Modal Split Model in the Penn-Jersey Transportation Study Area

ANTHONY R. TOMAZINIS, Transportation Planning Consultant, Delaware Valley Regional Planning Commission

•THE analysis and projection of mass transit trips of a metropolitan region have been in the center of interest of several major urban transportation studies in the recent past. This interest includes a desire for more accurate, detailed and comprehensive projection of transit system utilization at given future time intervals within the urban regions and, in a few cases, a desire to incorporate the effect of the transportation systems (highway and transit) themselves on the magnitude and the particular characteristics of the travel demand in a region.

The selection of the mode of travel by each individual has frequently been recognized as an event of substantial complexity, involving considerations of such diverse nature as personal preferences, availability of alternative means of travel, and sensitivity and meaningfulness of the means of measuring transportation systems. Various methods of incorporating these elements of the problem have been proposed and put to use by several study groups in the past few years. Relationships, frequently called mathematical models, were developed, and with various degrees of accuracy and confidence were put to use in simulating and projecting the transit travel pattern in various urban areas.

A concerned effort toward an accurate and reliable analysis and projection of the transit trips within the Philadelphia metropolitan area has also been part of the work program of the Penn-Jersey Transportation Study staff since early in 1961. Since then, several attempts were carried out in a continuous and cumulative effort to derive a model which will meet technical as well as policy objectives of the Study. The various individual projects which were undertaken can be considered as falling within three major phases of work: (a) the test of the 1947 O-D data and the multivariable model initially tested, (b) the simplified model of the 1960 O-D data and the initial 1975 projections, and (c) the complete modal split model for 1975 and 1985 projections.

THE 1947 TEST MODEL

One of the very first attempts to reproduce transit trip rates in the region was the one based on data of sample districts of the 1947 O-D survey. Data limitations made it necessary to limit the test to 15 districts of the Study area. The test was intended to investigate in a preliminary manner the relevance of several of the variables which appear initially significant in the modal split problem. Ten such variables were finally selected for the test, among a much larger number of conceptually suitable variables which were initially defined. The selected variables were formed on a district basis and were named as follows:

1. Car ownership rate (cars per 100 persons);
2. Density of residential development (D. U. per gross residential acre);
3. Transit system accessibility by cost codes;
4. Transit system accessibility by time codes;
5. Transit system serving capacity (vehicle departures within 24 hours x total passenger capacity of each vehicle);
6. Percent of persons between 5 and 19 years old to total district population;
7. Employed resident labor force;

Paper sponsored by Committee on Origin and Destination.

8. Percent of resident labor force to total district population;
9. Reported median number of years of school completed by residents; and
10. Reported median household income.

The dependent variable was the percent of total trips in the district which were made by mass transit (including railroad internal trips, subway and surface trips).

The geographic distribution of the test districts was extended to include the Philadelphia and Camden CBDs and several other districts of the Pennsylvania and New Jersey sides of the region, located at various distances from the Philadelphia CBD. The test was primarily a single multiple regression analysis including several runs and a step-by-step incorporation of the variables.

The results of this test are shown in Tables 1, 2, and 3. Table 1 gives the matrix of the correlation coefficients of each pair of variables. This table reveals several high intercorrelations such as the ones between car ownership rates and residential density, between the median household income and the median years of school completed, or between several other pairs of variables. Also one can point out the very low relationship demonstrated between the two types of system accessibility, first derived on the basis of time travel and then on the basis of travel cost, in the transit and highway systems of 1947.

The correlations of the ten variables with the percent of total transit trips of each district produced a coefficient of correlation of $R = 0.995$ and an $S_{yx} = 2.32$ percent. The step-by-step incorporation of the variables revealed, however, that for several rather apparent reasons a number of the variables contributed in a minor manner to the overall relationship. Examination of the significance of each variable with the help of the traditional tools, such as the simple correlation coefficients, the partial correlation coefficients, and the beta coefficients, indicated that if a different order of successive incorporation of the variables were adopted (than the one suggested by their listing), we could reach high levels of correlation with fewer than ten variables. Tests of this nature produced the results given in Table 2. From this table it became clear that an R of 0.99 and an S_{yx} of 2.80 percent could be reached using only six variables. Even four variables appear to be capable of producing an R of 0.98, if properly selected. The actual level of simulation achieved by each of these sets of variables is given in Table 3, on a district-by-district basis.

Among the additional conclusions which this preliminary analysis indicated was that the car ownership rate appeared to be the most significant variable in the 1947 set of circumstances and also that the level of transit service and the income appeared to be of equal and of high significance. Next in line of significance appeared to be the percent of labor force in the district, its transit system time accessibility, and the percent of people between 5 and 19 years of age.

THE 1960 ORIGINAL MODAL SPLIT RELATIONSHIPS

The second phase of the investigation on the modal split problem was carried out on the basis of the data of the 1960 O-D survey. This phase included several differences from the previous one; it also attempted to capitalize on the conclusions of the analysis of the 1947 data and other previous works, and the whole effort became essentially part of the trip generation procedure of the Study.

The trip generation analysis in PJTS emphasized trips in five groups of trip purpose. Home origin trips were divided into trips from home to work and trips from home to all non-work purposes. Non-home origin trips were divided into three groups—trips from work to home, trips from non-work origins to home and trips from non-home origins to non-home destinations. In addition to the above five individual trip purposes, attempts were made to develop relationships for total home origin trips and total non-home origin trips. In terms of trip generating types of land use, the trip generation analysis emphasized the derivation of relationships for trips from residential land use (home and non-home origin all under L. U. Code 0) from Offices (L. U. Code 1), from a combination of Retail and Services and Passenger Transportation land uses (L. U. Codes 2 + 5), from another combination of Manufacturing, Wholesale and Goods Transportation land uses (L. U. Codes 3 + 4 + 6), and from the combination of Public Buildings and Community Facilities (L. U. Codes 7 + 8).

TABLE 1

CORRELATION MATRIX

(Simple correlation coefficients between the indicated pairs of variables)

Variable	Y	1	2	3	4	5	6	7	8	9	10
Y	1. 000	-0. 787	0. 625	0. 663	0. 503	0. 675	-0. 311	0. 515	0. 551	-0. 491	-0. 663
1	-0. 787	1. 000	-0. 912	-0. 429	-0. 373	-0. 481	0. 035	-0. 532	-0. 061	0. 823	0. 872
2	0. 625	-0. 912	1. 000	0. 185	0. 253	0. 295	0. 100	0. 636	-0. 090	-0. 852	-0. 783
3	0. 663	-0. 429	0. 185	1. 000	0. 119	0. 920	-0. 807	-0. 068	0. 602	0. 074	-0. 557
4	0. 503	-0. 373	0. 253	0. 119	1. 000	0. 055	0. 030	0. 383	0. 230	-0. 404	-0. 103
5	0. 675	-0. 481	0. 295	0. 920	0. 055	1. 000	-0. 758	0. 008	0. 443	0. 015	-0. 626
6	-0. 311	0. 035	0. 100	-0. 807	0. 030	-0. 758	1. 000	0. 207	-0. 456	-0. 418	0. 163
7	0. 515	-0. 532	0. 636	-0. 068	0. 383	0. 008	0. 207	1. 000	0. 027	-0. 597	-0. 320
8	0. 551	-0. 061	-0. 090	0. 602	0. 230	0. 443	-0. 456	0. 027	1. 000	0. 186	-0. 192
9	-0. 491	0. 823	-0. 852	0. 074	-0. 404	0. 015	-0. 418	-0. 597	0. 186	1. 000	0. 614
10	-0. 663	0. 872	-0. 783	-0. 557	-0. 103	-0. 626	0. 163	-0. 320	-0. 192	0. 614	1. 000

TABLE 2

STATISTICAL RESULTS OF VARIABLE TESTING: 1947 MODEL

Case A				Case B				Case C			
According to Betas				According to Partial Coefficients				According to Simple Coefficients			
Variable	Successive R	Successive S	Betas of the Final Equation	Variable	Successive R	Successive S	Betas of the Final Equation	Variable	Successive R	Successive S	Betas of the Final Equation
1	0. 78	13. 9	-1. 169	8	0. 55	18. 8	0. 555	1	0. 78	13. 9	-1. 306
5	0. 85	11. 7	0. 718	5	0. 73	15. 5	0. 718	5	0. 85	11. 7	0. 681
10	0. 89	10. 4	0. 723	10	0. 81	13. 4	0. 722	10	0. 89	10. 4	0. 658
8	0. 98	4. 6	0. 555	1	0. 98	4. 6	-1. 169	3	0. 90	10. 1	-0. 485
3	0. 99	3. 3	-0. 290	6	0. 99	3. 3	0. 174	2	0. 90	10. 1	-0. 108
6	0. 99	2. 8	0. 174	3	0. 99	2. 8	-0. 290	8	0. 99	3. 2	0. 579

