger machines is considered by many to be less difficult than for the smaller machines. It is most unlikely that any state highway department or planning group will be able to afford installations of the large machines in the foreseeable future.

Usually then, if the larger machines are to be used, travel, shipment of equipment and data, scheduling and communication problems will be involved. Those who now operate that way report that the problems are nuisances but not real obstacles to the prosecution of their work.

The writer also believes that the highway planning staff should include people trained in computer programming and to a limited extent, machine operation.

Program Use

There is general agreement among the users of assignment programs that many assignments are necessary before a balanced system for any urban area can be achieved. The Washington Regional Planning Committee has completed their twenty-third system analysis. Short-range assignments have been made, as well as long-range, to answer questions concerning stage construction. In one case, a complete assignment was made to answer questions about one particular ramp. New assignments reflecting changes in land use are needed. The mass transit problem must be solved. The writer knows of no group who has been willing to settle for a single assignment once they have placed themselves in a position to do them quickly and inexpensively with electronic computers. The trend is now toward continuing studies in urban areas. The highway planner must be active over a broad range from land-use planning on the one hand to geometric design on the other. No one assignment can answer all the questions simply because there is no single solution to a transportation problem.

Capacity Restraint

All of the respondents to the questionnaire agree in principle that some sort of capacity restraint is necessary to achieve balanced assignments. Two of the respondents, Chicago and Toronto, have capacity restraint built into their assignment programs now. Others are actively working on the problem. Chicago has made several assignments to very large networks using this feature and very favorable results are reported.

There is a reluctance, however, on the part of many to rely on a completely automatic procedure to bring assigned volumes into agreement with highway capacity. Also there is not agreement as to the procedure to be used. The Chicago system varies link impedances as a network is loaded.

The Toronto method loads the whole network before any adjustment of impedance takes place. New routes are then calculated but the old are kept on record and the volumes split according to the travel time on the new and the old. This process is continued until the system stabilizes with as many as four alternate routes sharing a particular interzonal volume according to the travel time on each.

Others believe that trip time length should be a factor such that long trips would be assigned first and impedance adjustments made, then the next shorter trips and so on, so that the shorter trips will be forced to seek existing street routes if the desired freeway routes are functioning at capacity. Others argue that the intermediate length trips should have the first opportunity to use the freeways because the longest trips are more likely to have equal time freeway choices and so can be easily diverted to an alternate freeway route.

To say the least, capacity restraint is a controversial subject. Those who are pioneering in this field are to be commended. Proven techniques are bound to emerge from their efforts.

Land-Use Feedback

It is obvious that a transportation plan, if developed, will affect land-use patterns which will, in turn, affect the transportation system. Excellent developments in this area are under way and more can be expected.

It is interesting to note that since comprehensive assignments to entire highway networks have become a reality, the emphasis is returning to the area of traffic forecasting.

Network Size

The maximum size of networks that can be accommodated varies from a few hundred nodes to several thousand. The question arises as to what node and link capacity is required for cities or transportation plans of various sizes. This also, is a controversial subject. There is general agreement that the minor streets that can be classified as local service need not be defined in the network. All agree that the proposed freeways should be included. The arterial streets lying between the two extremes are the facilities that some say should be included sparingly if at all. Others maintain that a very comprehensive arterial system is required.

Network size depends on the size of the city and the needs of the particular study. If the problem is limited to a general system location study, inter-district movements may be assigned to a rather grossly defined system to obtain meaningful results. If locations are fixed within narrow limits and information is required concerning interchange spacing and number of lanes, interzonal movements should be assigned to a system that includes a fairly comprehensive arterial network. If information is required as to ramp configuration, ramp capacity and modifications to the existing street system to insure that the proposed system will function adequately requires a well-defined arterial system as well as relatively small assignment zones.

Assignments for various years for the purposes of establishing a schedule of priorities for stage construction of an established plan also require detailed definition of the network to avoid distortions. The Washington Regional Highway Planning Committee has been able to serve all needs in the area (forecast population 3,000,000) comfortably with a 4,000-node system.

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Developing a Traffic Model with a Small Sample

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● FOR YEARS the Boston Metropolitan Area has accomplished too little in its efforts to create and keep up-to-date reasonably good data dealing with the pattern of daily travel origins and destinations of its residents and visitors. The first and last comprehensive O-D study was undertaken in 1945 at a time when travel patterns were abnormal because of World War II. The study must now be considered useless. In more recent years partial O-D surveys have been made, but these have consisted of Cordon Count O-D surveys and studies of industrial plan commutation patterns (such as along Route 128). These surveys cannot be classified as the type necessary to properly guide a comprehensive public transportation policy.

Nevertheless, the construction of highway and expressway facilities has progressed with moderate speed. The process has been somewhat confusing, sometimes mixed with politics, and not always in the best interests of economic development of the region. More seriously, the highway program has progressed (with Federal financial help) unilaterally—and not with the parallel development of related transportation facilities such as parking lots, transit, local streets, and frequently other highways under other governmental jurisdictions.

For those reasons, and the simple fact that those highways already built exceed estimated 1970 traffic volumes, the great need for good and up-to-date O-D data and estimates of future traffic flows is intensified. And of course it was obvious that the traffic engineering profession should have a bigger role in the decision-making process.

At this time Boston College, with Ford Foundation help, had formulated a "Seminar Research Bureau" to carry out programs of research and citizen education on Metropolitan Boston Problems. The first problem identified and investigated was urban transportation. It quickly followed that the Boston College research program would consist of investigation and use of the Gravity Model as a means, first of making (hopefully) a small contribution to the science and progression of traffic engineering, and second, making a contribution to the process of data collection and analysis in Boston. It was intended, and still is, that the Boston College Study could create a good, reliable and inexpensive traffic analysis and estimation process that would be adopted by appropriate official agencies.

The general procedure of the Boston College Study was, as follows:

1. To undertake a small, carefully designed sample home interview.
2. To use the resultant data to verify that the daily travel frequency characteristics of Boston residents are of similar magnitudes and characteristics as has been demonstrated to be the case by other O-D studies in other cities. And in this case the sample data were designed to allow establishment of relationships between social-economic characteristics of the Boston residents, and then the amount of travel taking place each day.
3. To use the sample survey data to check the general validity of the O-D distribution of daily trips as calculated by the Gravity Model formula (the model used was that developed by Alan Voorhees).
4. The remaining steps of the procedure have less to do with the use made of the sample data, but are distinctly related to the conclusions of this paper; (a) Calculating the 1959 and 1980 O-D's with the Gravity Model. The Boston College Study made 1980 calculations based on 2 alternative patterns of future regional employment—one emphasizing the downtown as a job center and the other emphasizing the suburbs near Route 128. (b) Assignment of trips to the major transportation facilities, and here it must

be noted that some six alternative assignments and systems of transport have been analyzed.

The sample home survey was designed to interview 100 families in each of ten communities. Therefore, 1,000 families were interviewed out of a total of 850,000 in the entire Boston Metropolitan Area (a 0.12 percent sample). The ten communities were selected at random from among the 84 traffic zones of the region—with the qualification that 5 of the 10 were selected intentionally from the suburbs and 5 from the inner area. The 1,000 families were also selected at random.

The interviews were carried out by senior students majoring in marketing at the Boston College School of Business Administration. About 40 students participated and were paid for time and expenses. Each student was assigned 2 homes per day for 2 or 3 days a week. The interviews were conducted during the late afternoon and evenings of October, November and early December. The questions asked of the residents were essentially the same as those asked in regular O-D surveys. The professor of the marketing course acted as consultant on interview techniques.

The sample size was small by statistical design. Because others making more extensive studies of this kind had established that the travel habits of groups of people had distinct patterns and magnitudes, and that these patterns were related to various social and economic characteristics of the people, it was necessary to verify only that these patterns and relationships also applied to the Boston region and then to modify the relationships to be somewhat more accurate and applicable. Statistically speaking, other studies had considerably narrowed the areas of uncertainness—they had defined the degrees of variability and deviation. It was statistically expected that a sample of the design carried out would allow estimation of the amount of total daily trips, and the amount of daily work trips for each community within ± 10 percent, two out of three times.

The results of the survey proved capable of doing just that. If they had not, this study would have come to an abrupt halt.

The results provided data that allowed the formulation of travel and socio-economic relationships noted, as follows:

1. Correlation between total trips per family and persons per family and cars per family. This multiple correlation has a coefficient of 0.944 and a relative variation of 8.6 percent.

2. Correlation between daily work trips and persons per family. The coefficient of correlation is 0.941 and the relative variation is 8.1 percent.

3. A good result proved to be a correlation between daily total non-work trips. The coefficient of correlation is 0.908 and the relative variation only 4.3 percent.

4. Relationships dealing with the number of more specialized types of trips did not prove to be as strong:
   - (a) Shopping trips correlated with car ownership had a coefficient of 0.868 and a relative variation of 17.8 percent.
   - (b) Personal business trips, business related to work, and recreation trips—as a group—related to car ownership had a coefficient of correlation of only 0.761 and a relative variation of 33 percent. The probable accuracy of prediction is not very good.
   - (c) Social, civic, education and religious trips—as a group—had a coefficient of correlation of 0.819 and a relative variation of 17.7 percent when related to car ownership.

It is believed that the data from the sample were good enough and that the sample size was big enough to accomplish what was intended of it with regard to estimating travel frequency.

The results were used to calculate the 1959 and 1980 total, work and non-work travel frequency in each of the 84 zones.

The sample data were not specifically designed to guide the composition and use of the Gravity Model. It was intended only to check the distribution of trips by the model with the sample data. But after the survey was completed and the model was being checked it was noted that the value of the best exponent of the model appeared to be greater than in previous examples of its use in other cities. This could be expected to some extent because of the manner in which time and distance were measured between zones. A further explanation is the fact that a measure of "terminal time" was included in the measured travel time.

But what was disturbing was an apparent biased difference between the model and the sample data. It was noted in the investigations that a pattern suggesting that the best exponent for inner zones was different from the best exponent for outer zones when compared to the sample data.

Without going through all the details, it was finally concluded that the number of daily walk trips accounted for most of the difference and were adjusted accordingly. (Fortunately the number of walk-to-work trips had been sought out in the survey.) In the final stages the sample data established the level of the exponent in the model. The exponent settled on for work trips was 3.5 and for non-work trips was 5.0.

How accurate is the exponent? Statistically, it is not known, but the final determination of the exponent shows no bias and the distribution of trips by the model when compared to the sample data in 10 zones shows errors. In some cases large—in other cases small—as in any O-D survey estimates. But the errors show no pattern—or they have no bias. There is nothing to indicate that the errors are a function of too little data to accurately determine the travel habits from 84 different zones.

If this study were to be done again, it would be done in much the same way; but about twice as many families would be interviewed, not necessarily with the expectation of eliminating the errors that exist, but with the intent of being able to measure more accurately the errors that do occur.

But this interest is partially academic. As far as the numbers are concerned, it is felt that the normal process of aggregating and assigning the volumes tends to minimize the individual zone-to-zone O-D errors.

More impressive at this time are the differences that can occur because of various assumptions that must be made in any such study before it can rationally lead to recommendations of metropolitan transport facilities.

The influence (and related errors) of estimates of the following are important:

1. Future population distribution;
2. Future economic levels and job distribution;
3. Future car ownership;
4. The assignment procedure and its underlying assumption and/or policies regarding how easy and convenient shall travel be, what kind and how many trips shall be put on expressways, etc.;
5. The future utilization of mass transit.

There are more crucial factors that greatly affect the design of the system to be recommended. Even the simple, but not so simple to calculate, matter of future car occupancy can drastically affect the eventual design.

Who, or what O-D survey, for example, could predict that travel would increase so greatly between Cambridge and Washington, D.C. ?

These kinds of influence are as important as the errors of the model. These factors show that there are many errors involved—and one of these must not be the human error of combining the very accurate with the inaccurate and expecting the perfect.

The small sample proved adequate, and even though strained, gave results that have a level of accuracy consistent with the many other inputs of a metropolitan transportation study.

Capacity Restraint in Assignment Programs

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● TRAFFIC PREDICTION methods have been developed primarily to help shape and justify road planning decisions. It is an unfortunate fact that the traffic systems to which such methods must be applied are almost always inadequate. Some degree of peak-hour congestion exists in most cities today and will continue to exist in the future. To build a road network on which no congestion would occur would probably be prohibitively expensive. Any realistic method of traffic prediction must therefore recognize the presence of traffic congestion and its effect on traffic patterns.

An assignment program is essentially a means of estimating traffic flows on the basis of trip demand and traffic network data. Hitherto, designers of such programs have paid scant attention to the effect on traffic patterns, whether real or simulated, of road capacity limitations. Such limitations are, of course, the cause of traffic congestion. It is well known that delay caused by congestion will cause travelers to seek other less congested routes and will persuade some travelers to cancel their trips entirely; conversely, it is known that the existence of an uncrowded direct route between two areas will quickly draw traffic from other more crowded routes and will even create new trip demand between the two areas. These effects are implicit in the traffic pattern of any city. Assignment programs which do not take them into account in an explicit manner can make no allowance for changes in the pattern of congestion which will inevitably occur as the city evolves. In fact, such programs tend to freeze the congestion pattern to whatever shape it had when the last O-D survey was made. This can cause considerable error, especially if there are significant differences between the land-use pattern and/or traffic network proposed for the future and that in existence when the survey was made.

Under contract with the Metropolitan Toronto Planning Board, the Traffic Research Corporation has developed a systematic model for predicting vehicular traffic flow using high-speed electronic computing techniques. This model contains a direct feedback mechanism by which capacity restraints and the resultant congestion are allowed to affect route generation, trip distribution and vehicle assignment in successive program blocks. It has been tested in full-scale studies of the Toronto area and has been found to give promising results. This paper describes briefly how the simulation model works and shows how some of the results obtained from it compare with observed data.

DESCRIPTION OF TRAFFIC SIMULATION MODEL

Input data for the model falls into three basic categories; (a) land use (that is, where people live, work, shop, play, etc.): (b) traffic facilities (that is, what expressways, roads, etc., are available); and (c) trip characteristics (that is, on what basis people choose their destinations, mode of travel, route followed, etc.). This information is assembled in the form of tables and formulas.

Traffic simulation is then carried out by means of five types of program blocks, as follows: (a) trip generation, (b) route generation, (c) trip distribution, (d) vehicle assignment, and (d) travel time calculation. The order of occurrence of these blocks is shown in Figure 1. Briefly, the sequence is as follows:

1. A trip generation is carried out for the land-use pattern and the time period (hour of day) under study. Once completed, this block is never repeated, unless it is

desired to start another run based on a different land-use pattern and/or time period.

2. A first set of routes is determined, one between each pair of zones. Each route is the shortest possible in terms of travel time. Because at this stage there is no traffic moving on the road network, these travel times are called "ideal travel times" and the resultant routes are called the "ideal routes".

3. Trips generated in each zone are distributed to all other zones on the basis of the attractiveness of each zone and the ideal travel times as determined in step 2.

4. Trip interchanges from step 3 are translated into terms of vehicles and assigned to the pertinent ideal routes. The volume of vehicles per hour using each road section is then determined.

5. On the basis of volumes from step 4 a new travel time is calculated for each road section, or link.

6. A second set of routes is now generated. These are, in general, different from the ideal routes, because they are based on the new link times found in step 5.

7. A second assignment is carried out. The vehicles proceeding from an origin O, to a destination, D, are divided proportionately between the routes now available, on the basis of the route times.

8. A second travel time calculation is performed for each link and each route on the basis of link volumes determined in step 7.

9. The sequence of steps 6, 7, 8 is iterated twice again to produce up to four routes between each O-D pair.

10. A new distribution is performed to determine the trip interchange between each O-D pair which results when the congested travel time is used instead of the ideal time.

11. The sequence of steps 7, 8 is now iterated several times until changes in link volumes from one iteration to the next remain less than a predetermined value. In practice, the sequence of steps 10 and 11 may be repeated again if necessary. The resulting link volumes and travel times comprise the traffic pattern predicted by this simulation model for the specified time period, land-use pattern, road network and trip behavior.

