Forecasting Transit Use

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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

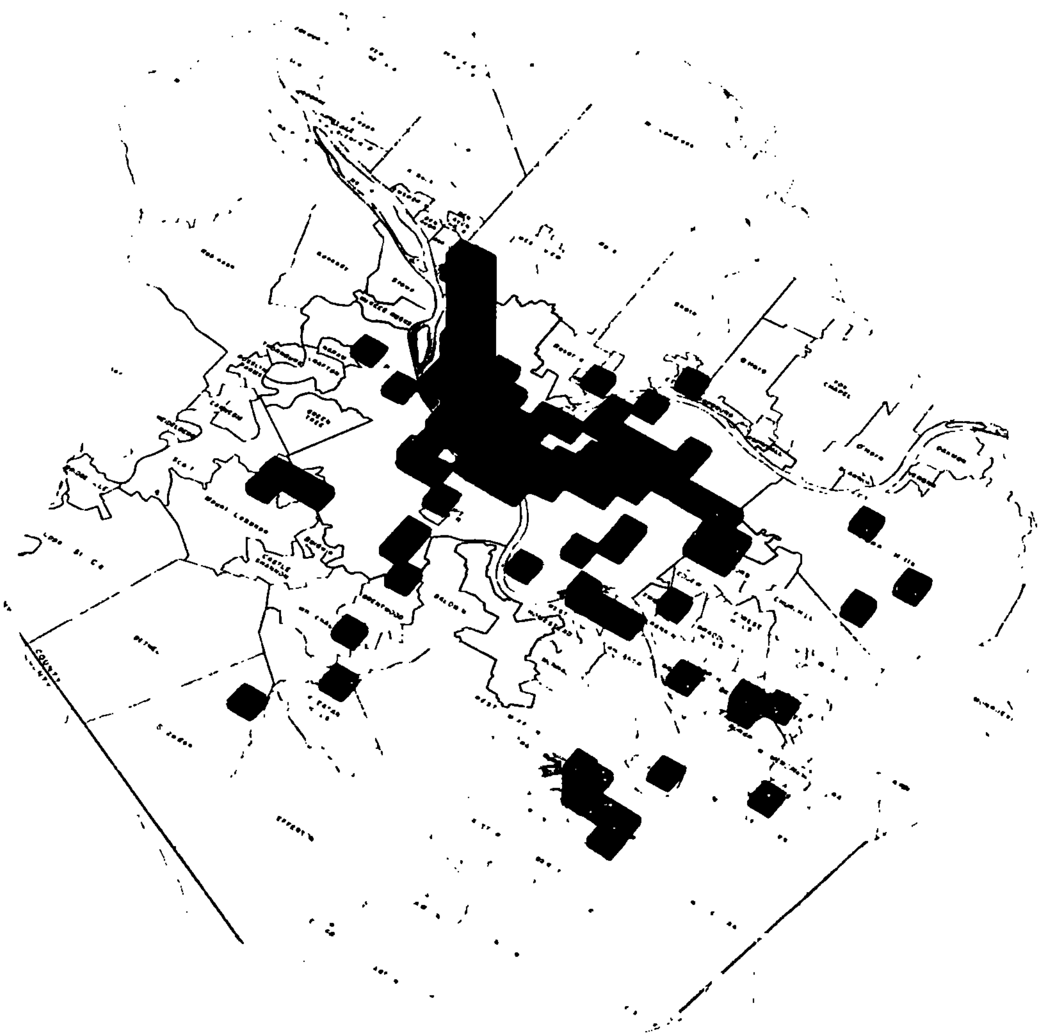

Figure 1. Model depicting mass transit trip destinations, by ¼-sq mi grid.