Predictive Equations

Cases A and B: $Y_1 = -149.221 - 4.031X_1 + 0.051X_5 + 0.023X_{10} + 4.012X_8 - 40.580X_3 + 0.758X_6$

Case C: $Y_1 = -115.131 - 4.505X_1 + 0.048X_5 + 0.021X_{10} + 68.090X_3 - 0.191X_2 + 4.190X_8$

TABLE 3

SIMULATION RESULTS: 1947 MODEL

Test District	Actual Mass Transit Trips of Each District	Actual Percent of Total Trips Made by Mass Transit	Calculated Mass Transit Trips (Percent of Total Trips): Original Run, Percent (10 variables)	Original Run, Residual (10 variables)	According to Betas or Partial R's, Percent (6 variables)	According to Simple R's, Percent (6 variables)
000	316. 171	86. 00	86. 03	+0. 03	86. 80	86. 45
012	23. 402	63. 00	64. 96	+1. 96	65. 98	66. 24
017	31. 254	73. 00	73. 21	+0. 21	73. 97	71. 86
021	31. 441	45. 00	46. 49	+1. 49	45. 10	43. 55
060	9. 803	44. 00	40. 44	-3. 55	41. 50	42. 86
039	18. 852	41. 00	40. 53	-0. 47	37. 85	37. 43
041	82. 774	70. 00	69. 71	-0. 29	66. 00	66. 20
054	50. 157	68. 00	65. 27	-2. 73	63. 55	64. 31
063	41. 572	65. 00	63. 54	-1. 46	63. 62	61. 10
202	20. 916	41. 00	40. 07	-0. 93	42. 89	41. 31
421	7. 429	26. 00	31. 44	+5. 44	31. 38	32. 26
451	2. 961	18. 00	16. 31	-1. 69	17. 86	19. 26
092	24. 411	69. 00	70. 58	+1. 58	72. 05	72. 46
084	75. 960	80. 00	80. 23	+0. 23	80. 60	83. 70
471	5. 363	14. 00	14. 17	+0. 17	13. 81	13. 97

TABLE 4

ORIGINAL TRANSIT TRIP EQUATIONS: 1960 DATA

Y	Equation	R	S. E.	B_1	B_2
Y_1	$52.45 + 0.002X_6 - 0.8X_1 + 0.04X_{55} - 1.2X_2$	0.81	6%		
Y_{383}	$0.25 - 0.74 \log X_2 - 0.03 \log X_6$	0.84	10%	-0.82	0.02
Y_{383}	$0.09 - 0.54 \log X_2 + 0.08 \log X_{55}$	0.82	10%	-0.62	0.22
Y_{385}	$0.12 - 0.45 \log X_2 + 0.13 \log X_{55}$	0.87	9%	-0.52	0.38
Y_{385}	$0.73 - 0.92 \log X_2 + 0.35 \log X_6$	0.88	9%	-1.04	0.22
Y_{388}	$148.44 - 92.38X_2 + 0.08X_{55}$	0.63	40.65 (trips)	0.60	0.03
Y_{400}	$16.86 + 0.02X_{45}$	0.75	10%		
Y_{401}	$0.22 + 0.0006X_{46}$	0.69	13%		
Y_{403}	$0.20 + 0.29 \log X_{57}$	0.78	13%		
Y_{335}	$0.07 + 0.17 \log X_8$	0.76	11%		
Y_{405}	$0.02 + 0.17 \log X_8$	0.75	11%		
Y_{407}	$0.22 + 0.0002X_{45}$	0.62	16%		
Y_{409}	$0.06 + 0.0006X_{46}$	0.74	11%		
Y_{411}	$0.17 + 0.0009X_{48}$	0.75	17%		
Y_{341}	$0.04 + 0.0005X_{78}$	0.68	5%		
Y_{342}	$0.05 + 0.0009X_8$	0.84	5%		
Y_{343}	$0.05 + 0.0002X_{45}$	0.75	8%		
Y_{344}	$0.01 + 0.0006X_{58}$	0.82	6%		
Y_{345}	$0.07 + 0.11 \log X_{57}$	0.66	6%		
Y_{429}	$0.06 + 0.0004X_{58}$	0.64	6%		
Y_{266}	$-0.14 + 0.22 \log X_{57}$	0.76	9 (trips)		
Y_{285}	$0.24 + 0.002X_{58}$	0.70	27 (trips)		

Y_1 = Percent of total mass transit trips from each district (excl. RR trips).
Y_{383} = Total mass transit trips from home per total person trips from home.
Y_{385} = Home to work mass transit trips per home to work person trips.
Y_{388} = Home to non-work mass transit trips per 100 persons.
Y_{400} = Work to home M.T.T. from Office L.U. per jobs from Office L.U.
Y_{401} = W-H M.T.T. from Retail L.U. per W-H person trips from Retail L.U.
Y_{403} = W-H M.T.T. from Manufacturing L.U. per W-H person trips from Manufacturing L.U.
Y_{335} = W-H M.T.T. from L.U. 3, 4 and 6 per W-H person trips from L.U. 3, 4 and 6.
Y_{405} = Non-work to home M.T.T. per non-work to home person trips.
Y_{407} = NW-H M.T.T. from Office L.U. per NW-H person trips from Office L.U.
Y_{409} = NW-H M.T.T. from Retail L.U. per NW-H person trips from Retail L.U.
Y_{411} = NW-H M.T.T. from Manufacturing L.U. per NW-H person trips from Manufacturing L.U.
Y_{341} = NH-NH mass transit trips per NH-NH person trips.
Y_{342} = NH-NH M.T.T. from L.U. 1-X per NH-NH person trips from L.U. 1-X.
Y_{343} = NH-NH M.T.T. from L.U. 1 per NH-NH person trips from L.U. 1.
Y_{344} = NH-NH M.T.T. from L.U. 2 and 5 per NH-NH person trips from L.U. 2 and 5.
Y_{345} = NH-NH M.T.T. from L.U. 3, 4 and 6 per NH-NH person trips from L.U. 3, 4 and 6.
Y_{429} = NH-NH M.T.T. from L.U. 2 and 5 per jobs from L.U. 2 and 5.
Y_{266} = Total M.T.T. from L.U. 3, 4 and 6 per jobs from L.U. 3, 4 and 6.
Y_{285} = Total M.T.T. from L.U. 2 and 5 per jobs from L.U. 2 and 5.
X_1 = Total cars per total population.
X_{45} = Office jobs per Office acres.
X_{46} = Retail jobs per Retail acres.
X_{57} = Jobs from L.U. 3, 4 and 6 per acres of L.U. 3, 4 and 6.
X_8 = Jobs per non-residential acres.
X_{48} = Manufacturing jobs per Manufacturing acres.
X_{78} = Total auto driver trips per non-residential acres.
X_{58} = Jobs from L.U. 2 and 5 per acres of L.U. 2 and 5.

Within the framework of the trip generation analysis, attempts were made to establish relationships for trip generation rates of each trip purpose from each major type of land use and for each mode of travel. Trips were classified as "total person trips," "auto trips," "auto driver trips," and "total transit trips." The mass transit trip generation rates were formed as trips per household, per person, and trips per job, or as a percent of total person trips made by mass transit in each trip type. This procedure, if successful, would permit the derivation or projection of transit trips in two ways—once directly on the basis of the mass transit trip relationships and again as the residual of the subtraction of auto trips from total person trips in each major trip type.

The trip generation analysis in PJTS has completed both these projection procedures before the actual selection of procedure was made. The effort to develop acceptable and reliable individual relationships directly for each type of transit trip (a total of 35 types of transit trips) did not produce finally a complete set of consistently acceptable and reliable equations.[1] While several types of transit trips produced substantially acceptable relationships, many other types of transit trips resulted in relationships largely unreliable. Making use of conclusions previously reached and the array of available data, the variables used in these attempts were car ownership rate (X_2), median household income (X_6), net residential density (X_{55}), and the various net job densities for each type of job. Table 4 gives the better equations of this attempt. The remaining equations resulted in R's below 0. 60, using either logarithmic or arithmetic forms of the variables.