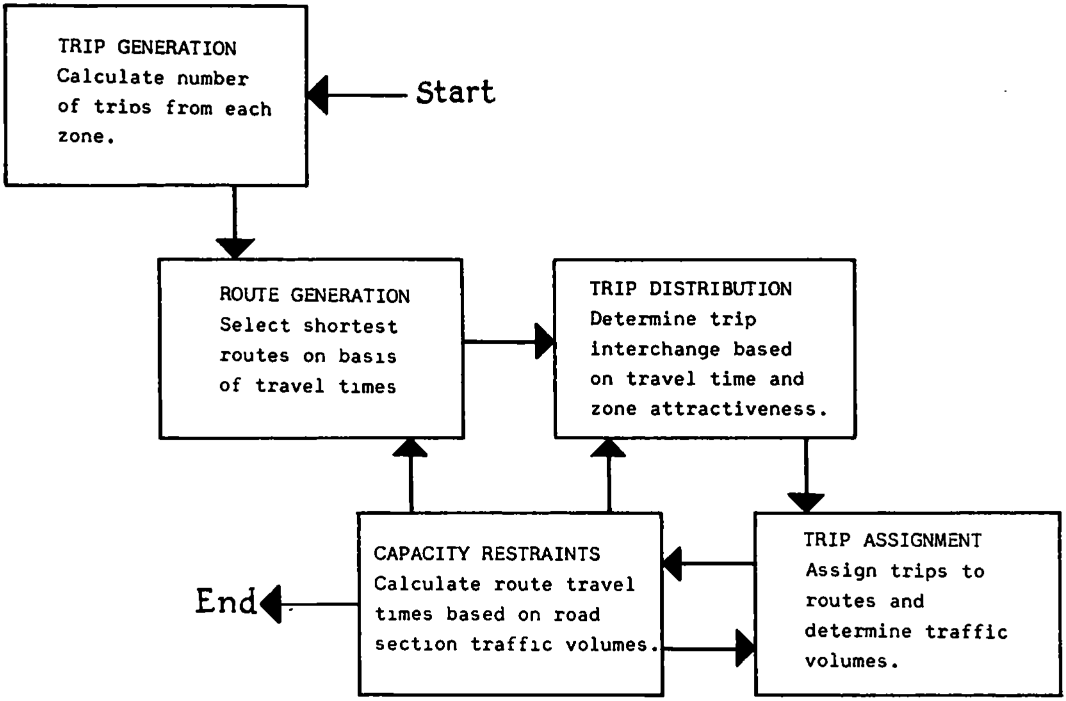

Figure 1. Flow diagram for traffic simulation model.

It can be seen from the foregoing that travel time is the variable which ties all blocks of the model together. It is, therefore, important that the formula by which it is calculated be clearly understood. This leads to a more detailed discussion of the means by which capacity restraints are used to calculate the effect of traffic volume on travel time.

CAPACITY FUNCTION

The term, "capacity function," as used in this paper, means the mathematical formula developed to describe the relationship between traffic volume and travel time for a given road section. Flow of vehicles along a road is a very complex phenomenon depending on many factors. From observations it is well known that larger volumes of traffic can be moved on multi-lane roads than on single lane roads, although the volume does not increase arithmetically as the number of lanes increases. It is also a known fact that as traffic volume increases the delay due to congestion and stoppage increases. The form of this time-volume relationship is obviously affected by many things: road width, lane markings, intersections, traffic signals, transit vehicles, transit stops, trucks, turning movements and pedestrian traffic, to name a few. Each road section is probably unique in its combination of these variables and should, for precise simulation, have a unique capacity function to describe it. Moreover, it should have a different capacity function for different time periods and different weather conditions, etc. Perhaps computer capacity and empirical data will be sufficient someday for this degree of precision. For present purposes, however, it has been approximated as follows:

The road network in the study area is represented schematically by a grid of nodes and links. Because the schematic grid can rarely be as detailed as the actual road network, each link usually represents several parallel adjacent roads having similar traffic flow properties. Each link then is classified into one of ten categories, according to the speed limit and number of signalized intersections per mile on the road sections which it represents. Link properties for each category are given in Table 1. The basic capacity function formula, which applies to all categories, is

$$T_v = \left[t_c + \frac{d(F_v - F_c)}{F_c} \right] L \qquad (1)$$

in which

F_v = link volume as calculated by assignment block (cars per hour per lane);
F_c = critical volume = practical capacity of link above which flow becomes unstable and travel time rises rapidly (cars per hour per lane);
T_v = link travel time at volume F_v (minutes);
t_c = link travel time per mile at critical volume F_c (minutes per mile);
L = link length (miles); and
d = delay parameter (minutes per mile); = d_1 for $F_v < F_c$; = d_2 for $F_v > F_c$.

The variables F_c and t_c, when substituted in Eq. 1, define a unique volume-time relationship for each of the ten link categories. The delay parameters, d_1 and d_2, could be made unique for each category, but present observations can be fitted adequately by using the same values for all categories; that is, $d_1 = 0.5$ and $d_2 = 10.0$.

The ten capacity functions resulting from these values are shown in Figure 2.

Data on which these curves are based come from a wide variety of sources. Most prolific of these has been the system of radar detectors mounted at the approaches to eight intersections in Toronto as part of the Computer Automated Traffic Control project. Input from these detectors is analyzed every two seconds by the computer in such a way that delay at each intersection approach can be calculated as a function of approach volume. Results from one such location are shown in Figure 3, in which the observations have been correlated by two straight line segments. The volume at which the slope changes is known as the critical volume, F_c, which could also be called the free-flow capacity of the link. Above this volume, flow becomes unstable and time delay tends to increase rapidly with volume.

Curves of the type shown in Figure 3, when reduced to a volume-per-lane basis, adjusted to a standard cycle and phase time, and grouped according to category characteristics, resulted in the ten functions of Figure 2. Some of these curves are based on sketchy evidence; experiments are presently being carried out in Toronto by the Metropolitan Toronto Traffic Department, the City of Toronto Traffic Department, the Metropolitan Toronto Planning Board and the Ontario Department of Highways to fill some of the empirical gaps.

Curves of the shape shown in Figure 3 were predicted theoretically on the basis of elementary queuing theory before the observations were made. Different assumptions of arrival and departure distribution could lead also to curvilinear functions. It was felt, however, that straight line segments were the best simple functions to fit present data.

DESCRIPTION OF PROGRAM BLOCKS

Trip Generation

The study area is broken down into zones, each of which is represented schematically in the model by a centroid point or node possessing all properties of the zone except size. Land-use data for the area provide significant information such as population, employment, car registration, number of dwelling units, etc., for each zone. Relationships between this information and the number of trips actually generated in a zone were determined as follows:

The Metropolitan Toronto Planning Board carried out a home-interview survey in 1956. This indicated how many trips for each purpose and mode of travel were generated in each zone for all time periods during the day. Regression analyses were carried out to correlate the data for each time period, trip purpose and travel mode. Workable relationships were found between automobile trips generated and three land-use parameters: population, dwelling units and car registration. Multiple correlation coefficients for the time periods studied exceeded 0.95.

Using these relationships, the following categories of trips emanating from each zone are calculated:

1. Primary trips; that is, trips having one terminus at the place of residence. These are broken down into three purpose categories: (a) work, (b) business-commercial, and (c) social-recreational.
2. Secondary trips; that is, trips having neither terminus at place of residence. These are subdivided into the same three categories of trip purpose. The distinction between primary and secondary trips is necessary because different generating relationships are required for each type.

TABLE 1

CAPACITY FACTORS

Description of Link: Speed Limit (mph)	Description of Link: Signalized Intersections (no./mi)	Capacity Table Code	Critical Volume, F_c (cars/hour/lane)	Travel Time per Mile, t_c, at Volume F_c (minutes/mile)	Mean Speed, S_c at Volume F_c (mph)	Travel Time per mile, t_o, at Zero Volume (minutes/mile)	Mean Speed, S_o, at Zero Volume (mph)
30	10	0	400	5.8	10.3	5.3	11.3
30	5	1	450	4.4	13.6	3.9	15.4
30	3	2	500	3.7	16.2	3.2	18.8
30	2	3	550	3.2	18.8	2.7	22.2
30	1	4	600	2.8	21.4	2.3	26.1
40	2	5	750	2 4	24.6	1 9	31.6
40	1	6	900	2.2	26.7	1.7	35.3
50	1	7	1,100	2.0	30.0	1.5	40.0
50	0	8	1,300	1.7	35.3	1.2	50.0
60	0	9	1,400	1.5	40.0	1.0	60.0

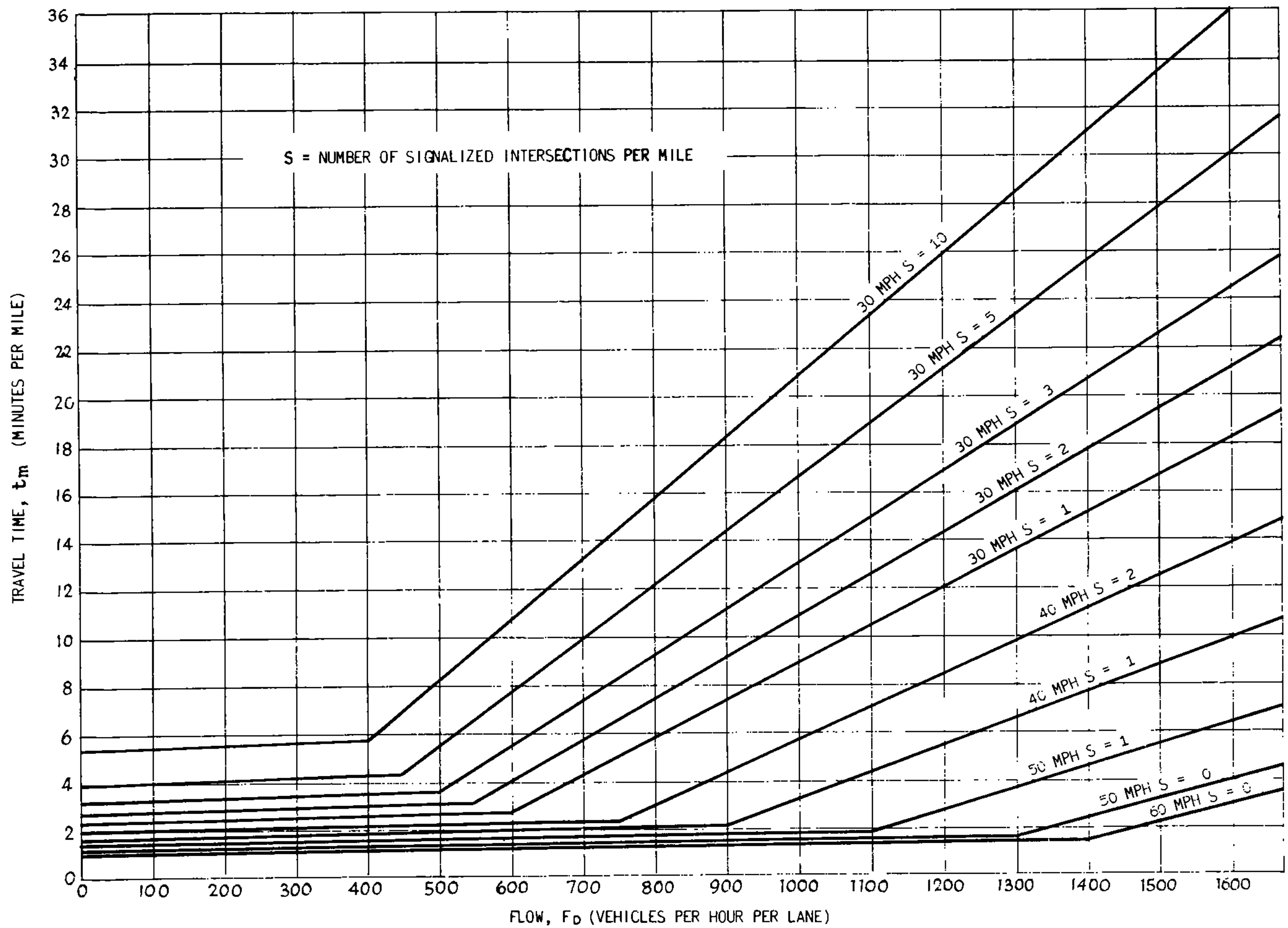

Figure 2. Capacity function curves.

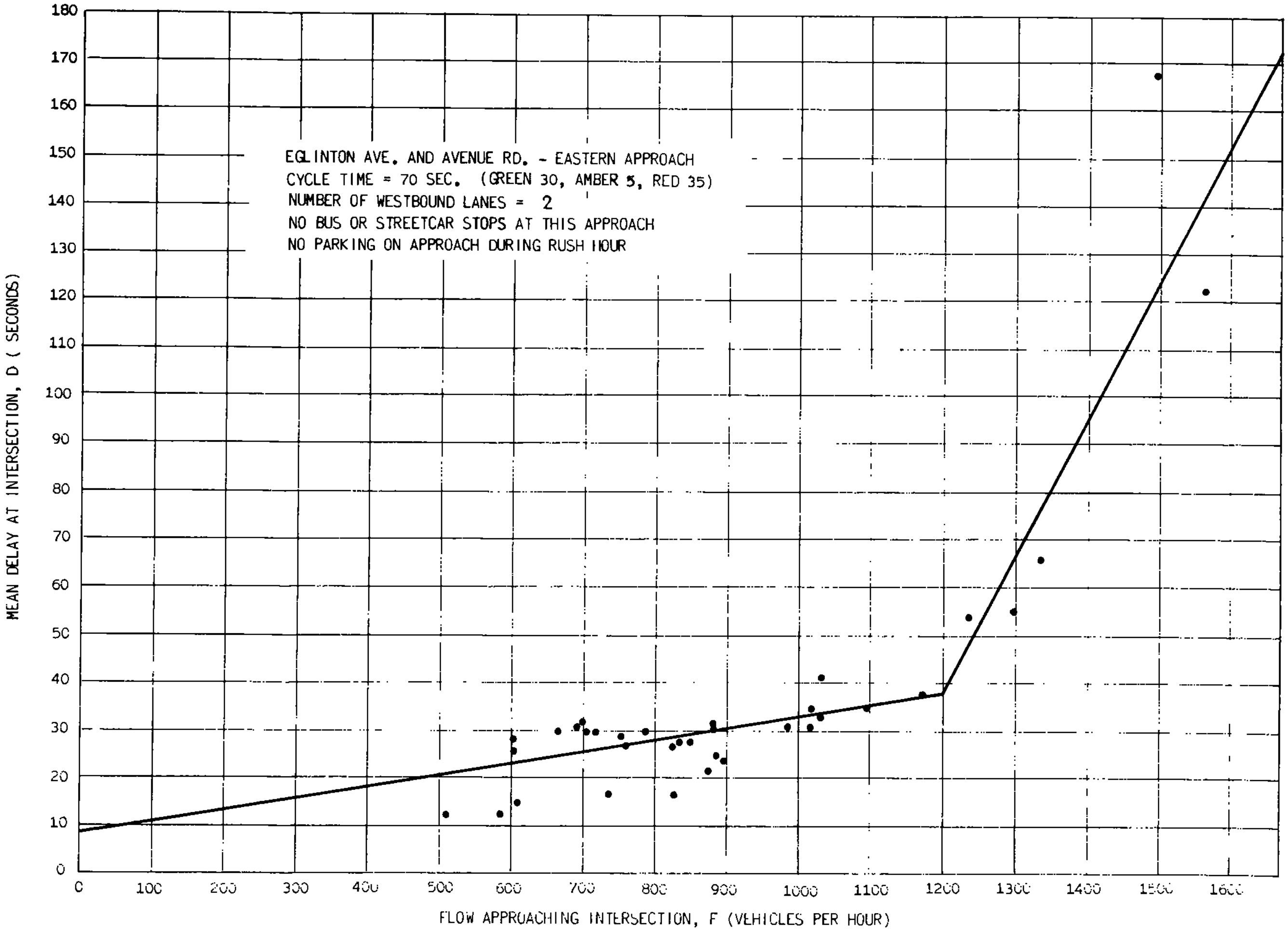

Figure 3. Volume-delay properties of a signalized intersection.

As input for the trip distribution block later in the program it is also necessary to determine how many trips of each purpose will be attracted to each zone during the period under study. Again the home-interview survey was used to determine relationships between land-use parameters and trip attractor figures for the three purposes. It was found that the work attractors (that is, the number of work trips arriving at each zone) could best be correlated by the variable total employment; business-commercial attractors were correlated by retail employment, and social-recreational attractors by population. In dealing with vehicle trips the availability of parking in a zone was also a factor.