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	0	28	54	82	88	46
trips/1,000	1	39	73	166	286	117
population	2	36	56	155	250	127
Total		35	66	157	267	104
CBD transit	0	145	197	138	109	163
trips/1,000	1	104	110	90	64	98
population	2	92	90	55	43	69
Total		117	126	87	59	106
CBD total	0	159	221	170	177	187
trips/1,000	1	202	196	164	142	182
population	2	334	248	177	148	214
Total		195	209	167	145	188
Transit as per-	0	88.2	89.1	81.5	61.5	87.5
cent of CBD	1	51.3	55.9	55.2	45.3	53.8
total	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/	0	239	290	284	136	263
1,000 popula-	1	108	91	69	38	82
tion	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

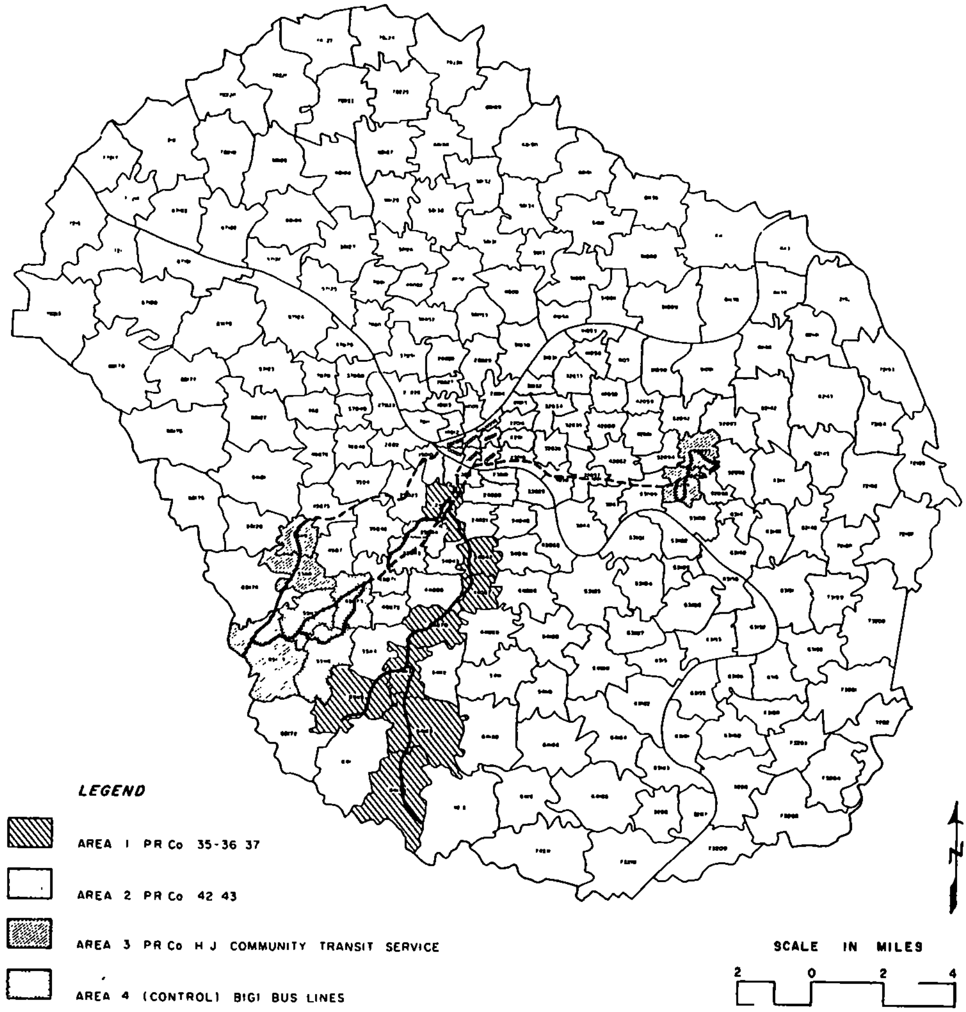

Figure 2. Test areas—effect of transit improvements.

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			CBD Total Trips			Percent Transit to Total			Net Res'd Density
	Car/Household			Car/Household			Car/Household			
	0	1	2+	0	1	2+	0	1	2+	
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
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