As a result of the unsatisfactory consistency and reliability of these transit trip equations, the first round of the 1975 transit trip projection was completed almost exclusively by subtracting auto trips from total person trips. This was done for each of the five trip purposes (H-W, H-NW, W-H, NW-H, NH-NH) and for each of the six types of land use aggregations (L. U. 0, 1, 2+5, 3+4+6, 7+8, 9) which were the land use types finally agreed upon to be projected in the 1975 land use plans. For home origin trips the projection of person trips and auto trips was made on the basis of predictive equations which have had generally better predictive capability than the transit trip equations. For non-home origin trips, the projections of person trips were made by use of a combination of mean rates and statistical relationships. Auto non-home origin trips were projected primarily with predictive equations which utilized job density and, in several cases, the proportion of jobs, by type, in each district vs the jobs in the region.

The projection procedure resulted in several imperfections. First, the necessity of using means for the projection of several types of person trips and auto trips from non-home origins precluded the direct introduction in these cases of the influence of rider or area variables such as residential or job density in each district. Second, a detailed investigation of the results of the predictive equations of the home origin trips, on a district basis, revealed that although these equations produced highly satisfactory results on a regional basis (e.g., a simulation error of 19 percent of actual auto trips in 1960), they did overstate significantly auto trips in the central part of the City of Philadelphia where the vast majority of transit trips of the region took place. Further, the same equations were found to generally understate auto trips in the New Jersey districts and overstate auto trips in the Pennsylvania districts. Figures 1 and 2 show this overstatement of auto trips (and consequently understatement of transit trips). Finally, nowhere in the projection process is the effect of the system (and of its potential changes) directly or indirectly incorporated.

The projections were improved by incorporating in an elementary manner, at least, the effects of the 1975 alternative systems. This incorporation was made by an ad hoc, generally upward adjustment of the total number of transit trips. For each district, use was made of a relationship between highway and transit travel time to the Phila-

[1]The 35 types of transit trips were three trip purposes from home (H-W, H-NW, Total) and four trip purposes (W-H, NW-H, NH-NH, Total) from each of the following land uses: Residential (0), Offices (1), Retail and Services (2), Passenger Transportation (5), from the combination of (2) and (5), from the combination of Wholesale with Stocks (3), Manufacturing (4), and Goods Transportation (6), from the combination of Public Buildings (7) and Community Services (8), and from Recreation Land Use (9).

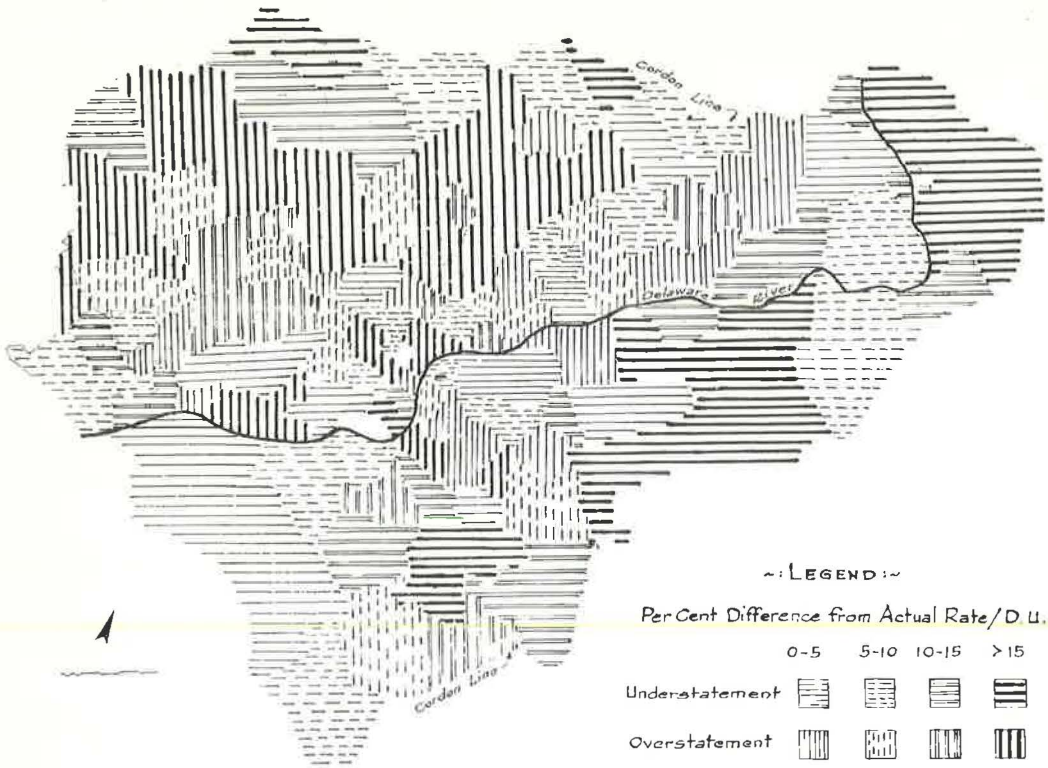


Figure 1. Residuals of auto home to work trip generation equations.

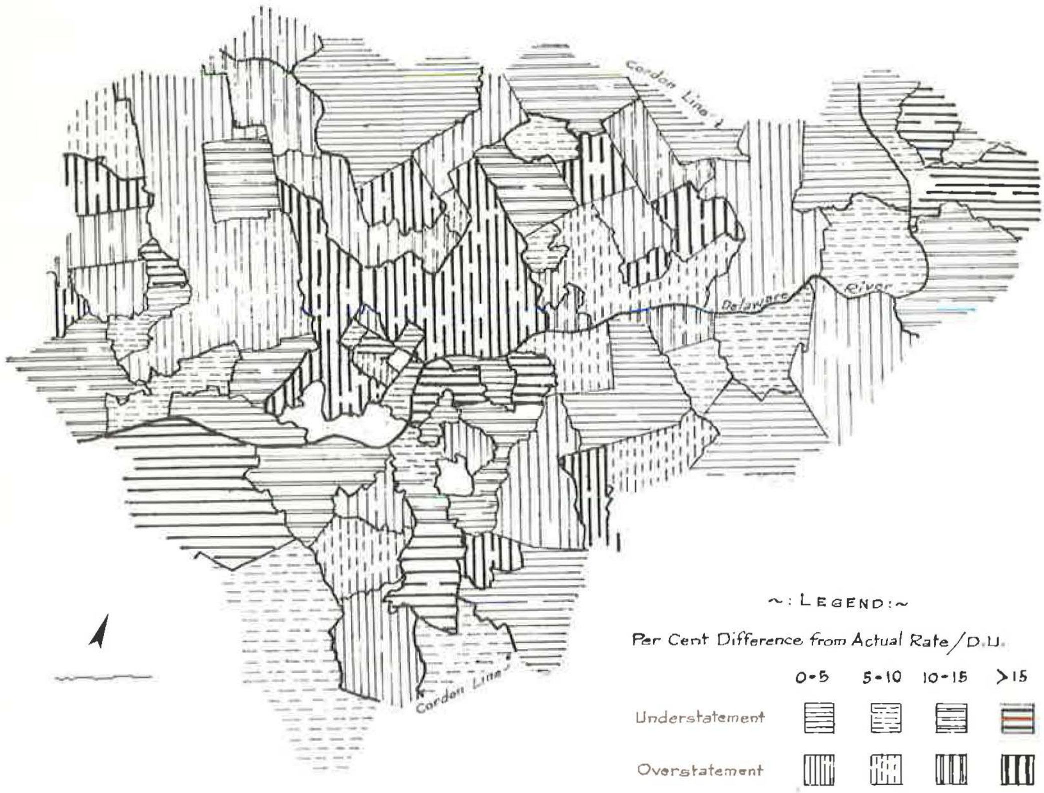


Figure 2. Residuals of auto home to non-work trip generation equations.

delphia CBD and the percent of total transit trips in each district. Changes of this relationship between 1960 and 1975 were used as the basis of an adjustment of total transit trips projected for 1975 in each district. This adjustment served an intermediate purpose and helped to indicate, at least partially, the effect that might be produced by different rates of transit/highway capital investment in the 1975 plans. The results of this adjustment were considered sufficient for the occasion but, at the same time, they helped to emphasize the need for continuation of the modal split analysis and for the completion of a systematic and comprehensive method with which the effects of the car ownership rates, the density of development, and the transportation system of the region are directly and simultaneously incorporated in the analysis and projection process.