The three attractors are thus calculated for each zone on the basis of employment and population within the zone. They are then adjusted on a pro rata basis so that the sum of the attractors over all zones for a given trip purpose is equal to the total trips generated in all zones for that purpose. This matching of totals is necessary to insure reasonable closure of the simulation model.

When 1956 land-use data are used, these calculations yield values of trips generated and attracted for each zone in good agreement with the survey figures, as would be expected. Relationships established for 1956 will not necessarily remain valid for future years, and a study is being carried on to determine what trends exist, if any. For present purposes, however, the established relationships must suffice. Quantities such as population, employment, car registration, etc., can be estimated for the future on the basis of past trends, zoning restrictions and economic forecasts. If desired, ranges of such quantities can be studied. Having made these estimates, the trips generated in and attracted to each zone can be calculated for the future time period under study. This is the function of the Trip Generation program block.

Route Generation

As previously mentioned, the road network under study is represented by a grid of nodes and links. Each link is fully described for purposes of traffic simulation by three variables: one indicating which capacity function is applicable, a second indicating its number of lanes and a third indicating its length in tenths of a mile. Turning delays and restrictions can also be included, if desired.

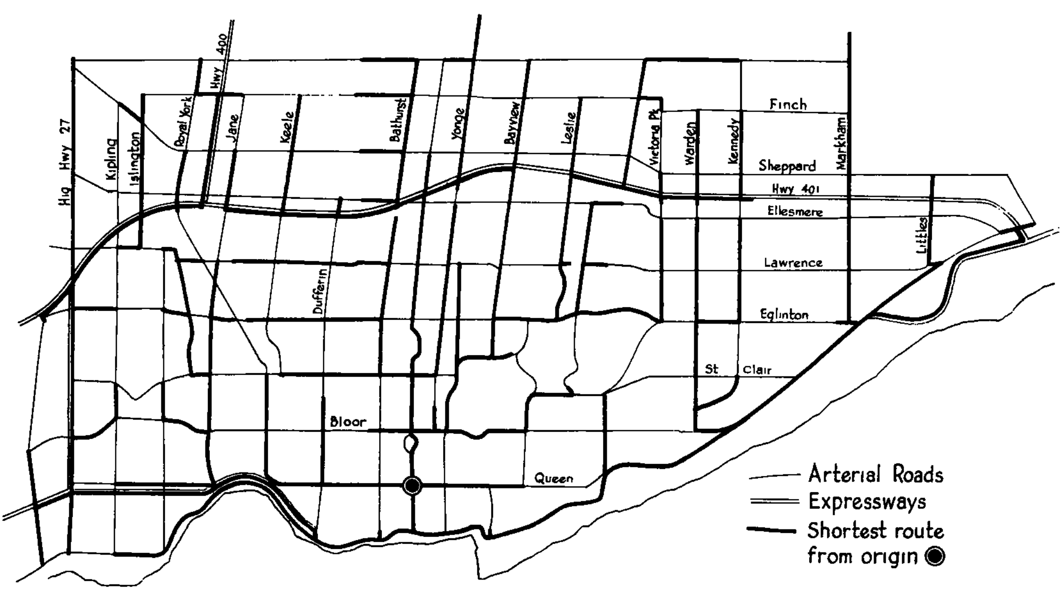

Figure 4. A typical set of routes emanating from a selected node.

Given the volume of cars per hour using a link at any time during the simulation procedure, it is possible, using the appropriate capacity function, to calculate the travel time required to traverse that link. This information is required by the Route Generation block, which determines by a rapid method of trial and error the shortest route in terms of travel time between every pair of centroid nodes in the grid.

The algorithm used is based on that developed by E. Moore and G. Dantzig but has been modified to minimize the number of times a given node must be queried. This means that routes going from an origin to nodes close by are minimized before longer routes are built onto them. In this way revisions of the longer routes are avoided with a resultant saving in machine time. A typical set of routes emanating from one node is shown in Figure 4.

As the simulation commences, link volumes are all zero, so that link travel times are all ideal. The set of routes found on the basis of these link times is known as the set of ideal routes. The grid shown in Figure 4 contains 250 nodes, of which 99 are centroid nodes. The number of routes in the ideal set is therefore 99 x 98 = 9702. (Note that the direct route A to B and the reverse route B to A may follow quite different paths.) As the simulation proceeds, other sets of routes are generated on the basis of whatever link times apply at the time. A given set of routes tends, therefore, to avoid areas which are congested at the time it is generated. All ideal routes are stored in the computer memory for later use. Most routes generated in subsequent iterations are also stored; as many as four routes can at present be retained for any O-D pair. The effect of this procedure is to allow travelers from an O to a D a reasonable choice of routes to follow. This is illustrated in Figure 5 where four such routes are shown: the first route follows a roundabout course to use 60-mph expressways for most of its length; route 2 also makes use of an expressway, whereas routes 3 and 4 are forced by expressway congestion to use slower arterial roads.

The generation of a new route is initiated only if the ratio of O-D travel time after the last updating of link times to the ideal O-D travel time exceeds a parameter which can be pre-set at any desired level or which can be changed by the program itself during the run. To avoid duplication a new route is recorded only if it differs in at least one link from any of the previously recorded routes.

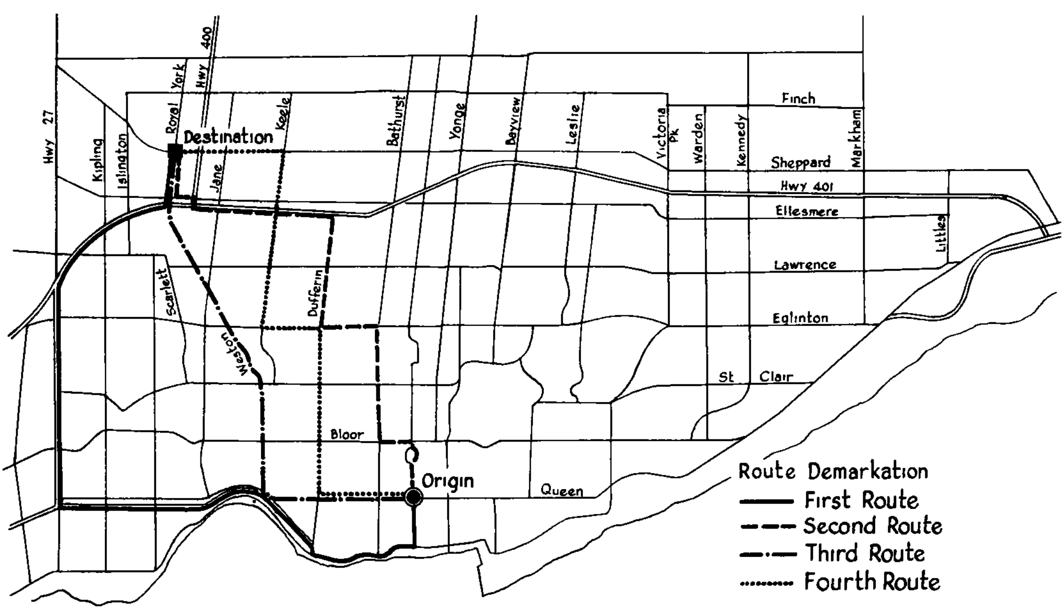

Figure 5. Example of four routes between an O-D pair.

Trip Distribution

The distribution problem consists of determing what number of trips will be made from each origin to each destination. It is assumed that this number will depend, for each trip purpose, on the total number of trips available for distribution at the origin in question, the total number of trips attracted to the destination in question, and the ease of getting from O to D, as measured by the travel time. This leads to the basic Gravity Model formula:

$$J_{ij} \propto G_i \; A_j \; F_{ij} \tag{2}$$

in which

J_{ij} = number of trips going from origin i to destination j for the purpose in question;
G_i = trips generated for this purpose at origin i;
A_j = trips attracted for this purpose at destination j;
F_{ij} = $(T_{ij})^{-a}$ = time factor for the trip between origin i and destination j; and
T_{ij} = average travel time from origin i to destination j.

To insure that the number of departures from an origin actually equals the trips generated there (that is, that $\sum_j J_{ij} = G_i$) the basic formula is put into proportional form:

$$J_{ij} = \frac{A_j \; F_{ij}}{\sum_j A_j \; F_{ij}} G_i \tag{3}$$

However, this formula does not insure the correct number of arrivals at each destination; (that is, there is no guarantee that $\sum_i J_{ij} = A_j$. In practice with 99 centroid nodes and the pattern of G_i and A_j as found in Toronto, it is found that a significant number of nodes have a factor $A_j / \sum_i J_{ij}$ less than 0.5 or greater than 2. To lessen this effect, a second iteration of the distribution calculation is carried out using adjusted attractors:

$$A'_j = A^2_j / \sum_i J_{ij} \tag{4}$$

in which

A'_j = adjusted attractor at destination j, for use in second iteration of trip distribution calculation.

One such iteration within the trip distribution block brings the attractors and arrivals into balance to within 5 percent in most cases.

A separate distribution calculation must be carried out for each of the three trip purposes, because each purpose has its own set of generators and attractors. It has been found also that different time factor indices are necessary for different purposes. Those currently being used in the vehicular simulation are, as follows:

(a) for work trips: $F_{ij} = T_{ij}^{-1}$ (5)
(b) for business-commercial and social recreational trips:

$$F_{ij} = T_{ij}^{-2} \tag{6}$$

Investigations presently being carried out indicate that these indices should be reduced.

The modified gravity formula produces results which compare well with observed data. It takes into account the effect of travel time and, as modified, insures adequate balancing of arrivals with attractors. This form of distribution calculation therefore allows the effects of capacity restraints and congestion to make themselves felt on inter-zonal trip interchange in a reasonable way. It has been adopted as the best empirical formula available and one that is capable of further refinement as experience grows.

Vehicle Assignment

In the assignment block, vehicles going from each O to each D are loaded onto the links comprising the route or routes available between each O-D pair.

Where more than one route is available the vehicles are proportioned among them according to the following formula:

$$J_{rij} = \frac{(T_{rij})^{-b} \; J_{ij}}{\sum_{r=1}^{n} (T_{rij})^{-b}} \qquad (7)$$

in which

J_{rij} = number of trips going from origin i to destination j via r^{th} available route $(1 \leq r \leq n)$;
n = number of routes available between i and j $(1 \leq n \leq 4$ in present program);
T_{rij} = travel time from i to j via r^{th} available route;
J_{ij} = total number of trips going from i to j via all n available routes; and
b = index which can be adjusted empirically.

At present this proportional assignment is carried out with b set to 1. Further investigation is proceeding to determine a more representative value if necessary.

It can be seen that the proportional assignment is another means by which capacity restraints are taken into account in this simulation model. Although the ideal route from an O to a D will have the shortest travel time under non-loaded conditions, its popularity may lead to traffic congestion which increases its travel time to a higher value than that for the other available routes. The proportional assignment allows this effect to be simulated in a reasonable manner.

Travel Time Calculation

Having obtained link volumes from the assignment block, this block calculates link travel times using the capacity function formula. The new link travel times are stored for possible use in subsequent route generations. They are also used to update all route times, should these be necessary for an assignment or a new trip distribution. For the latter the O-D time is calculated as the average of all route times between the O and D, weighted by the number of O-D vehicles using each route:

$$\overline{T}_{ij} = \frac{\sum_{r=1}^{n} (J_{rij} \; T_{rij})}{\sum_{r=1}^{n} (J_{rij})} \qquad (8)$$

in which

$\overline{T}_{ij}$ = average travel time between origin i and destination. j.

EFFECTS OF CAPACITY RESTRAINTS—SUMMARY

The effects of capacity restraints on travel time make themselves felt at three points in this simulation model:

1. In finding of routes. Route generations are carried out under differing conditions of congestion to provide several reasonable routes from every O to every D.
2. In choice of destinations. Trip distributions are carried out under conditions of practical as well as ideal traffic patterns to simulate the effect of congestion on travelers choice of destination.
3. In choice of route. Confronted with several possible routes from an O to a D, simulated travelers are allowed to choose among them so that more take the shortest route than take the longest.

It should be emphasized that this model is still in the development stage. Much more work is required to verify and refine many of the functions and parameters used. Nevertheless, it is capable of producing meaningful results even in its present state, as results of a current production run will show.

RESULTS OF TEST RUN

Under contract with the Metropolitan Toronto Department of Roads, the Ontario Department of Highways and the Metropolitan Toronto Planning Board, the Traffic Research Corporation is presently applying this traffic simulation model to a study of the Toronto area. The area of emphasis is the Toronto by-pass expressway, Highway 401, and the time period is an evening rush hour in the year 1980.

Before being applied for a future time period the model is always applied to a recent historical time period for the city in question. Observed volume counts across cordons and screenlines can then be compared with simulated volumes to check the accuracy of parameters and functions used. On the successful completion of the test run, the model is applied to the future time period using the same program sequence.

The preliminary test run for this study was an evening rush hour in 1958. For checking purposes, comparisons were made between simulated and observed values for that time period. Some of these comparisons are shown in Figures 6 through 10.

Figures 6, 7 and 8 are mainly a check on the validity of the simulated trip distribution. Observed data for these graphs were taken from the O-D Survey of 1956, expanded to 1958 on the basis of land-use changes. As it can be seen in Figures 6 and 7, tolerance limits must be set wide because of wide variability in the survey data. It is evident, however, that the trend of trip interchange volumes and O-D travel times as simulated is close to that shown by the observed data.

Figures 9 and 10 show a comparison of volumes along Highway 401 and across a typical screenline several miles south of the highway. Observed counts were taken during the period 1957 to 1959. Again, simulated volumes are seen to follow the observed trend quite closely.

A convenient yardstick for comparing transportation costs in a system under various conditions is the total time spent by all vehicles on the road during the period in question. This "system cost" is usually expressed in terms of vehicle minutes. Mathematically it is the volume of vehicles using each link multiplied by the travel time for that link, summed for all links in the system:

$$\text{System cost} = \sum_{\text{all links}} (F_V \times T_V) \tag{9}$$

This parameter is also useful as an indication of the degree of program settlement as successive iterations are carried out during the simulation. Figure 11 shows how the system cost varied during the 1958 run.

The value at point D1 (first distribution) indicates system cost under ideal conditions (zero congestion on all links) with one route (the ideal route) available between each O-D pair. System cost between D1 and A4 (fourth assignment) has little absolute

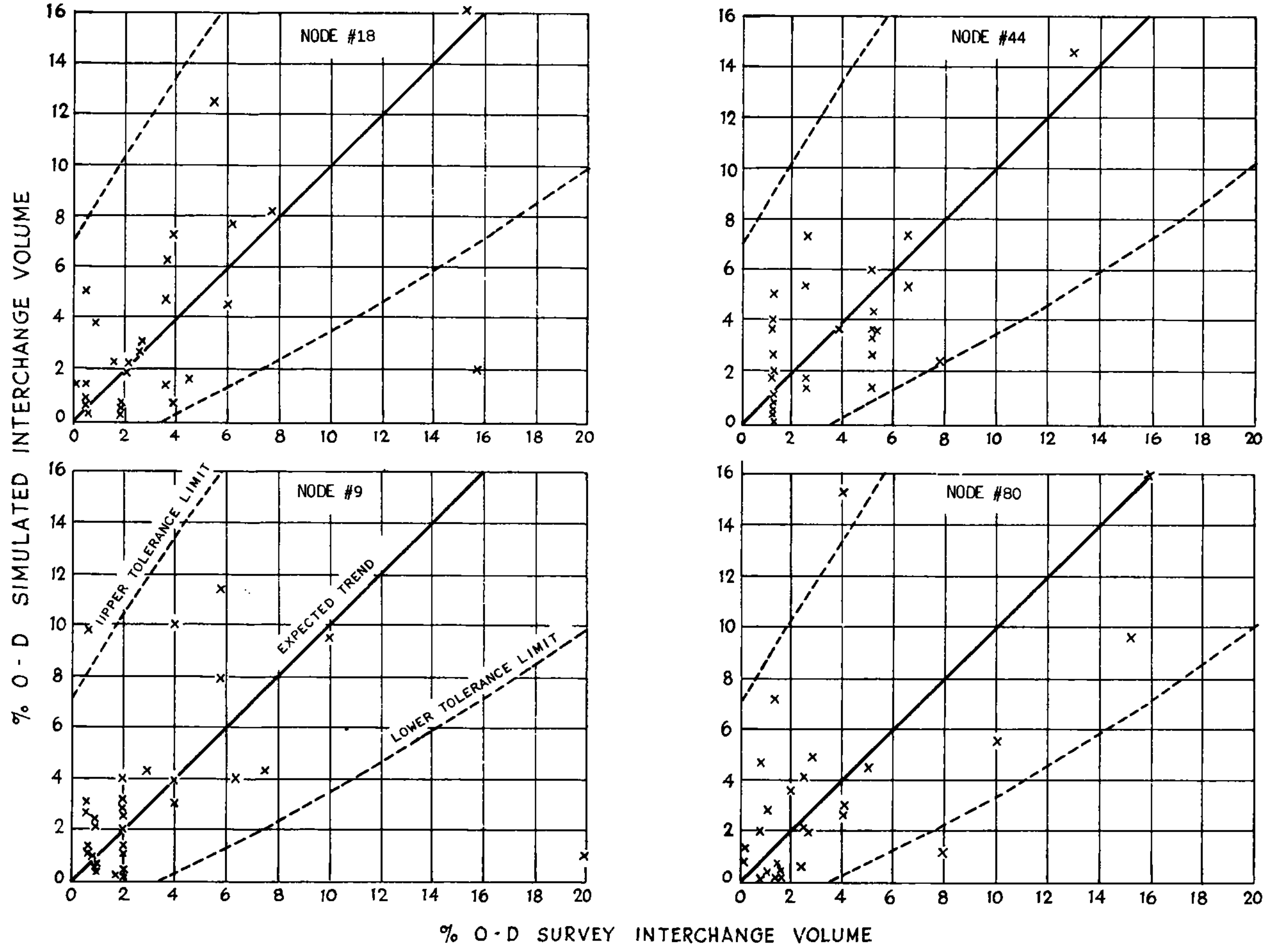

Figure 6. O-D trip interchange comparison: simulated vs observed.