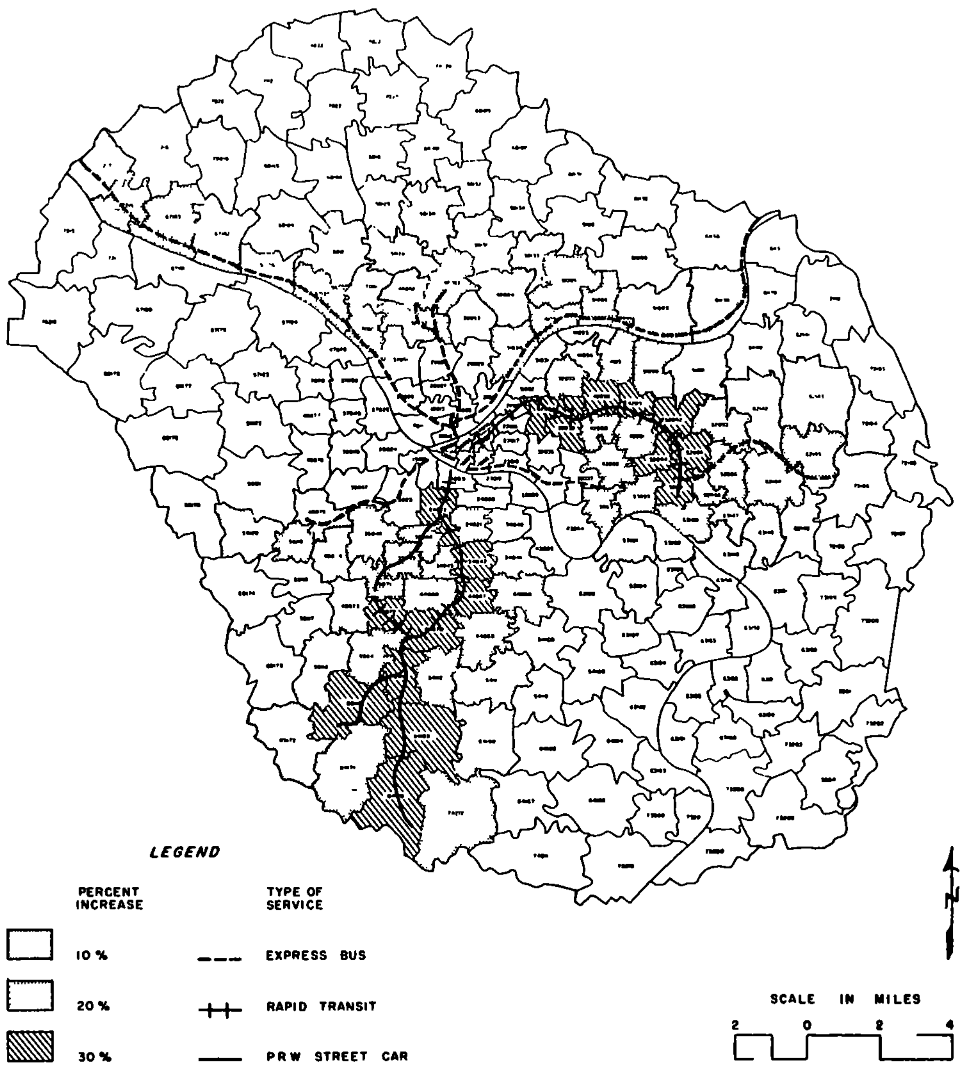

Figure 3. Assumed 1980 transit service improvements.

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.