THE 1975 TRANSPORTATION PLANS

The need for a direct and as complete as possible incorporation of the effects of the transportation system on the process of determining the selection of the mode of travel becomes better understood when one relates this objective with the extent of future changes in the transportation system of the region. Within the context of PJ circumstances, it may be pointed out that the proposals for the 1975 transportation system for the PJ region include two alternative highway plans and three alternative transit plans. These five plans produce six combinations of systems (2 × 3) including both highway and transit facilities. The minimum highway plan anticipates $1, 269 million capital investment while the minimum transit plan anticipates $163 million capital investment in transit facilities. Correspondingly, the maximum highway and maximum transit plans anticipate $1, 632 million and $718 million capital expenditures each. By adding the highway system cost and the transit system cost of each combination of plans, the total estimate is found varying from a minimum of $1, 432 million to a maximum of $2, 350 million in capital expenditures. Each plan anticipates a technology for both highway and transit basically similar to the present-day modern and operational technology of these systems. In terms of amount of facilities, the highway plans anticipate 226. 4 or 330. 4 miles of new expressways and the transit plans anticipate 7. 6, 12. 2, or 33. 1 miles of subway in three or nine line-extensions plus the conversion of three railroad lines (62. 9 miles) into electrified suburban-commuter rapid lines. The detailed specifications of the 1975 plans are shown in Figures 3, 4, 5, 6, and 7.

SYSTEM VARIATIONS AND TRANSIT TRIPS

A method incorporating the effects of alternative transportation systems into the planning process becomes meaningful exercise only when it can, indeed, trace and effectively take into account any or all of the particular effects of the different systems. One of these effects, and perhaps one of the most significant ones for a transportation study which such a method would be asked to trace and measure, is the effect of alternative transportation systems on the magnitude and the characteristics of the travel demand in the region.

Clearly there should be at least two basic technical concerns in establishing alternative transportation systems. One is the amount of travel demand served by a system and the sufficiency and efficiency of the system in doing so. The second is the additional effect that each system will have in determining the basic characteristics of travel demand. We usually recognize the system effects in the distribution of trips when we use one of the synthetic models (e.g., a gravity or a probability model) which greatly influence the particular interchanges of travel according to the transportation system of the region. We also recognize partially the system's effect in the assignment of trips by assigning trips on these facilities which form the "minimum path" or the "best alternative" path. Frequently, however, it has been proved difficult to incorporate the effects of a transit and highway system in estimating the number of transit trips which the combination of transportation systems facilitate and induce in a region. In the case of PJTS, the acceptance for testing of three alternative transit systems, varying by $600 million, increases in meaning decidedly if the effect of each system could be associated with the number of transit trips induced and served by each system.

Figure 3. Regional transportation system: Freeway Plan 1, 1975.

Figure 4. Regional transportation system: Freeway Plan 2, 1975.

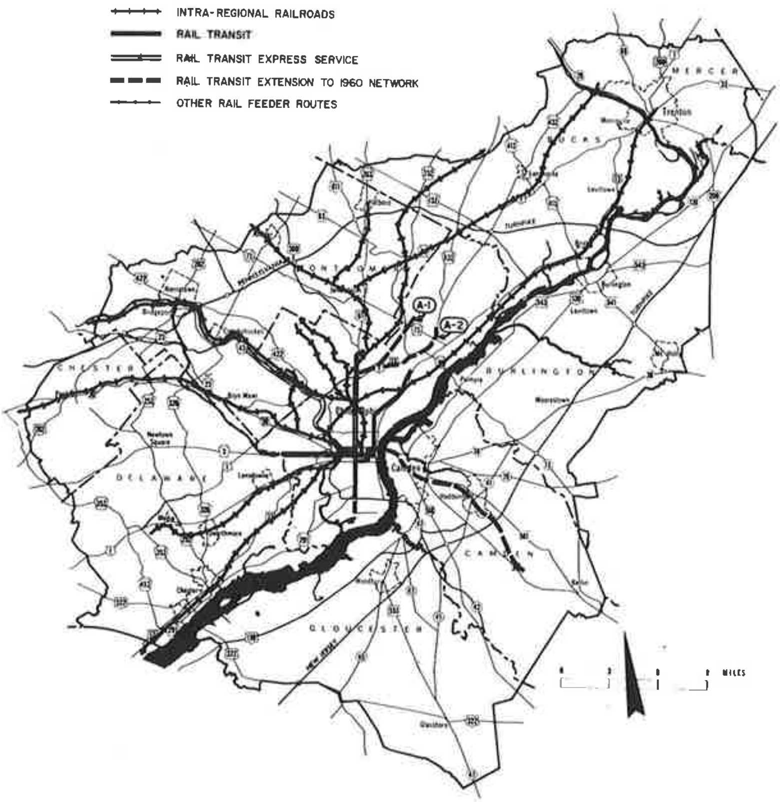


Figure 5. Regional transportation system: Mass Transportation Plan A, 1975.

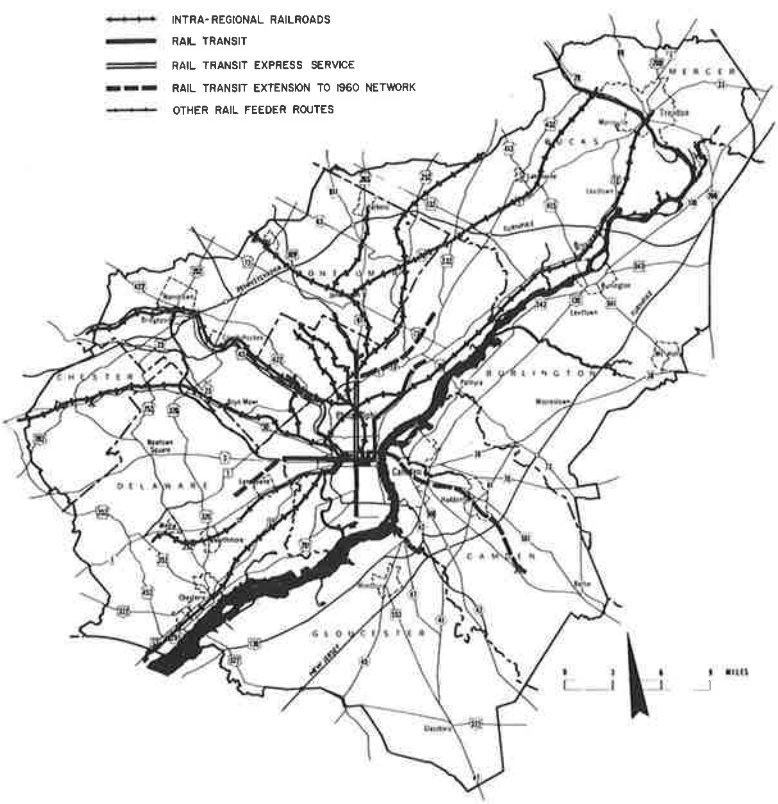


Figure 6. Regional transportation system: Mass Transportation Plan B, 1975.

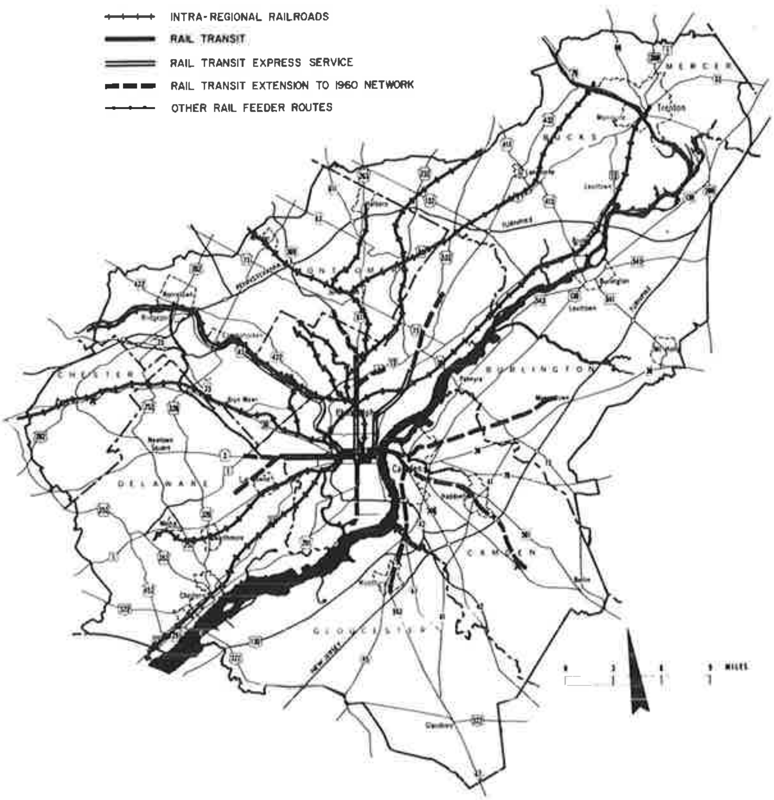


Figure 7. Regional transportation system: Mass Transportation Plan C, 1975.