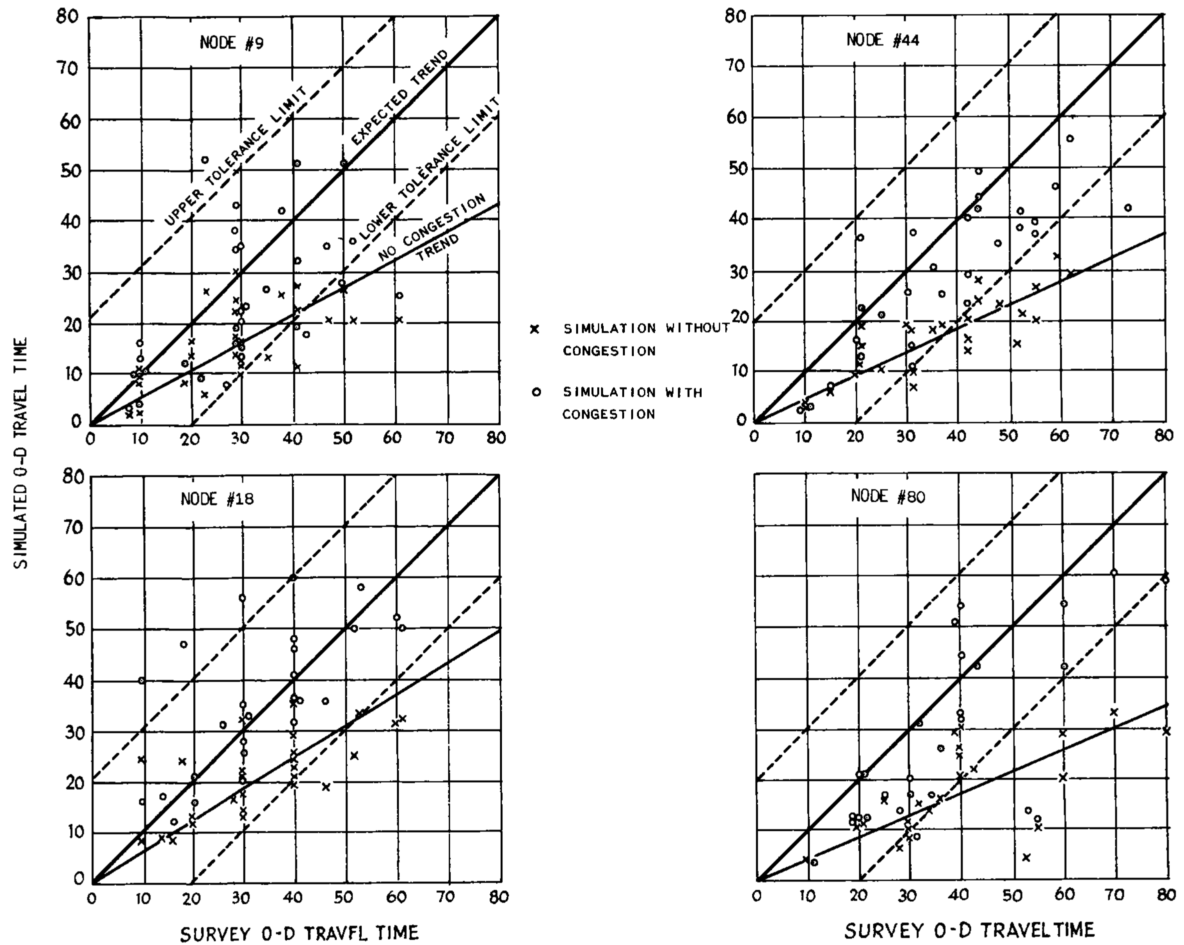

Figure 7. O-D travel time comparison: simulated vs observed.

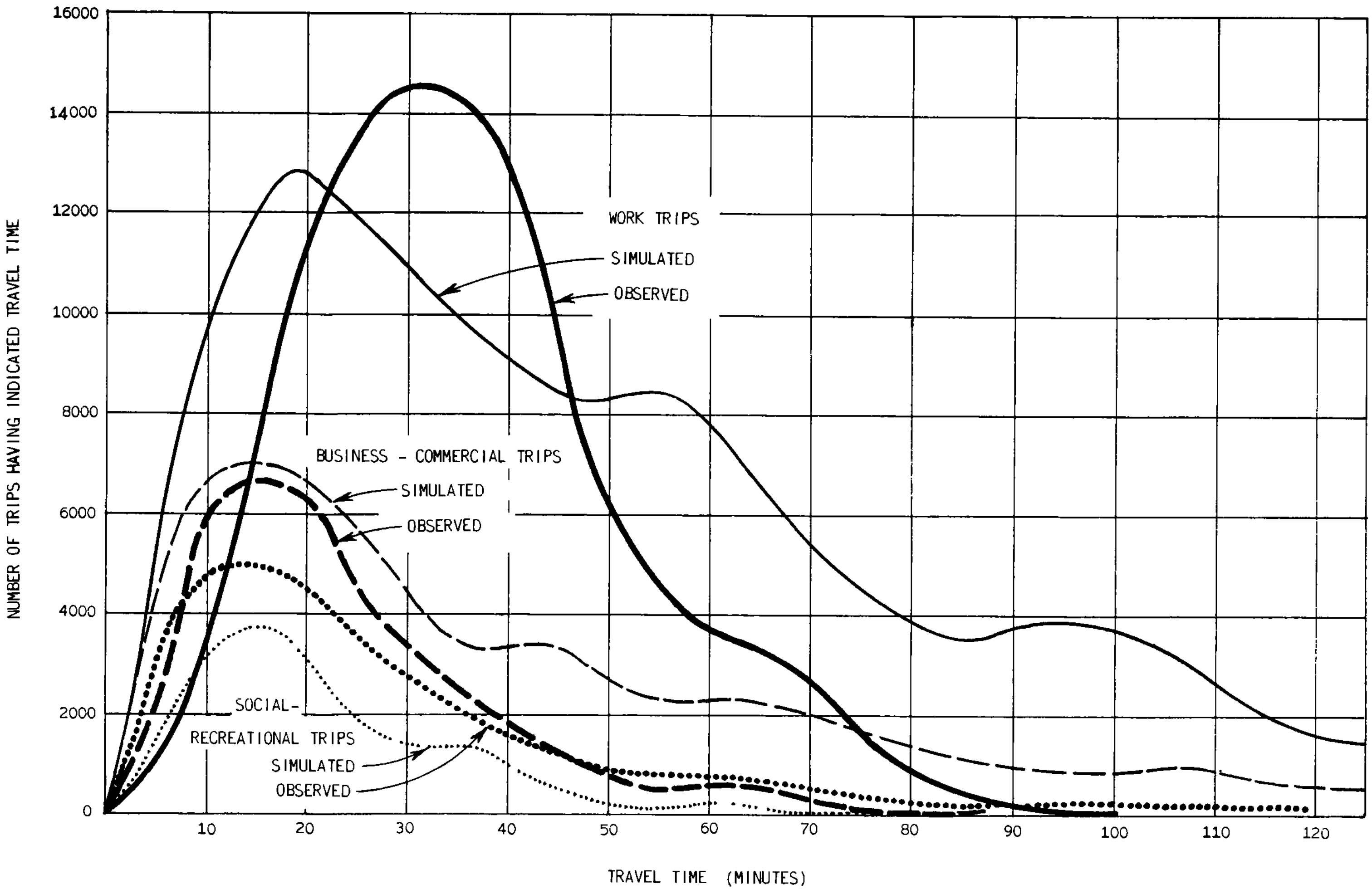

Figure 8. Trip frequency—travel time comparison: simulated vs observed.

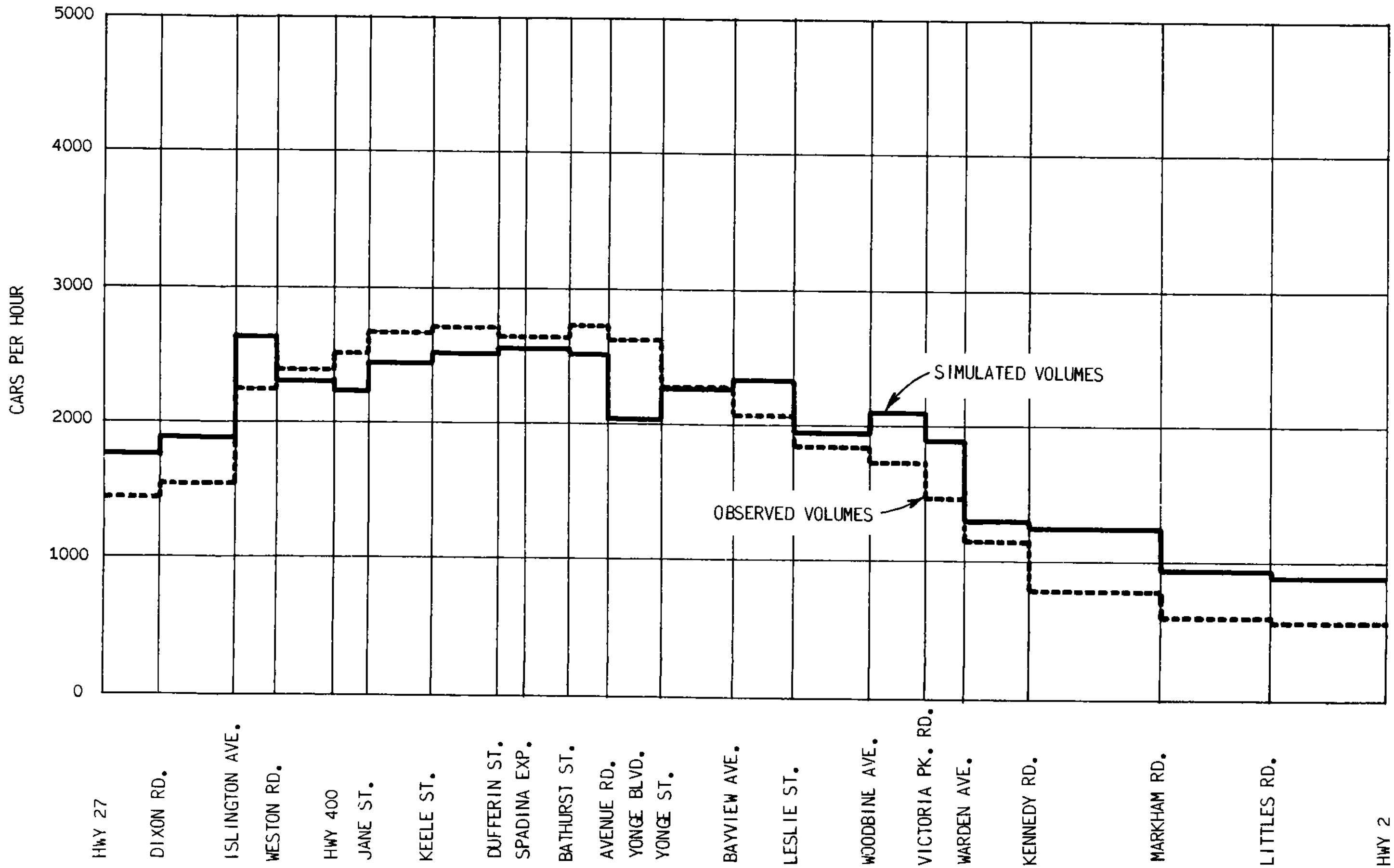

Figure 9. 1958 traffic volumes on Highway 401—Westbound, P.M. weekday rush.

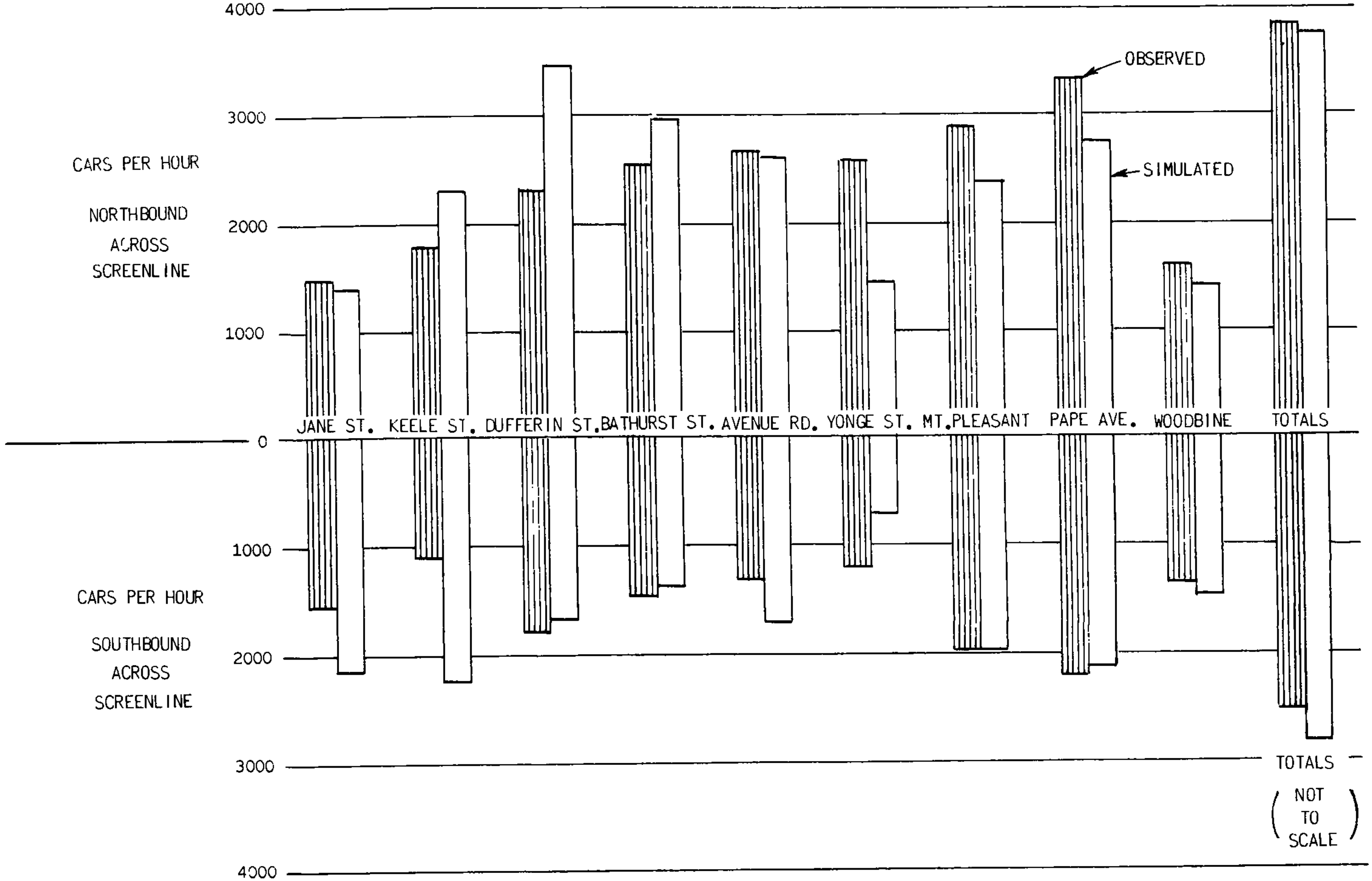

Figure 10. Traffic volumes crossing screenline just north of Bloor Street.