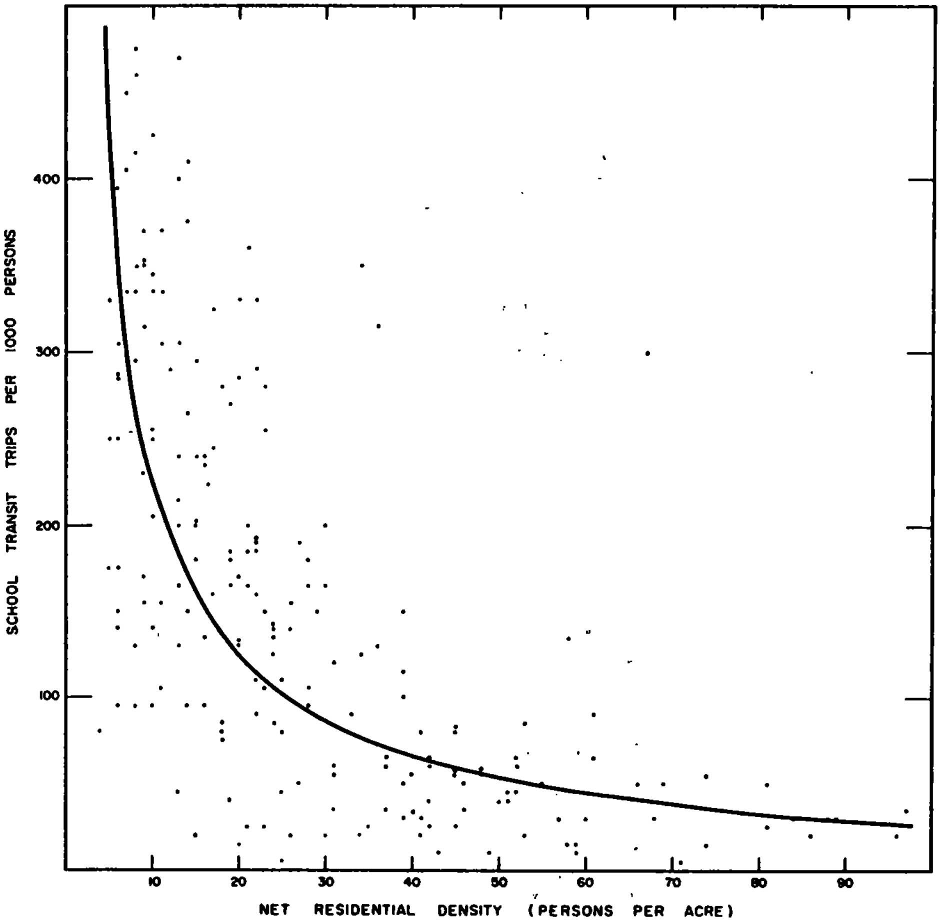

Figure 4. School transit trips as related to net residential density.

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

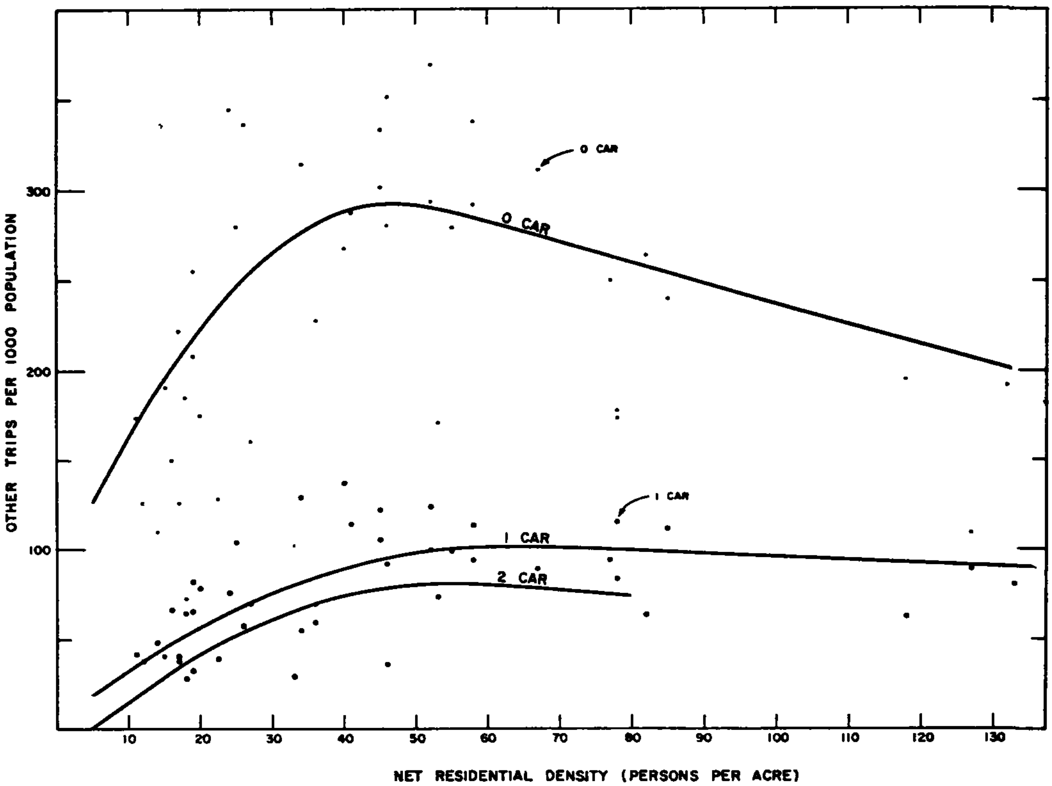

Figure 5. Other transit trips by car ownership and net residential density.

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 (School and Other)	197,755	10.2 (School and Other)	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.

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