Several recent studies and monographs have dealt with the problem of incorporating transit system characteristics in the determination of the number of transit trips in the system (1, 2, 3). Some of these studies have also attempted to incorporate system characteristics in actual trip projections with various degrees of success.

In the first group of studies, several major system "dimensions" were pointed out as being of direct relevance; among them the following have been pointed out as being of particular significance: (a) speed of travel, (b) cost of travel, (c) quality of service, (d) amenity and convenience, (e) safety during and to and from a trip, and (f) stability of service.

Of these major dimensions, various studies attempted to incorporate primarily the one which is expressed in speed of travel. Recent efforts attempted to improve this variable by introducing various relationships between highway and transit travel speeds, as well as the concept of total travel time, including "excess time" or time spent in getting to and from the travel vehicle (4, 5). In fact, until today, only very limited efforts can be recorded which include other system variables than some comparative statements of the average highway and transit travel speeds or of travel time or cost.

The incorporation of system variables includes certain difficulties which exceed in several respects the difficulties that are part of the incorporation of the non-system variables of the modal split problem. For instance, one of the major problems which such an undertaking includes is the quantification of system variables which should be expressive of critical system quality and applicable to highway and transit systems. It has also been generally accepted by now that a comprehensive modal split model requires that variables expressing the type of rider, the type of area, and the system of travel be included. However, incorporation of three types of variables immediately raises one of the initial problems of an analytical process, i.e., the number of variables which is feasible and reliable in a projection model. Both techniques which are presently available (diversion curves and correlation analysis) include technical as well as theoretical obstacles in incorporating more than a handful of variables at a time. Even the small additional flexibility which a correlation analysis permits is frequently not enough to facilitate incorporation of more than a very few system variables in the model, if ample room is to be left for the incorporation of variables expressing the rider and the area.

An additional problem is the nature of the system variables themselves. A simulation or predictive model of modal split requires variables which are sufficiently continuous, objectively defined and reliably predictable. Unfortunately, it has frequently been shown that variables expressing amenity, comfort, safety, or quality of service are usually discontinuous in nature, open to subjective configuration and interpretation and difficult to be predicted in a reliable and systematic fashion.

In light of the problems in modal split models, the PJTS efforts followed several specific and consecutive steps. The first step was to incorporate travel speed and travel cost variations in each system into one parameter which was expressed as "total travel cost." Minimum paths, formed on the basis of total travel cost in the highway system, may express speed variations (translated into time cost), operating cost, bridge or turnpike tolls and, if desired, parking costs. Similarly, minimum paths of the transit system may express speed variations, a generalized measure of time required to reach the transit line, a transfer time penalty, the fares of the line, and any additional toll or transfer fare. Minimum cost paths between any pair of points formed on this basis for the highway and transit system express speed and cost differences between highway and transit systems on a systematic and uniform basis.

The second step was a comparison of the two transportation systems on the basis of their minumum cost paths and the associated land use pattern. This step resulted in the formulation of a new concept and measure of highway and transit system accessibility of each sub-area in the region. According to this concept of accessibility, any variation in the minimum cost paths of the highway system or of the transit system, or any change in the distribution and in the densities of land use in the region, can be reflected directly in the system accessibility of each district.

The detailed description of this variable is as follows. On the basis of the highway minimum cost paths of each district of origin the region was divided into cost zones of successive travel cost intervals, i.e., areas within 0-10, 10-20, 20-30, etc., cents of total travel cost from each district of origin. The formation of cost zones is repeated using each district successively as the origin of the cost zones. Cost zones are also formed on the basis of the transit system minimum cost paths. The person trip destinations in each cost zone are summed up. These person trip destinations of each cost zone are then added up to form the successive cumulative total person trip destinations from each district of origin. Thus person trip destinations for areas within 0-10, 0-20, 0-30, etc., cents of travel cost intervals are estimated for each district or origin, separately for the highway system and the transit system. For each cost interval a ratio is formed of the cumulative person trip destinations reached by transit vs the cumulative person trip destinations reached by highway and car. Such ratios become available for each cost interval, i.e., 0-10, 0-20, 0-30, etc., cents of total travel cost. The last (effective) ratio which is taken into account is the one which includes the last increment of trip destinations in the region, formed on the basis of the system which required the least total travel cost while traveling in the region. This last effective ratio is usually determined on the basis of the last highway cost zone.[2]

Each effective ratio of cumulative person trip destinations is taken into account in forming a mean ratio for each district. This ratio expresses the weighted proportion

---

[2]This is so because the speed in the highway system is usually higher than that in the transit system, which results in having the region covered by a much smaller number of highway travel cost intervals than transit travel cost intervals. In many cases the difference is substantial. For instance, it was found in PJ that the region could frequently be covered from a district of origin with less than 250¢ total highway travel cost while it required up to 450¢ of total transit travel cost for the same distances.

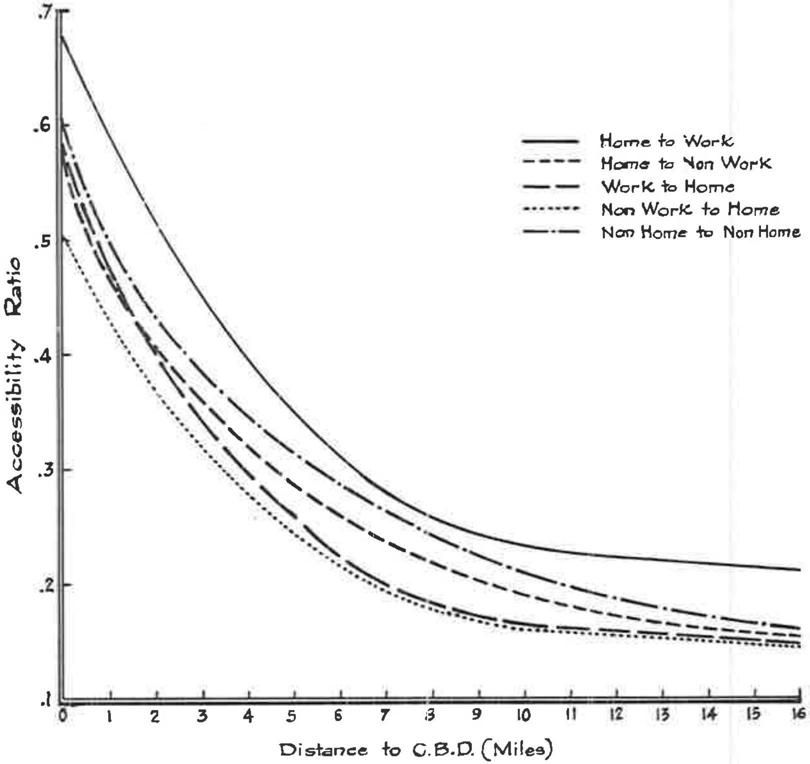


Figure 8. Transit system accessibility, 1960.

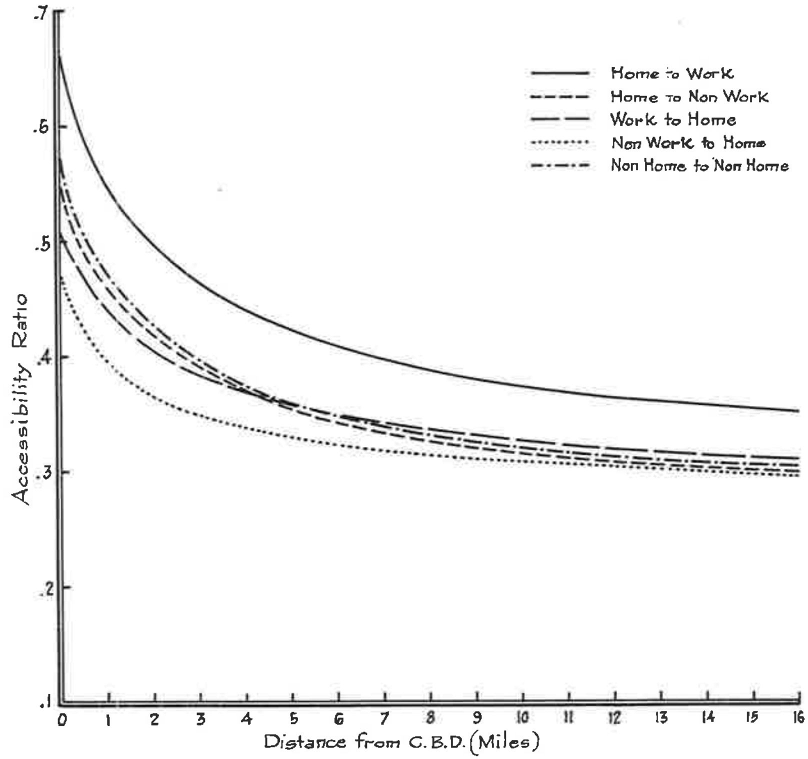


Figure 9. Transit system accessibility, 1975 (System 82—maximum transit, minimum highway).