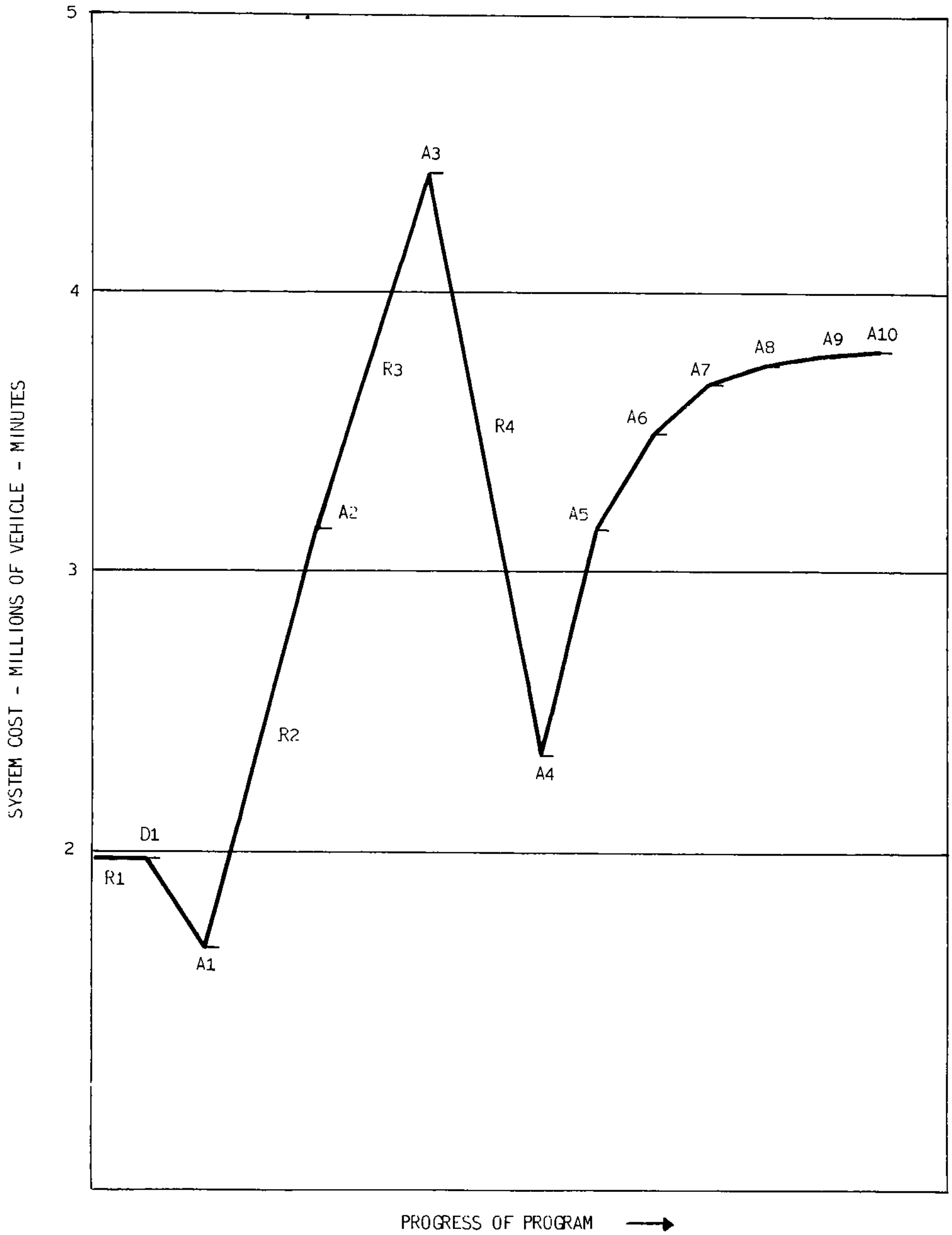

Figure 11. Behavior of system cost as program progresses.

meaning because arbitrary percentages of distributed trips were assigned in order to find alternate routes as quickly as possible. The value at A4 represents the system cost again under ideal conditions, but now with up to four routes available between each O-D pair. This is higher than the cost at D1, as would be expected, because the second, third and fourth routes found could not, under ideal conditions, be as short as the ideal set. The system cost at A10 (tenth assignment) is that under actual equilibrium conditions as found by the simulation model. As would be expected it is higher than either of the ideal system costs.

When early trials were made of the simulation model, it was found that individual link volumes and times (and hence the system cost also) had a tendency to fluctuate violently from iteration to iteration. A degree of link time dampening was introduced to reduce these oscillations and speed convergence: whenever a link time is calculated it is modified by a weighted function of the previous time for that link. The effect of this dampening can be seen as the system cost rises from A4 to A10 Subsequent runs with less dampening than was used here have approached the point of critical dampening, with even faster convergence as a result.

CONCLUSIONS

The use of capacity restraints and the resultant feedback of congestion effects by means of travel time is felt to be essential in traffic simulation programs.

The model described in this paper incorporates such effects and has been shown to give realistic results.

Further research into the method is progressing. Similar techniques are being applied to the simulation of combined transit and vehicular traffic, with promising results.

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A Simplified Method for Forecasting Urban Traffic

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During the last year, new concepts of origin-and-destination studies and traffic forecasting were applied for the first time in Iowa. In 1959, an 11-member study committee was created by Iowa's 58th General Assembly. The committee was directed to make a fiscal, administrative and engineering survey of Iowa's highways, roads, and streets, and report its findings to the 1961 session of the legislature. Subsequently, two firms were employed, the Automotive Safety Foundation and the Public Administration Services, to supervise and direct the studies.

One phase of the engineering study was to determine what city street improvements would be needed by 1980 to provide a tolerable level of traffic service. The problem was naturally most acute in the larger metropolitan areas where the greatest population gains for the next 20 years are expected. The purpose of this paper is to discuss briefly the techniques employed in forecasting 1980 traffic volumes in Iowa's seven largest urban areas. Some discussion of the application of this data in selecting arterial street systems is also included.

● O-D INTERVIEW methods currently used in collecting Iowa traffic data were discarded because all data for the seven cities had to be collected, processed and analyzed within six months. Concepts of mathematical traffic models and traffic synthesis from land-use data were introduced to overcome the obstacles presented by conventional techniques. Basic population and land-use data were supplied by the local officials of the seven cities, data processing was handled by the Iowa State Highway Commission, and the Automotive Safety Foundation supervised the operation. Within this organizational framework, the processing and evaluation of all seven O-D studies proceeded simultaneously.

In 1957 a complete O-D survey was made of the Cedar Rapids-Marion Urban Area (1). Information from this survey was used to develop trip production, trip attraction and time-distance relationships. Design of the gravity traffic model was similar to the one used in Baltimore, Maryland (2). All auto-driver trips were placed in one of the following trip purpose groups: (a) home to work, (b) other home base, and (c) non-home base. Social and shopping trips are examples of the other home base category where the auto-driver's home was one end of the trip. The non-home base group included all trips not beginning or ending at the driver's residence.

Work trip production was related to the labor force residing in each zone. In calculating the number of auto-driver work trips originating in any zone, adjustments were made for transit riders and auto passengers. Zonal employment data was the basic attraction factor for the work trips. Other home base trip production was directly re-

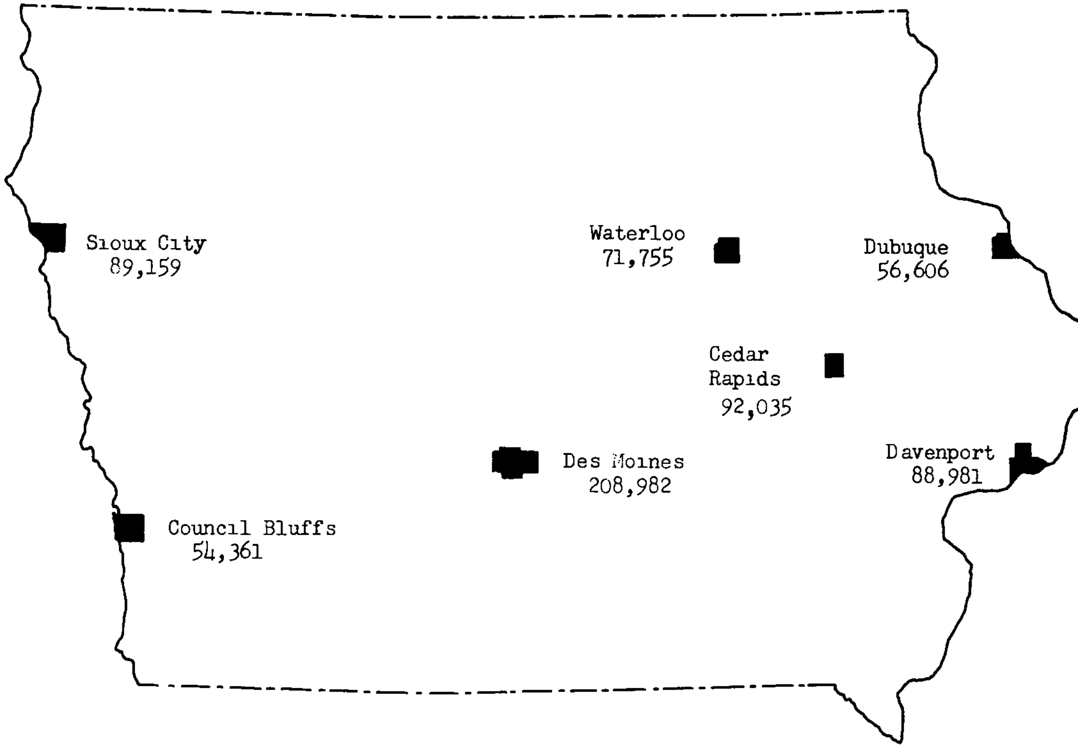

Figure 1. Iowa cities where traffic forecast techniques were applied. Population figures are from 1960 census data.

lated to car ownership and the zonal attraction factor used for this trip purpose was population plus 25 times retail employment. The total number of non-home base trips produced was related to total car ownership in the urban area, and the number of trips beginning or ending in a particular zone was associated with that zone's respective percent of the urban area's population plus 25 times retail employment. Factors were also derived from the Cedar Rapids data to describe the relation of travel time and trip frequency.

After preparing a computer program to handle the trip distribution calculations (3), the model design was checked against the interview data by trip length and desire line comparison. Results of the trip length comparison are given in Table 1.

The first desire line comparison revealed that the traffic model estimate of travel between Cedar Rapids and Marion was 50 percent higher than the home-interview observations (Fig. 2). Further research indicated that the relation was constant for all trip purposes. Marion is a satellite community of approximately 10,000 people and is located just northeast of Cedar Rapids. The differential in calculated and actual trip movements between the two communities was adjusted by "weighting" the trips with an origin or destination in Marion to make them conform to actual observations. In effect, more trips were confined to Marion and Cedar Rapids by the weights with less travel interchange between the two areas.

Travel patterns similar to those between Cedar Rapids and Marion cropped up in other urban areas with a neighboring satellite community. Between Sioux City, Iowa and South Sioux City, Nebraska, Davenport and Bettendorf and Waterloo and Cedar Falls, the traffic model overestimated the interchange of trips. The smaller neighbor community was not a matching segment of the larger urban area as far as travel habits were concerned. In some cases, this result was completely contrary to local opinion.

TABLE 1

COMPARISON OF TRIP LENGTH DISTRIBUTION FROM CEDAR RAPIDS TRAFFIC MODEL AND HOME-INTERVIEW DATA

Trip Length (min)	Accumulated Percent of Trips—By Trip Purpose							
	Work		Other		Non-Home Base		All	
	Model	Actual	Model	Actual	Model	Actual	Model	Interview
1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3	90.1	90.1	79.7	80.5	76.5	74.7	82.5	82.7
6	65.8	66.7	55.5	51.6	50.6	44.5	57.9	55.4
9	44.7	43.6	36.0	31.4	32.3	25.9	38.1	34.6
12	28.6	27.2	23.2	21.1	21.1	16.0	24.6	22.2
15	19.1	18.2	16.4	16.6	14.9	10.3	17.0	15.8
18	14.0	13.9	13.2	14.3	11.8	8.3	13.2	12.9
21	10.8	11.7	11.2	13.1	10.4	7.2	10.9	11.4
24	10.0	11.3	10.7	12.9	10.0	7.0	10.3	11.1
27	9.2	10.7	10.0	12.1	9.2	6.4	9.6	10.4
30	7.6	8.7	8.3	9.9	7.3	5.1	7.9	8.5
33	6.4	7.5	6.5	7.7	5.7	4.2	6.3	6.9
36	3.7	4.3	3.4	3.9	3.5	2.4	3.5	3.7
39	2.6	2.9	2.1	2.7	2.0	1.4	2.2	2.5
42	1.4	1.4	1.1	1.8	1.0	0.9	1.2	1.4
45	0.4	0.4	0.2	0.4	0.2	0.3	0.3	0.4
48	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1

Local officials had previously assumed that travel behavior was similar throughout an urbanized area containing a satellite city.

After "weighting" the model to reflect the true interchange of Cedar Rapids-Marion trips, the traffic model desire line volumes were compared to their home-interview counterparts. The Cedar River which cuts diagonally across the city was used as a screenline and this comparison revealed that there were 2.4 percent more model trips across the river than indicated by the home-interview information.

To further assess the accuracy of the model calculations, a comparison was made with the home-interview data using the trip-trace method employed in evaluating sample size in the Phoenix, Arizona survey (4).

The first trip-trace comparison was made using the original traffic model data from the Cedar Rapids study. Volume deviations related to both trip production and trip distribution are measured in this analysis. Results of this comparison are included in Table 2.

Root-mean-square error means that two-thirds of the time, this error will be less than indicated. The percent root-mean-square error is found by dividing the RMS error by the interview mean volume for the volume group under consideration.

The traffic model calculations produced about three percent more trips than were included in the home-interview figures. This error is included in the previous comparisons and constitutes part of the deviations measured by the statistical analysis.

A second trip-trace comparison was made using gravity model data with controlled trip production. The actual trip production and attraction values from the home-interview data were substituted for the zone figures calculated and used inthe original model. Identical trip distribution methods were applied to these data and the resulting zonal movements were compared to the home-interview material using the trip-trace program. Deviations measured in this analysis are related only to trip distribution and are summarized in Table 3. These tests would indicate that in dealing with volumes in the 5 to 10 thousand range, that about 40 percent of the errors of the model are related to trip production variation between zones.

TABLE 2

GRAVITY MODEL VERSUS HOME-INTERVIEW TRAFFIC VOLUMES CROSSING TRIP-TRACE SCREENLINES IN CEDAR RAPIDS, IOWA

Volume Group	Number of Sections	Mean Volume		Root-Mean-Square Error	RMS Error (%)
		Interview	Model		
0- 99	66	47	101	87	185.1
100- 249	47	169	233	112	66.3
250- 499	48	358	397	130	36.3
500-1,499	65	884	985	293	33.1
1,500-2,499	66	1,962	2,105	447	22.8
2,500-4,999	54	3,717	3,870	539	14.5
5,000-9,999	38	6,839	7,117	914	13.4
10,000+	10	15,894	17,045	1,984	12.5

TABLE 3

TRAFFIC VOLUME DEVIATIONS ACROSS TRIP-TRACE SCREENLINES RELATED ONLY TO TRAFFIC MODEL DISTRIBUTION ERRORS

Volume Group	Number of Sections	Mean Volume		Root-Mean-Square Error	RMS Error (%)
		Interview	Model		
0- 99	66	47	93	77	163.8
100- 249	47	169	223	94	55.6
250- 499	48	358	385	119	33.2
500-1,499	65	884	940	235	26.6
1,500-2,499	66	1,962	1,661	336	17.1
2,500-4,999	54	3,717	3,667	368	9.9
5,000-9,999	38	6,839	6,933	508	7.4
10,000+	10	15,894	15,138	1,212	7.6

Using the same basic trip production, trip attraction and travel frequency factors derived from the Cedar Rapids-Marion study, 1959 travel patterns were synthesized for the six other urban areas included in the study. Results from these calculations were verified by screenline counts. In the cities that were a segment of a larger metropolitan area (for example, Davenport-Rock Island-Moline and Council Bluffs-Omaha), the screenline counts indicated that trip production levels were lower than the figures derived from the Cedar Rapids research. Previous research has indicated that there are fewer trips per car in larger cities (5).