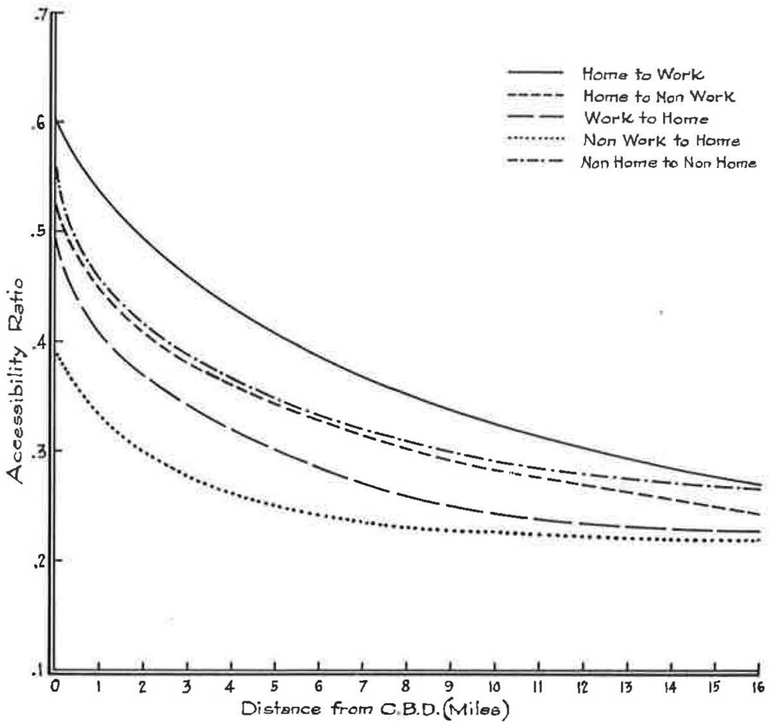


Figure 10. Transit system accessibility, 1975 (System 83-A—mimimum transit, maximum highway).

of person trip destinations reached by transit out of the total person trip destinations reached by highway. This weighting of the mean increases the significance of the close-by person trip destinations by taking them into account repeatedly in each successive cumulative estimation of trip destination by cost interval. This mean ratio is in essence the highway and transit system accessibility for each district. As long as transit travel is in any respect slower or costlier or more restrictive than highway travel this ratio is always below 1. 00, usually varying to about 0. 10. The highest values are found in the districts with the best transit service available, usually the center of the region and the other transportation centers.

Accessibility ratios can be formed for each set of a highway system, a transit system, and a land use distribution. Figures 8 to 10 indicate the values of this variable with the 1960 set of inputs and with the 1975 land use for each alternative pair of projections and two combinations of systems, the minimum highway-maximum transit system (82) and maximum highway-minimum transit system (83-A).

Since 1961, when the present concept of "transit system accessibility" was first publicly proposed, several other professional attempts were made to develop a system accessibility relevant to modal split (6, 7, 8). Most frequently discussed is the use of the gravity model denominator as an index of accessibility. Comparing the PJ concept of system accessibility with the gravity model denominator, one can see the similarities and the differences. For instance, both utilize the land use pattern. The difference is primarily in the simultaneous use of the highway and transit system, in the weight which is placed in the nearby trip destinations in the PJ model and in the manner in which the land use pattern is taken into account.

The PJ modal split analysis focused separately on each of the five trip purposes which were universally analyzed and projected within the Study. In each case the relevant person trip destinations were taken into account, as follows:

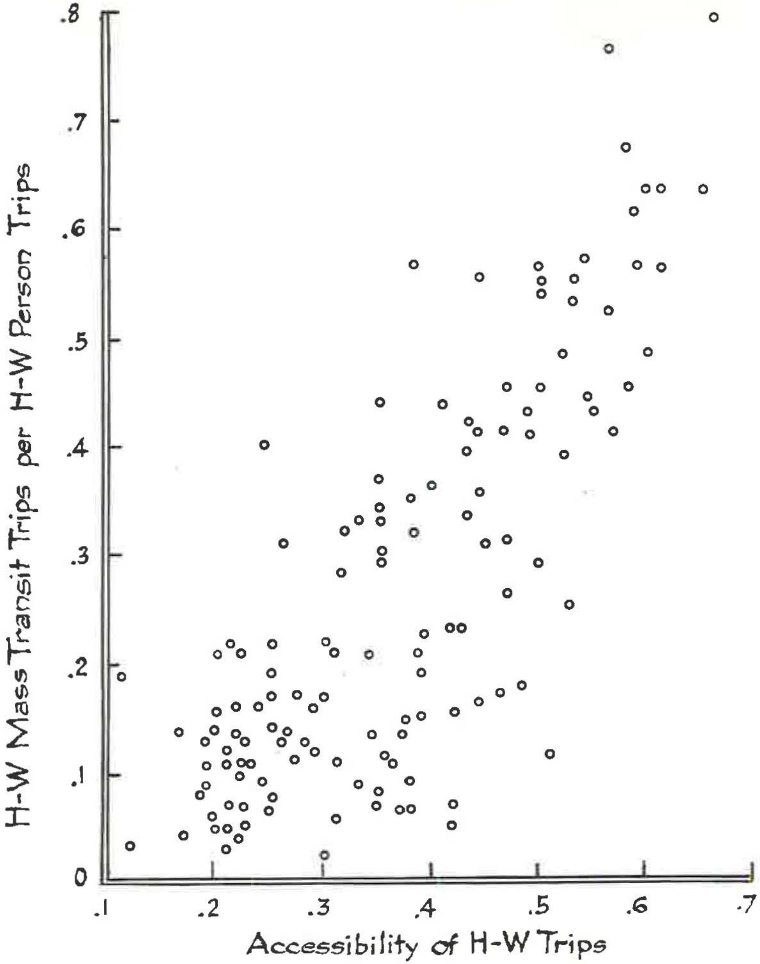


Figure 11. Home to work mass transit trip rates vs accessibility ratios.

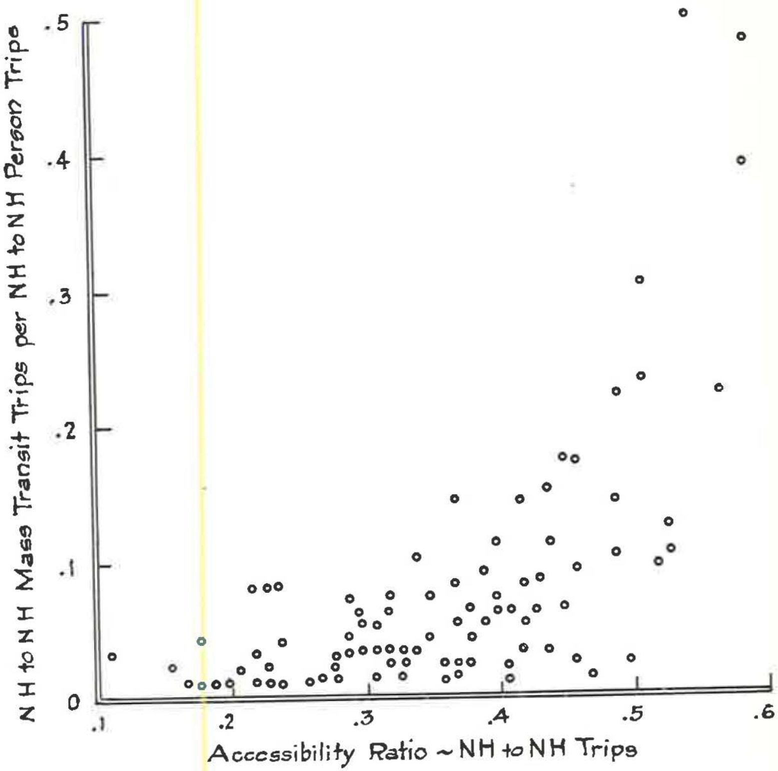


Figure 12. Non-home to non-home mass transit trip rates vs accessibility ratios.

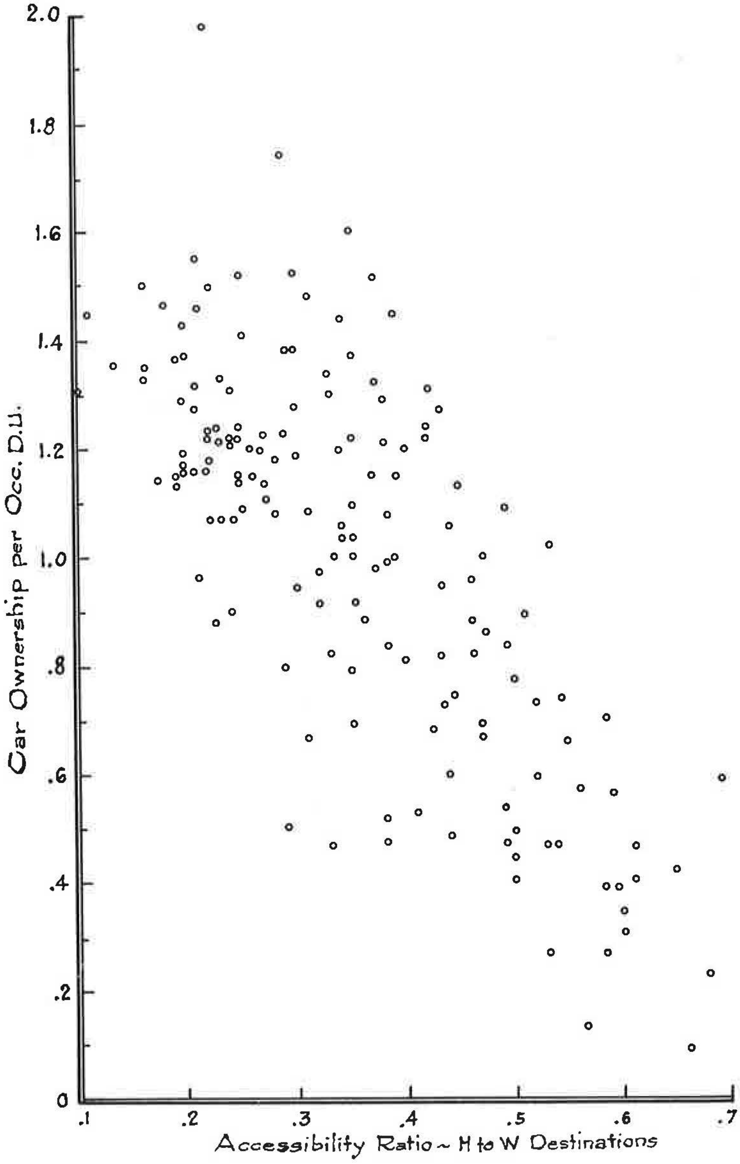


Figure 13. Car ownership rates vs H-W accessibility ratios.

Home to work trips = work to home destinations
Home to non-work trips = non-work to home destinations
Work to home trips = home to work destinations
Non-work to home trips = home to non-work destinations
Non-home to non-home trips = non-home to non-home destinations

Transit system accessibility for each purpose of trips was formed and initially checked in the form of scatter diagrams. Figures 11 and 12 provide a good sample of the relationship between transit system accessibility and percent of transit trip generated in each district. (The percent of transit trips in each district is determined on the basis of all trips generated in the district for a given travel purpose, regardless of the land use of origin.)

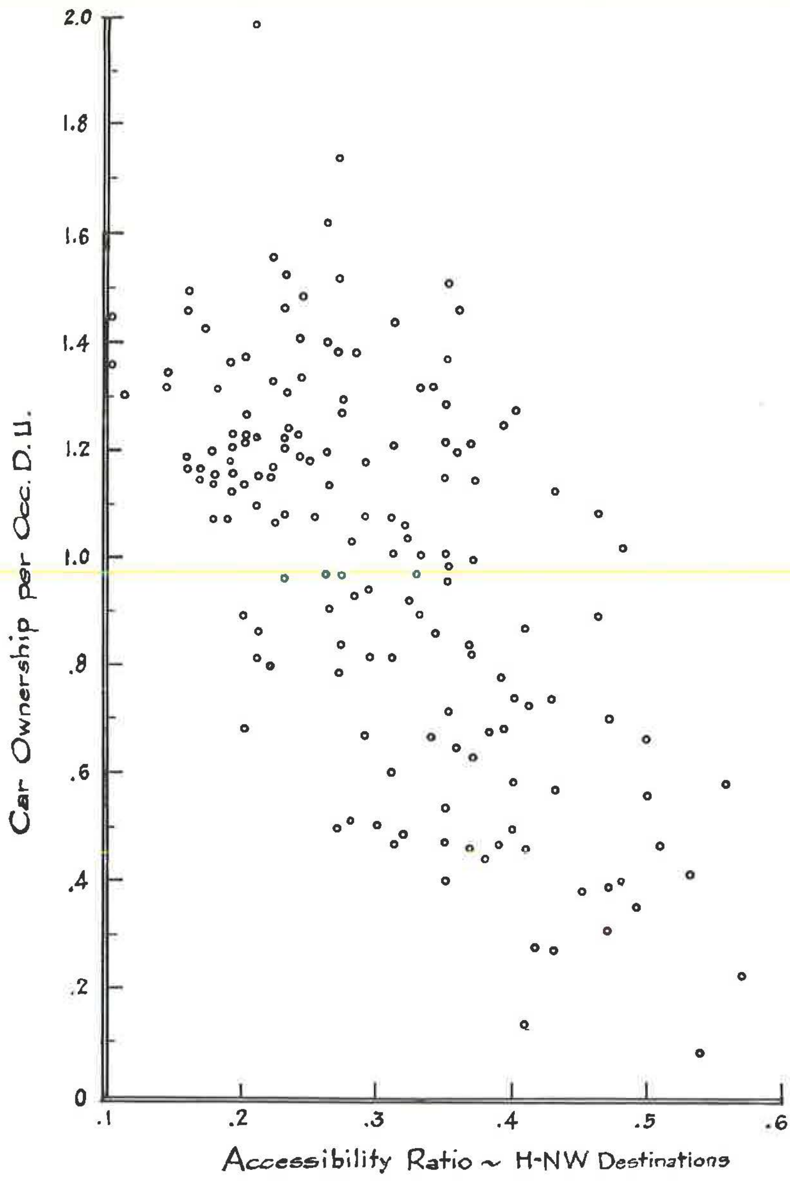


Figure 14. Car ownership rates vs H-NW accessibility ratios.

Another interesting test was an investigation of the relationship between transit system accessibility and mean car ownership rate in the district. Figures 13 and 14 show the results together with a simplified income stratification of each district. The available evidence clearly supports the contention that transit accessibility (or availability) is associated with and to a certain degree influences the rate of car ownership in an area. It was found that the greater the transit accessibility to work and to non-work trip destinations, the smaller the car ownership rate in the district. Correlation analysis between the two variables verified this relationship. The correlation coefficient between car ownership and system accessibility of work trip and non-work trip destinations was correspondingly -0. 65 and -0. 56 which, although not high enough to stand alone, clearly indicates an existing relationship. (Car ownership rates were