FORECASTING TECHNIQUES

After formulating the 1959 traffic patterns for the seven cities by use of the gravity model and land-use concepts, the next step was to make an evaluation of what traffic desires would be in 1980. This work was based on the premise that if it is possible to synthesize today's traffic pattern from land use and population data, future traffic desires could be formulated from the prediction of expected land use and population distributions. Estimates of the 1980 population, employment and car ownership expected in each zone of the study areas established the basic framework for the traffic forecasts. By substituting these values for the 1959 data originally used in the traffic model the 1980 O-D pattern was calculated. The accessibility model approach used to forecast future land use was a modification of the concepts presented by research work of Hansen (6).

POPULATION ESTIMATES

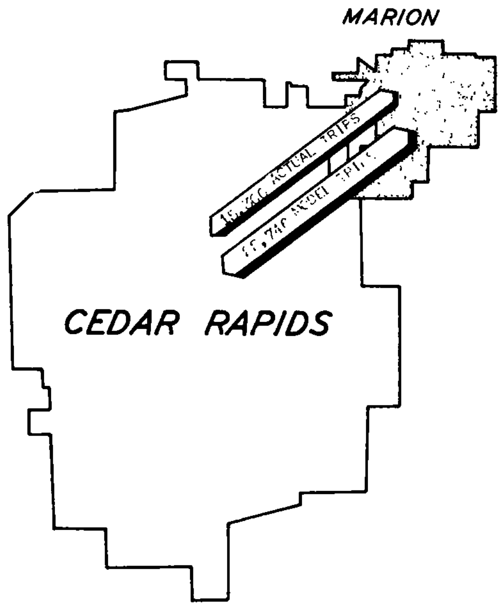

Figure 2. Comparison of travel between Cedar Rapids and Marion as indicated by traffic model calculations and actual interview data. "Weights" were used to adjust this differential.

Population trends since 1950 in each zone of the urban areas were analyzed and a theoretical growth was computed for each zone. The first step in calculating the theoretical growth quantity was to multiply the additional holding capacity, C, available for new homes in 1950 times the accessibility index, I, of the zone to employment. Holding capacities were in terms of people rather than square feet so as to resolve the differeng residential densities encountered. Accessibility index values for each zone were computed as a part of the gravity traffic model distribution program used in the first phase of the Iowa study. It is a relative measure of the availability of employment to a particular zone. The index for a zone equals the sum of the products of the employment, A, times the travel frequency factor, B, for each of the other zones in the study area. It could be expressed as:

$$\text{Index (I)} = \Sigma AB = A_1B_{1-1} + A_2B_{1-2} \ldots \ldots + A_nB_{1-n}$$

Actual population growth was plotted over the accessibility-additional holding capacity products, IC, for each zone and an exponent was derived to describe the resultant curve. Thus the term, $(IC)^x$, was a measure of the theoretical growth of a zone relative to the other zones in the study area. Total population growth observed for the area was distributed in accordance to each zone's portion of the sum of the accessibility-additional holding capacity products. For example, zone n's share of population growth would be determined by the ratio of $\frac{(I_nC_n)^x}{\Sigma(IC)^x}$.

This calculated distribution of growth accounts only for the effects of available land and accessibility to work. Other considerations which affect an individual's decision in selecting a residential lot probably include the accessibility to schools, churches and shopping centers. Topographic conditions and the availability of sanitary sewers and other utilities also play a part in the growth of a particular residential zone. To evaluate this multitude of variables, the actual population change for each zone since 1950 was divided by the calculated growth for the same period. This quotient was a measure or "weight" of the influence of factors other than available land and accessibility to employment which prevailed over the zone's rate of residential development during the last ten years.

Results of these calculations for the Cedar Rapids-Marion study are illustrated in Figure 3. This figure shows that zones 5, 6, and 7 grew about twice as fast since 1950 as explained by the factors included in the computations. In reviewing this material with the local officials, these zones were considered the most desirable area in the city for medium-priced housing. Zone 36 grew over three times faster than expected by the calculations and this was due primarily to the outstanding promotion efforts of the builder subdividing the area. On the other hand, there were zones whose growth did not keep pace with the rest of the city; for example, zones 12, 39, 20 and 32. Local planners pointed out that growth was restrained in these areas by the lack of sanitary sewers. Zone 33 has a growth ratio of only 0.1 and this was explained by the fact that most of the area is zoned for industrial purposes, thus reducing its residential desirability.

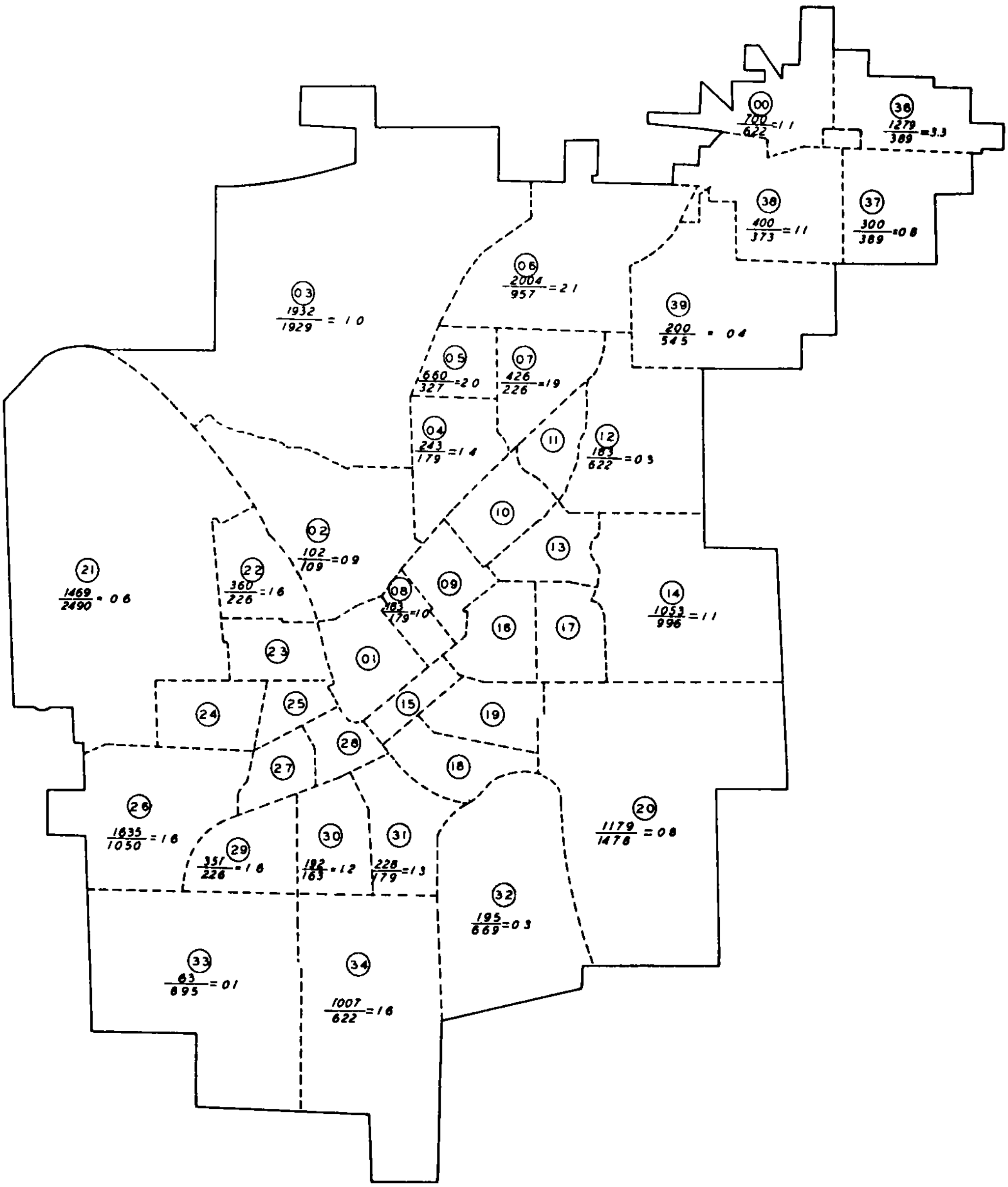

Figure 3. Transportation zones of Cedar Rapids—Marion urban area with zone ratios of actual/calculated population growth.

In reviewing the results of this technique with the local planners and engineers of the six cities where this method of residential growth analysis was applied, they could easily rationalize the deviations in the growth ratios. What was even more significant was that the six groups came up with the same reasons in explanation of the divergent ratios. They were in agreement that zones with ratios of from 2.0 to 3.0 were considered the most desirable areas in their city and that when the ratio approached 4.0 there was some unusual promotional activity in the background. Also in zones with low ratios from 0.1 to 0.8, generally growth was restricted by lack of public utilities or the areas were dominated by racial groups. Some zones had topographic features which would require higher development expenditures and the extra expenses involved in improving these areas had been a deterrent. However, these zones may become more important in the future as other available land supplies are exhausted.

After reviewing the growth ratios with the local officials, discussion turned to the future. What weights would in their judgment be applicable for the next 20 years? Would zones continue to grow at the present rates? Were sewer expansion programs planned or underway? Were urban renewal programs going to alter the present residential areas? These were a few of the considerations that would influence the future growth patterns. In some cases sewer projects had just been completed in zones that had experienced slow growth rates over the last decade. In others, the projects were in the planning and early construction stages. After reviewing the calculated growth ratios and the characteristics of the zones involved, local planners modified the growth ratios to reflect future conditions.

In applying the future growth weights, obviously the available land in some zones would be exhausted long before 1980. The accessibility model permitted growth to continue in these zones until the saturation point was reached and then growth was shifted to zones that still had holding capacity at this point.

In addition to making appraisals of the future zonal growth weights, local officials provided data on the estimated 1980 population of their areas. Changes in travel time between zones and in the distribution of employment opportunities were also considered before proceeding with the zonal population distributions. Techniques used in estimating and distributing future employment is covered in another section of this paper. Anticipated changes in travel times by 1980 were based on the judgment of the local engineers after reviewing the probable changes in their street systems over the next 20 years. With the exception of freeway construction, the local jurisdictions felt that future widening and paving programs would not do much more than maintain the present level of traffic service, and auto travel times would not change appreciably.

After obtaining new estimates of employment distribution and travel times, employment accessibility indexes for 1980 were calculated in the same fashion as those for 1959. Using the 1980 index, I, and the holding capacity, C, available now for development, new values of $(IC)^x$ were calculated. These values times the future growth weights estimated by the local planners were used to distribute the total anticipated population growth of the urban area to the zones.

EMPLOYMENT ESTIMATES

In making estimates of future employment, the available jobs must obviously be in balance with the anticipated population growth. Knowing that about 40 percent of the population composes the employed labor force, the future employment requirements to support the added population can be estimated. The percent of present employment in retailing, services and manufacturing was used as a basis for distributing the future jobs to these general groups. These relationships for six Iowa cities are given in Table 4.

Inasmuch as manufacturing and other industries which need relatively large quantities of land for their operations are generally restricted to industrial sites, future employment is limited to a few zones. The distribution of this portion of future added employment was handled by the local planners who were familiar with their local industrial areas. When there was some indecision about the apportionment, the additional holding capacity of a zone for manufacturing employment and the accessibility of this zone to people and retailing activity were used as factors to distribute the total quantity. The product of these two figures for a particular zone divided by the sum of the accessibility-capacity products for the urban area was used to determine that zone's share of manufacturing employment.

The next step was to distribute the added employment in the service category. Location of these jobs is related to the accessibility to the people which they serve and also to the existing retail areas. On this premise, the service employees added by 1980 were distributed to the zones by using the product of the accessibility index (to people) times the present retail employment as an index. Thus a zone would receive a percentage of the total added service jobs equal to the percent of its accessibility index-retail employment product related to the sum of the zonal index products for the city.

Present employment plus the estimates for manufacturing and service employment for each zone gave an approximation of 1980 employment which was sufficient for computing the 1980 employment accessibility indexes. These were discussed previously in regard to the distribution of added population.

Distribution of the additional future employment involved in retailing were undertaken after the 1980 population calculations were completed. The local planners were consulted for their knowledge of any special retail activity such as new shopping centers under construction or in the planning stage. After allocating retail employment for these centers, the remaining jobs were distributed in accordance with the ratio of population growth for a particular zone to the total population growth of the zones involved. By adding the future retail, service and manufacturing employment figures to the present total employment for each zone, the 1980 distributions were completed.

CAR OWNERSHIP ESTIMATES

Research by the Bureau of Public Roads has indicated that the type of residential area and family income were directly related to car ownership per family. The number of cars per family rises with income levels and when annual income reaches $8,000-$10,000 in a given type of residential area, car ownership does not change appreciably. Figure 4 illustrates this relationship. Thus in outlying zones where residential lots are generally the largest, the car ownership ceiling would be about one car for every two persons. In densely populated zones, car ownership would be only about two-thirds of that figure.

A study in Hartford, Connecticut revealed that car ownership rises toward the ceiling level in direct proportion to the rise in real income. During the last 10 years,

TABLE 4

POPULATION CHARACTERISTICS OF SIX IOWA CITIES

Urban Place	1950 Population	Employed (%)	Employment Class (%) Retail	Services	Mfg. & Other
Cedar Rapids	72,296	44.6	26.6	19.5	53.9
Council Bluffs	45,429	39.3	29.2	18.0	52.8
Davenport	74,549	41.5	28.3	20.5	51.2
Dubuque	49,671	41.2	26.3	19.0	54.7
Sioux City	83,991	42.0	28.2	22.2	49.6
Waterloo-Cedar Falls	79,532	43.1	23.3	17.5	59.2

real income has been increasing nationally about two percent per year. Car ownership would be expected to have increased 20 percent in the last decade in areas where income trends were similar to the national average. This increase would be expected without any population change. The car ownership pattern of families moving into new homes was found to follow the ceiling value of the particular zone involved in the Hartford study.

In view of these relationships and of Iowa car ownership trends, the number of cars in each zone was expanded by a factor of 1.5 for the 1959-1980 period. This expansion was restrained by the ceiling level applicable to the zone involved. Cars for the people moving into new homes during the 1959-1980 period were added to the expanded residual ownership figures to complete the 1980 car ownership estimates.

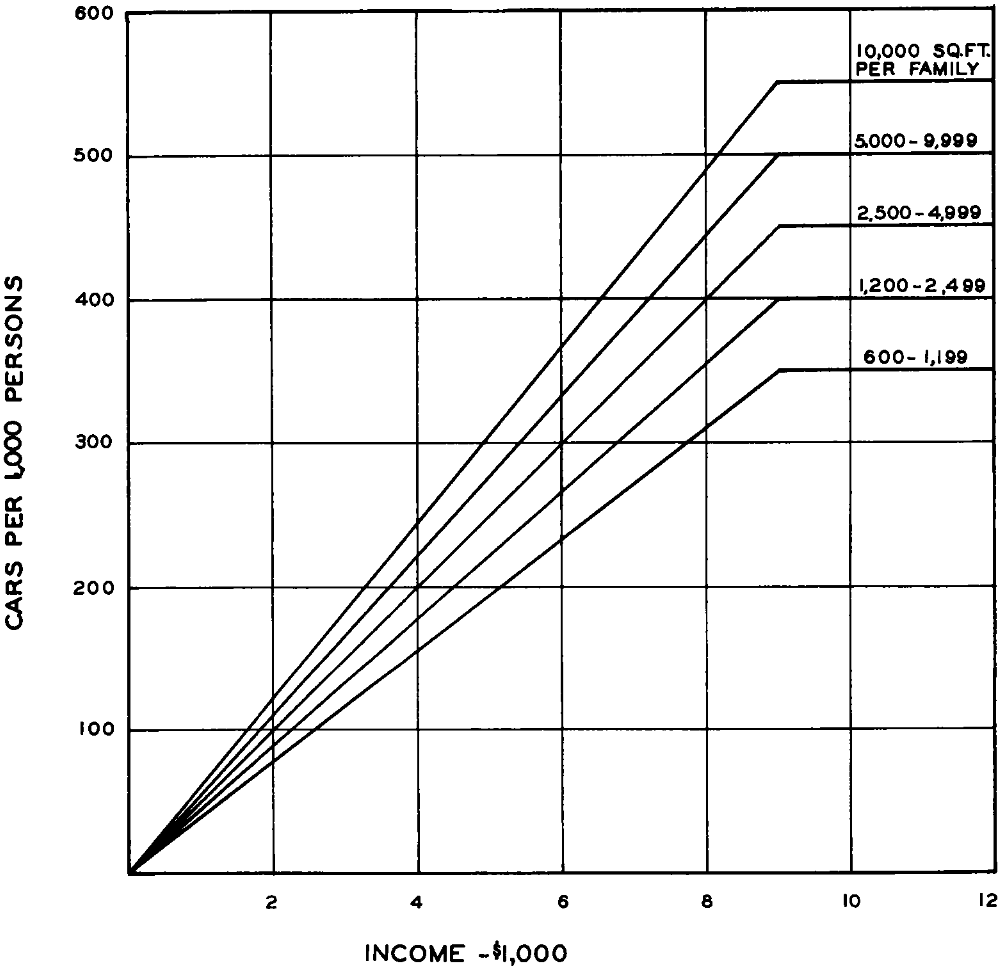

Figure 4. Car ownership ceilings for different residential densities.

SUMMARIZATION OF RESULTS

After the O-D computations had been completed, they were assigned to a desire leg network. Zone centroids were connected by desire lines as illustrated in Figure 5. Trips were assigned to the most direct route or series of desire legs between the O-D zones. Total volumes were accumulated on each desire leg by summing the zonal trips assigned to it. The results of this desire line summarization are illustrated in Figure 6. Desire line volume totals for 1959 and 1980 are included in Table 5.

One variation of this summarization process was to assign traffic to a freeway passing through the city. This was done by spotting the interchanges on the desire layout and adding desire legs between these points and connecting them to the desire pattern established earlier. Zonal movements that would be expected to use the freeway path may then be reassigned to this route and the volumes remaining on the original desire line network would have to be accommodated by the regular street system. Results of this type of assignment are illustrated in Figure 7.

The desire legs may be considered as the only streets available for the traffic desires between zones. Considering this, the future desire leg volume can be apportioned to the streets presently available for arterial traffic. After assigning each desire leg volume to the existing system, there can be a quick determination of where capacity problems may develop. More detailed study can be made of the composition of the traffic on each desire line by examining the zone-to-zone movements assigned to it.

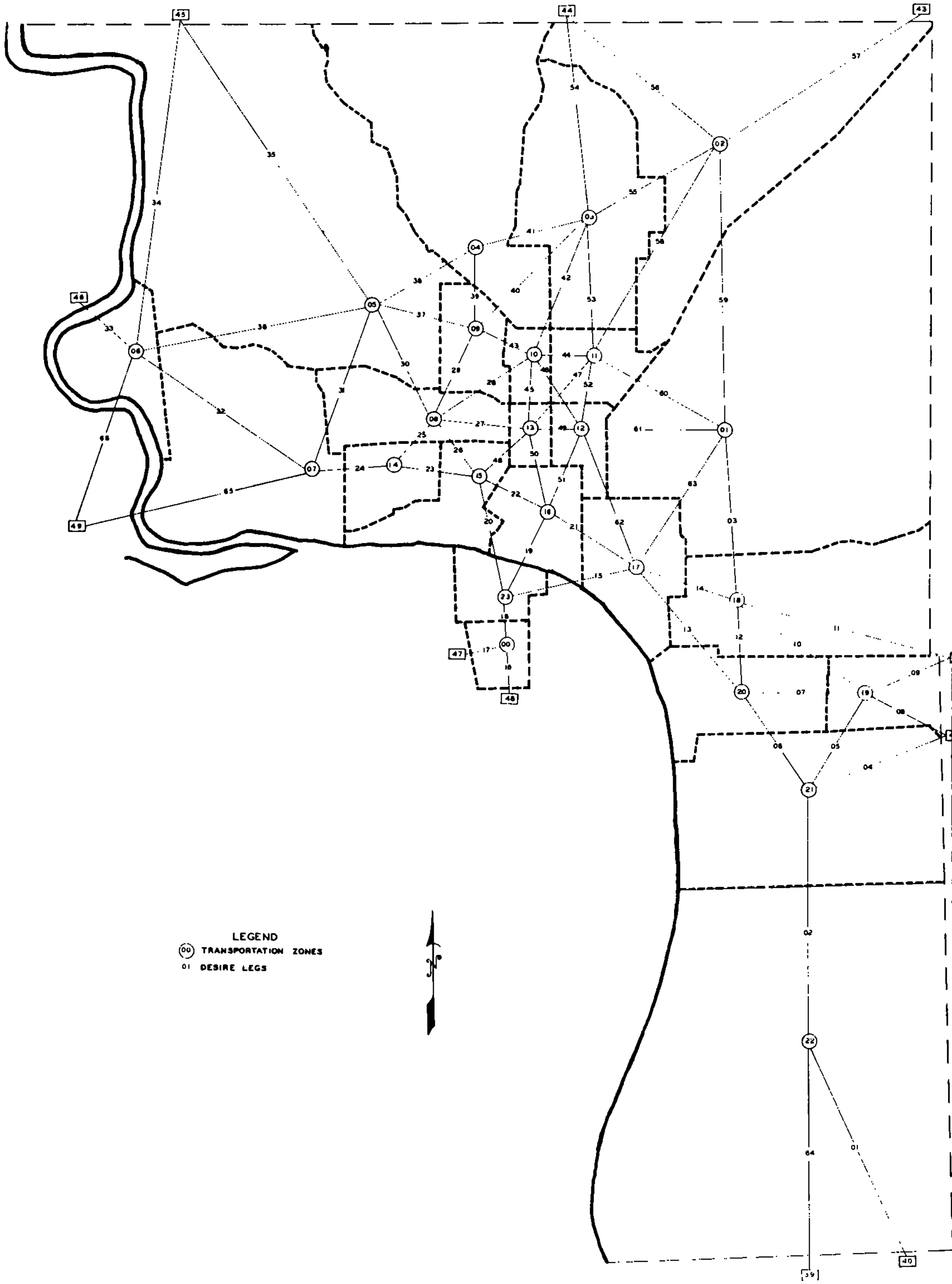

Figure 5. 1959 Sioux City area O-D traffic desire lines.

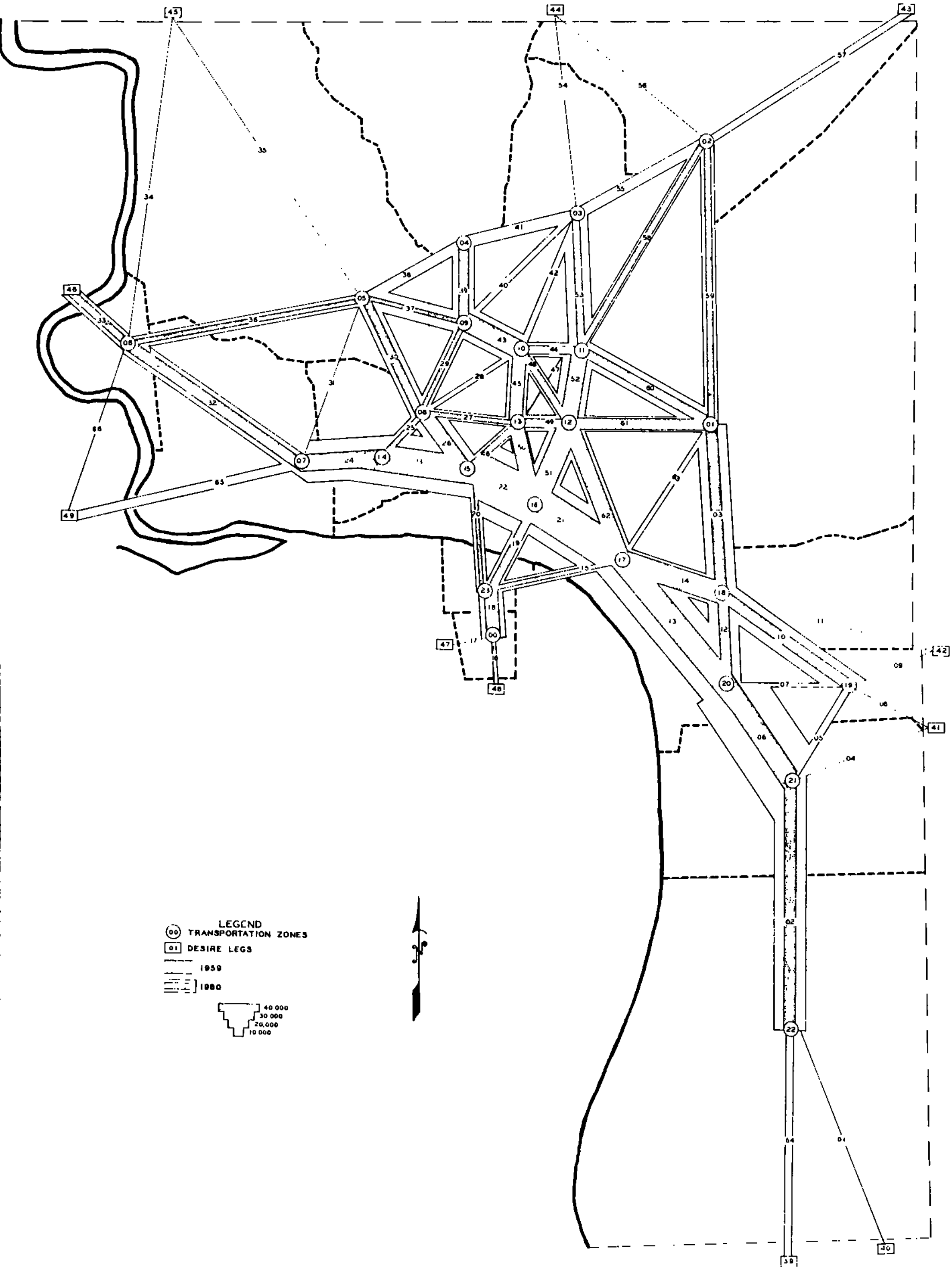

Figure 6. 1959-80 Sioux City area O-D traffic desire lines derived from land-use data, population figures and use of a gravity traffic model.

TABLE 5

DESIRE LEG VOLUMES FOR SIOUX CITY ROAD STUDY TRAFFIC MODEL DATA

	Volume				Volume		
Leg	1959	1980	1980 with Freeway Assignments	Leg	1959	1980	1980 with Freeway Assignments
01	2,065	2,882	2,882	44	7,595	13,856	13,672
02	12,126	29,260	15,551	45	13,476	19,730	20,935
03	11,389	28,603	27,174	46	7,081	11,764	12,264
04	144	359	359	47	2,674	3,779	4,172
05	2,122	7,366	7,366	48	7,104	12,420	11,422
06	20,177	67,783	54,074	49	9,560	16,277	15,450
07	3,162	4,088	4,088	50	16,385	18,225	19,262
08	1,462	1,449	1,449	51	21,625	32,228	32,479
09	700	1,550	1,550	52	16,473	29,560	30,373
10	11,180	13,909	13,909	53	7,355	24,586	24,586
11	2,191	3,559	3,559	54	554	763	763
12	10,110	28,367	26,938	55	3,600	11,326	11,117
13	23,696	52,184	39,904	56	98	162	162
14	21,024	27,202	27,202	57	3,961	7,244	7,244
15	4,607	10,559	7,349	58	6,404	10,778	10,569
16	2,824	5,156	5,156	59	6,115	13,512	13,512
17	2,250	4,517	4,517	60	9,328	21,776	20,963
18	13,416	29,189	29,189	61	10,955	15,250	14,806
19	8,044	13,553	13,553	62	13,625	22,756	21,937
20	3,996	11,878	9,005	63	4,509	6,078	7,138
21	36,440	57,767	44,308	64		7,015	000
22	43,435	70,458	53,735	65		8,749	000
23	26,053	51,180	31,202	66		563	000
24	16,522	43,409	27,638				
25	5,655	12,750	12,683				
26	15,708	30,102	30,446				
27	4,656	9,076	9,076	70			9,312
28	2,823	5,513	5,169	71			16,648
29	5,009	12,129	12,750	72			17,864
30	7,943	18,826	18,826	73			14,477
31	508	3,816	2,676	74			18,745
32	11,367	20,846	12,684	75			13,709
33	7,346	13,419	13,419	76			7,015
34	48	80	80	77			9,694
35	555	1,029	1,029	78			6,674
36	5,296	12,000	12,263	79			3,058
37	4,064	9,505	9,505	80			2,520
38	2,355	11,188	10,311	81			6,244
39	10,721	20,889	21,166	82			4,268
40	1,617	5,170	5,170	83			11,860
41	2,718	12,254	11,654	84			11,440
42	2,336	6,295	6,686	85			6,083
43	18,239	31,414	31,070				

CONCLUSIONS

The techniques described in this paper were used to delineate 1980 arterial street systems in Iowa's seven largest cities. Time and money were not available to permit use of an O-D interview method and these methods were employed to overcome these obstacles.

Total cost of the traffic model forecasting work in Iowa was approximately $22,500. This figure includes work on statewide O-D research in addition to the seven cities studied. The salaries of the local officials who provided most of the basic data are not included. About $5,000 was expended on development of computer programs to handle the traffic distribution and summarization aspects of the work. Average total cost per study was a little less than $3,000. Contrast this to the cost of an interview operation. The cost of an Iowa external-internal cordon line survey made in 1959 was twenty cents an interview. Total costs of the 100,000 interview study was $20,000.

After completing the seven-city study, it was felt that some sample interviewing in each city would have improved the results of the gravity model. The factors derived from the Cedar Rapids home-interview data were applied to the other six cities with some trip production adjustments. Data from a few home interviews would have indicated more precisely what modifications were in order.

The 1960 census data would have been very helpful in providing basic information on

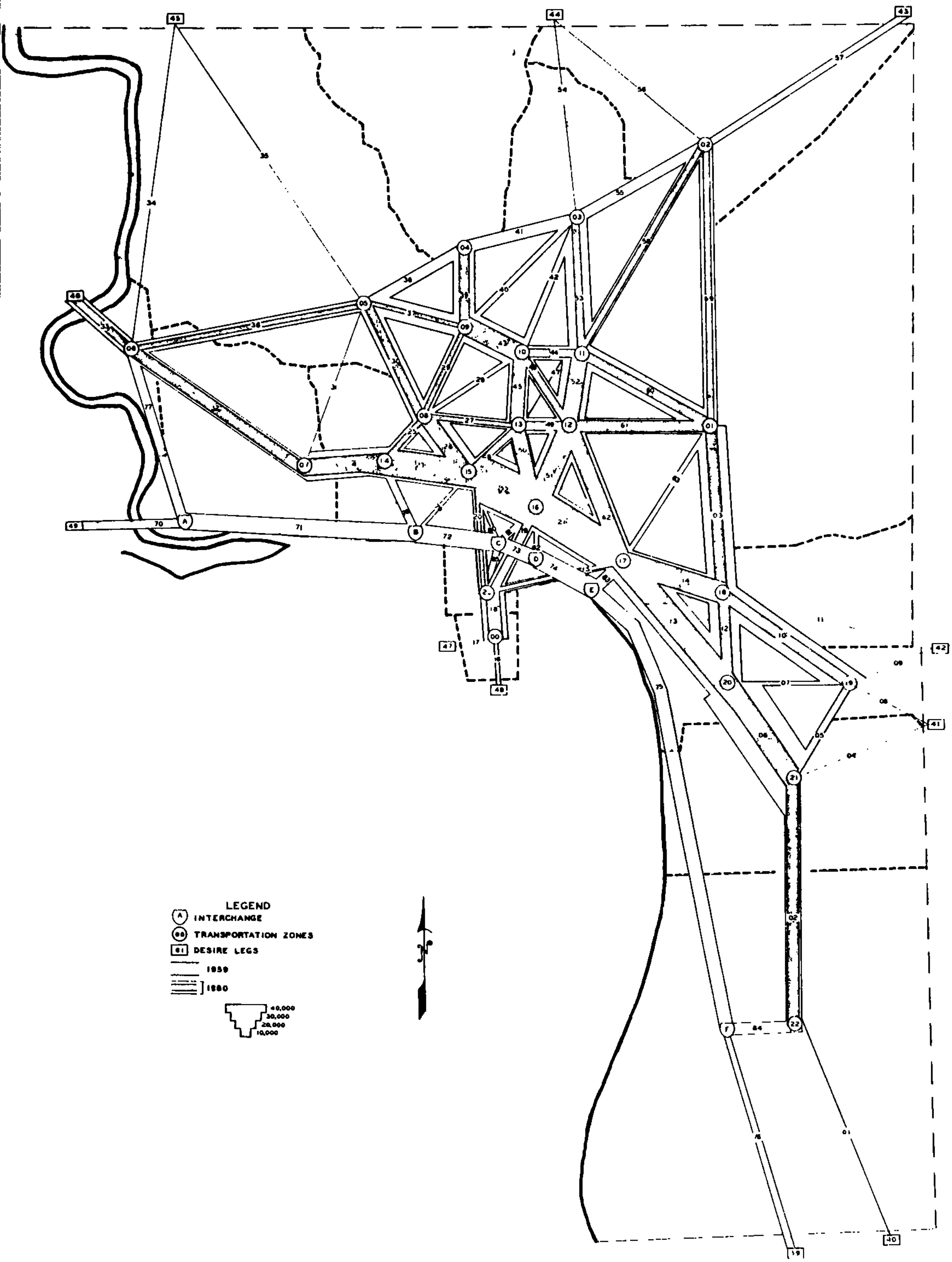

Figure 7. 1959-80 Sioux City area O-D traffic desire lines derived from land-use data, population figures and use of a gravity traffic model.

population labor force and car ownership Local officials provided estimates of these characteristics for use in the traffic model studies. Some areas had no city planning departments and the estimates were made hurriedly and of necessity by people unfamiliar with these characteristics. Current census data would very likely have improved the results in these areas.

Methods outlined here are relatively simple and by using a computer, results can be obtained quickly. In forecasting, alternate land-use plans and the resulting impact of traffic desires could be easily evaluated. The costs of applying the techniques are relatively low. With these things in mind, it is difficult to overlook the potential value of the mathematical approach to traffic synthesis.

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Appendix

SAMPLE COMPUTATIONS

Travel frequency factors were derived empirically from the Cedar Rapids-Marion home-interview data. They describe the effect of travel time on trip frequency between zones. Factors derived from the Iowa data for three trip purposes are included in Table 6. The accessibility index of a zone is equal to the sum of the products of the attraction factor in each of the other zones, times the respective frequency factor for the travel time linking the zones. This is clarified by Table 7.

In calculating a theoretical growth quantity for each zone, the employment accessibility index, I_n, was multiplied times the additional holding capacity, C_n, in 1950. The actual growth for each zone was plotted over the products of I_nC_n and an exponent was derived which described population growth in terms of I_nC_n. Figure 8 illustrates the slope of the hand-fitted curve for the Cedar Rapids study. The exponent, x, for this study was equal to 0.6. Thus the term, $(I_nC_n)^x$, describes the theoretical growth of each individual zone relative to the others. The total population growth for all zones is then distributed to each of the zones by the ratio of $\frac{(I_nC_n)^x}{\Sigma(I\ C)^x}$. The resulting theoretical growth quantity is divided into the actual growth observed and the quotient indicates the size or "weight" of factors other than available land and accessibility to employment which influence the growth rate of urban zones. These calculations are given in Table 8, from which

$$F = \frac{\text{Population growth of all zones}}{\Sigma(IC)^{0.6}} = \frac{16,780}{2,156} = 7.78.$$

After obtaining new estimates of employment distribution and travel times, employment accessibility indexes for 1980 were calculated in the same fashion as those for 1959. Sample calculations are given in Table 9.

TABLE 6

TRIP FREQUENCY FACTORS

ravel Time (min)	Relative Trip Frequency, by Purpose		
	Work	Non-Home Base	Other-Home Base
1	2.00	3.00	5.00
2	2.00	2 25	3 66
3	2.00	1 80	2 20
4	1.50	1 40	1.45
5	1.25	1.15	1 20
6	1.10	1.00	1 00
7	1.00	0 90	0.90
8	0 93	0 80	0 80
9	0 87	0.70	0 70
10	0 84	0 62	0 62
11	0 80	0 56	0 56
12	0 76	0 49	0.50
13	0 72	0 43	0.45
14	0 68	0 38	0 41
15	0 64	0 34	0 38
16	0 61	0 30	0 35
17	0.58	0 27	0.32
18	0 55	0.24	0.30
19	0 52	0 22	0.27
20	0.49	0 20	0.25
21	0.47	0 18	0.23
22	0.45	0 16	0 21
23	0 43	0.14	0.19
24	0 41	0 12	0.17
25	0 39	0 10	0 15
26	0.37	0 09	0 13
27	0.35	0 08	0 11
28	0 33	0.07	0 10
29	0.31	0 06	0 09
30	0.29	0 05	0 08
31	0.27	0 04	0 06
32	0.25	0.03	0 04
33	0 23	0 02	0.03
34	0.21	0 01	0.02
35	0.19	0 01	0 01
36	0.17		
37	0 15		
38	0.14		
39	0.13		
40	0.12		
41	0 11		
42	0.10		
43	0 09		
44	0 08		
45	0.07		
46	0.06		
47	0.05		
48	0 04		
49	0.04		
50	0 04		
51	0 03		
52	0.03		
53	0 02		

TABLE 7

COMPUTATION OF EMPLOYMENT ACCESSIBILITY INDEX FOR ZONE 00

To Zone	(A) Present Employment	Present Travel Time	(B) Work Trip Frequency Factor	AB
00	61	1	2 00	122
01	10,260	14	0 68	6,977
02	445	12	0 76	338
03	381	7	1.00	381
04	1,294	11	0 80	1,035
05	54	9	0.87	47
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
39	00	4	1.50	00
			Index (I_{00}) =	ΣAB

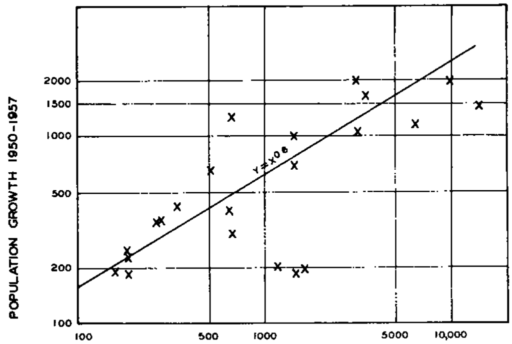

Figure 8. Relation between population growth and accessibility and additional holding capacity.

Using the 1980 employment accessibility index, I, and the holding capacity, C, available now for additional population growth, new values of $(I\ C)^{0.6}$ can be computed. These values are taken times the future weights or growth ratios estimated by the local planners and the products are used to distribute the total anticipated population growth for the urban area. Remembering that future growth cannot exceed present holding capacity, adjustments must be made in the distribution calculations so as not to "overfill" any zone with population. Succeeding approximations must be made of the "F" factor in distributing the population to satisfy the restraint of zone holding capacities. Table 10 illustrates the procedure in distributing estimated population growth. Only zones with additional holding capacity in 1959 are included in this table.

As discussed previously, the number of cars presently owned in each of the zones was expanded by a factor of 1.5 which reflected the anticipated increase in real income by 1980. This expansion was restrained by the ceiling ownership level associated with the residential zone as illustrated in Figure 4. Figure 9 illustrates the relation between 1959 car ownership patterns in five Iowa cities and the residential density where they were located. Cars were added for each zone's increased population at the ceiling rate of applicable to the residential density of the zone. Sample car ownership computations are given in Table 11.

TABLE 8

CALCULATION OF POPULATION DISTRIBUTION WEIGHTS

Zone	ΣAB=I Employment Accessibility Index	Additional Holding Capacity, C, 1950	IxC	$(IC)^{0.6}$	Theo. Growth $F(IC)^{0.6}$	Actual Growth 1950-1957	Ratio, Actual Theo.
00	0.568	2,600	1,477	80	622	700	1.1
01	1.105	55	61	12	93	55	-
02	0.809	102	83	14	109	102	0.9
03	0.744	13,132	9,770	248	1,929	1,932	1.0
04	0.765	243	186	23	179	243	1.4
05	0.777	660	513	42	327	660	2.0
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
39	0.671	1,760	1,181	70	545	200	0.4
All				2,156		Pop. growth =16,780	

TABLE 9

COMPUTATION OF 1980 EMPLOYMENT ACCESSIBILITY INDEX FOR ZONE 00

To Zone	(A) 1980 Employment	1980 Travel Time	(B) Work Trip Frequency Factor	(AB)
00	275	1	2.00	550
01	13,440	14	0.68	9,139
02	482	7	1.00	482
03	3,411	5	1 25	4,264
04	1,332	11	0.80	1,066
05	59	8	0.93	55
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
39	107	4	1.50	161
			1980 Index, I = ΣAB	

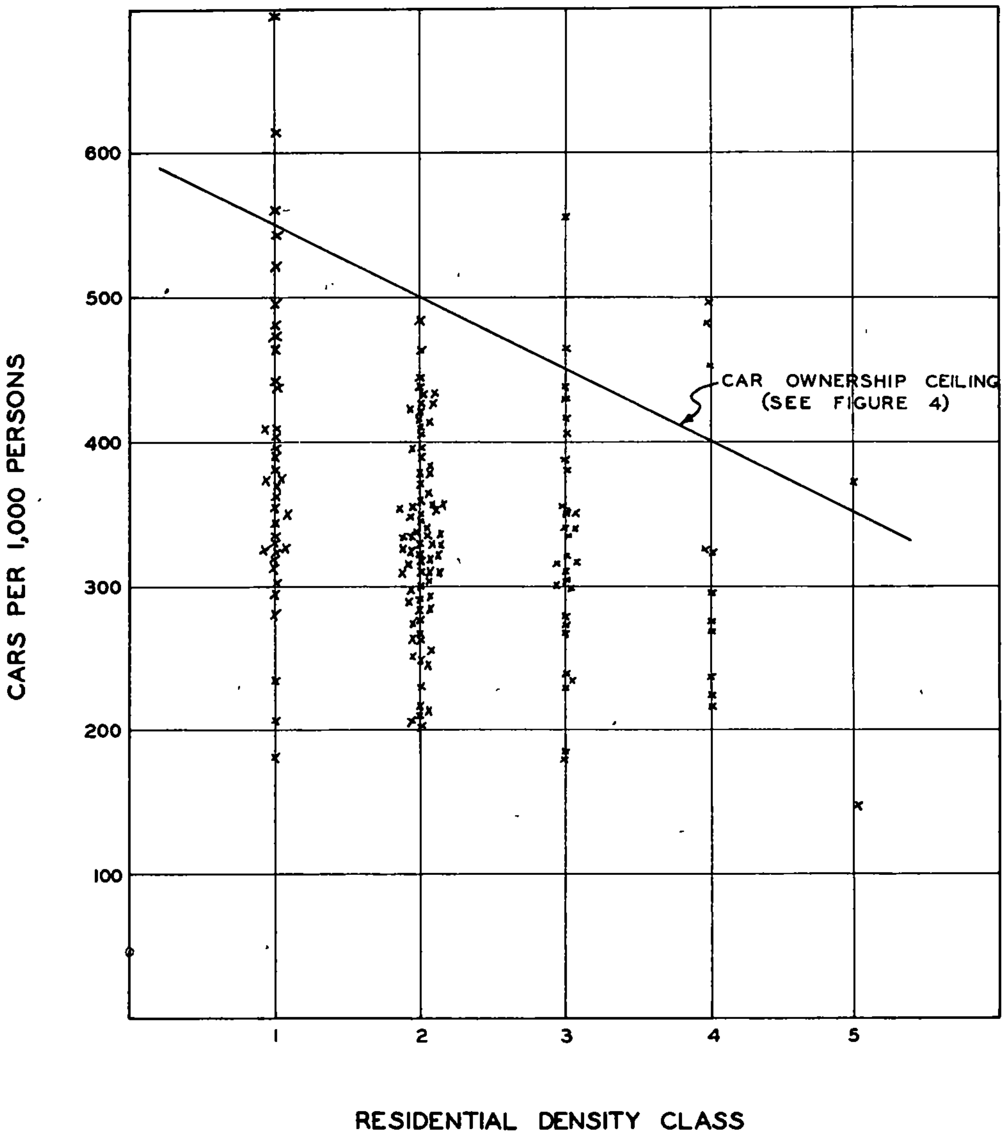

Figure 9. Car ownership related to residential density in five Iowa cities.

TABLE 10

1980 POPULATION DISTRIBUTION COMPUTATIONS
(Additional Population to Be Distributed—40, 000)

Zone	1980 Access. Index, I	Present Add Holding Capacity, C	$(IxC)^{0.6}$	Future Weight, W	$\left(\frac{(A)}{W(IC)^{0.6}}\right)$	Population Growth A(F) 1st Est	A(F_1) 2nd Est	A(F_2) 3rd Est	Present Population, P	A(F_2) + P 1980 Population
00	C 377	1,900	52	1 0	52	1,788	2,164	1,900*	1,597	3,497
03	C.541	11,200	186	1 0	186	6,397	7,739	7,881	3,994	11,875
06	0 481	2,240	66	2 0	132	4,539	2,240*	2,240*	4,571	6,811
12	0 457	1,680	54	0 8	43	1,479	1,789	1,680*	1,850	3,530
14	0 419	3,360	78	0 8	62	2,132	2,580	2,627	5,283	7,910
20	0 372	8,960	130	0 8	104	3,577	4,327	4,407	3,310	7,717
21	0.446	19,040	228	1 0	228	7,841	9,487	9,660	6,006	15,666
26	0 477	2,800	75	1 5	113	3,886	2,800*	2,800*	3,389	6,189
32	0 418	2,240	61	0 3	18	619	749	763	1,494	2,257
33	0 448	3,920	88	0 3	26	894	1,082	1,102	48	1,150
34	0 425	1,120	40	1.5	60	2,063	1,120*	1,120*	2,335	3,455
35	0 360	300	17	1 0	17	585	300*	300*	264	564
36	0.311	140	10	2 0	20	688	140*	140*	3,499	3,639
37	0 311	1,120	33	1 0	33	1,135	1,120*	1,120*	1,258	2,378
38	0 391	700	29	1.0	29	997	700*	700*	1,095	1,795
39	0 437	1,560	50	0 8	40	1,376	1,664	1,560*	-	1,560
					1,163			40,000	39,993	79,993

$F = \frac{40,000}{1,163} = 34\ 39$

$F_1 = \frac{31,580}{759} = 41.61$

$F_2 = \frac{26\ 440}{624} = 42\ 37$

	Present Population, P	A(F_2) + P 1980 Population
Population in zones with no growth	50,787	50,787
Total population	90,780	130,780

*Zones limited in growth by present additional holding capacity

TABLE 11

CALCULATION OF 1980 CAR OWNERSHIP

Zone	(A) Present Popula-tion	(B) Cars/Person Ceiling	(C) Ceiling Total Cars (AxB)	(D) Present Cars Owned x1.5	(E) Popula-tion Added by 1980	(F) Added Cars For New Pop. (BxE)	Total Cars 1980 (D+F)
00	1,597	0.50	799	834	1900	950	1,749*
01	1,544	0.35	540	338	-	-	338
02	1,361	0.45	612	548	-	-	548
03	3,994	0.55	2,197	2,019	8500	4675	6,694
04	2,196	0.50	1,098	1,145	-	-	1,098*
05	1,735	0.50	868	831	-	-	831
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.

*Expanded car ownership (Col. D) exceeded car ceiling (Col. C) for this zone. Total cars 1980 = Col. C + Col. F.

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