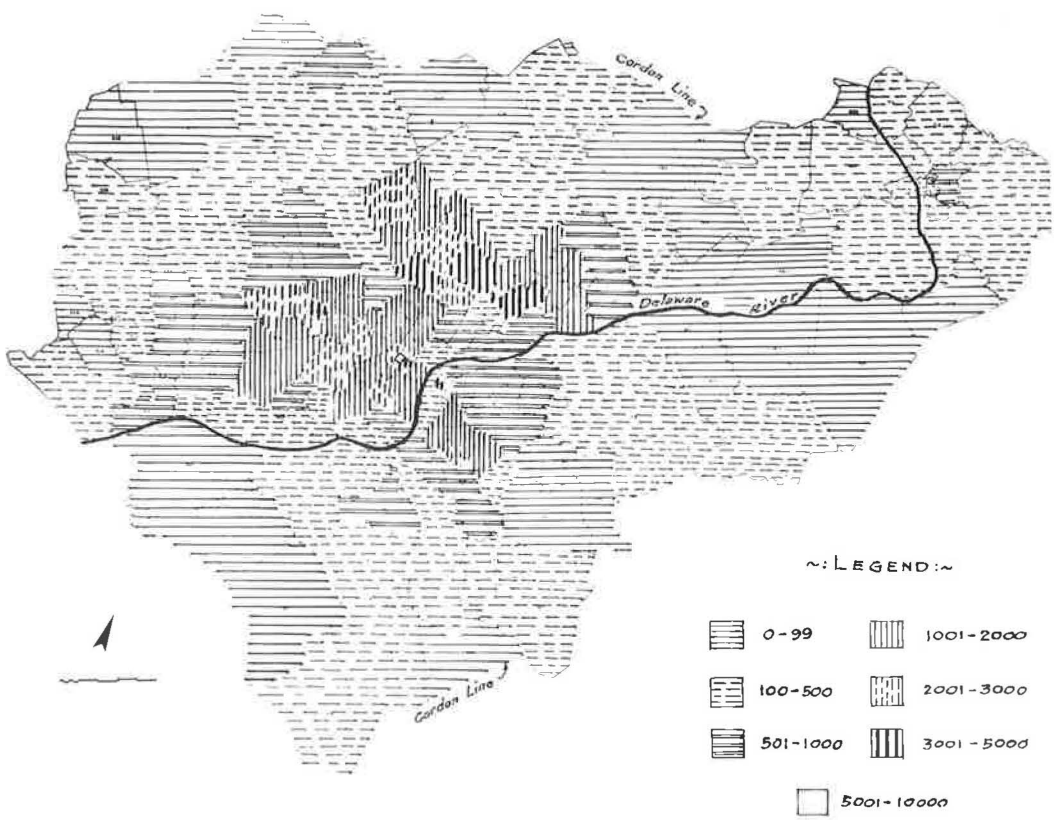


Figure 15. Average daily transit service frequency.

also found to be closely associated with residential density, size of household and, most of all, with median household income. To the extent that the present investigation did not include all these pertinent and possible relationships, the present findings should be considered as conditional and only partially indicative of a direct, causative relationship between transit system accessibility and car ownership rates. Clearly, residential density is also related to transit system accessibility due to the present-day distribution of densities and transit systems in our metropolitan areas.)

A second system variable was also explored to a great extent and was finally incorporated as part of the predictive modal split model. This variable expresses the frequency of transit service available to a district. It is measured in terms of the number of transit vehicle departures occurring in a district within 24 hours, in all transit lines serving the district. Originally a subway train departure was multiplied by the mean number of subway cars in a train. However, this highly overstated the statistical significance of the subway and resulted in substantial overstatement of rates at the simulation tests. Accordingly, a departure in the final form of the model signifies just a departure of a means of transit without indicating whether a bus, a subway train, or a commuter train is involved. Of course, the previously discussed variable of system accessibility already places greater weight on subways and commuter railroads because of the generally higher speeds that these facilities provide. No additional consideration was given (beyond what was warranted statistically) to these systems also because of their various conflicting characteristics. For instance, climbing stairs, limiting the number of stops, concern for public safety, lighting considerations, and fear of missing a particular departure might be considered as balancing out most of the security of finding a seat in a five-car train. What might remain as additional significance can be considered as simply an adjustment of supply to demand without any discernable additional effect of the supply of facilities on the demand for service. Figure 15 shows the distribution of vehicle departures by district in the PJ region.

THE PJ MODEL

The preparatory work based on the 1947 data and on the first two rounds of analysis of the 1960 data was helpful in discovering several consistent, general, and significant relationships between transit trips originating in a district and the various characteristics of the riders and the district. The development of the conceptual framework within which the transportation system serving a district can be considered and the formulation and initial testing of two specific system variables were helpful in making available the basic components with which a more complete modal split model for the PJ region could be formed.

The basic approach in this case can be considered as focusing on two items: (a) that mass transit trips could properly be divided into the five distinctly different trip purposes but need not be divided into trips by type of land use at the origin; and (b) that, where possible, the predictive model should include components which express the rider, the density of development and the transportation system.

The reasoning behind the division of transit trips by purpose is basically a realization that trips made for various purposes are made under different conditions and for various considerations. For instance, work trips have a dominant character which suggests that these trips might have the first choice in the family means of travel. Trips from home to non-work purposes are usually made without strict time schedules and frequently demonstrate preferences for easily obtainable travel means. Trips with no home connections are usually made in the commercial centers of the region and are the shortest trips on record. Therefore, proximity of service might be crucial in selecting the system of travel. Trips from non-work purposes to home are usually made without strict time schedule but by people already in action for some time; therefore, they are made by people who might appreciate proximity of service above other features (such as speed of travel). Finally, trips from the three major central business districts of the region were considered to be of sufficiently particular nature to warrant special but systematic treatment.

In view of these considerations, it was decided that the model should be formed in such a manner that it would be able to depict the individual influences on travel mode selection. Thus the following types of trips and relationships were selected in simulating and projecting the transit trips in the PJ region.

1. Home to Work Trips: to be related with car ownership rates (indicating car availability), with residential density (indicating proximity of transit service), with system accessibility (indicating travel speed and cost difference), and with frequency of transit service.
2. Home to Non-Work Trips: to be related with car ownership rates, residential density, system accessibility, and frequency of transit service.
3. Work to Home Trips: (a) from the Philadelphia, Camden, and Trenton Central Business Districts; (b) from the rest of the region. In both cases trips to be related with total job density (indicating proximity of transit service), system accessibility, and frequency of transit service.
4. Non-Work to Home Trips: (a) from the Philadelphia, Camden, and Trenton Central Business Districts; (b) from the rest of the region. In both cases trips to be related with total job density, system accessibility, and frequency of transit service.
5. Non-Home to Non-Home Trips: These trips are primarily from non-residential areas and especially from the central business districts; to be related with total job density, system accessibility and frequency of transit service.

Before any selection of mathematical relationships could be made, the dependent and independent variables were related in an arithmetic, logarithmic and non-parametric manner. The final relationships were selected on the basis of their overall as well

TABLE 5

MODAL SPLIT MODEL FOR THE DVRPC REGION

(Generation of Transit Trip Origins in Each District Using Transit and Highway System Variables)

Trip Purpose	Equation	Area	R	S	F	1960 Simulation Error	Std. Dev. Y	Mean $\overline{Y}$
H-W	Y_{385} = Percent of person trips made by transit = $0.1626 - 0.4107 \log X_2 + 0.0709 \log X_{55} + 0.0702 \log X_{43} + 0.0001 X_{54}$	Cordon Area	0.902	0.08	149.20	-0.82	0.18	0.26
H-NW	$\log Y_{387} = -2.1544 - 0.7255 \log X_2 + 0.3314 \log X_{55} + 0.2142 \log X_{56} + 0.3058 \log X_{54}$	Cordon Area	0.839	0.20	76.23	-7.19	0.35	0.08
W-H	$\log Y_{397} = -1.6234 + 0.1553 \log X_8 + 2.0913 X_{19}$	CBD Phila., Camden & Trenton	0.914	0.13	28.01	-0.81	0.21	0.43
	$\log Y_{397} = -2.0513 + 0.2285 \log X_8 + 0.5700 X_{19} + 0.3104 \log X_{54}$	Cordon Area	0.864	0.16	109.47	+4.17	0.25	0.19
	$\log Y_{405} = -2.0556 + 0.6244 \log X_8 + 0.6143 X_{24}$	CBD Phila., Camden & Trenton	0.909	0.17	26.18	+8.11	0.25	0.32
NW-H	$\log Y_{45} = -2.3800 + 0.4332 \log X_8 + 0.0371 X_{24} + 0.3198 \log X_{54}$	Cordon Area	0.807	0.21	68.25	+3.50	0.35	0.07
NH-NH	$Y_{342} = -0.0257 + 0.0007 X_8 + 0.1971 X_{67}$	Cordon Area	0.894	0.04	200.17	+4.82	0.09	0.07

X_2 = Total cars per total Occ. D.U.
X_8 = Jobs per non-residential acre.
X_{19} = Accessibility ratio for W-H trips.
X_{24} = Accessibility ratio for NW-H trips.
X_{43} = Accessibility ratio for H-W trips.
X_{54} = Average transit vehicles per day.
X_{55} = Perm. Occ. D.U. per residential acre.
X_{56} = Accessibility ratio for H-NW trips.
X_{67} = Accessibility ratio for NY-NW trips.

TABLE 6

STATISTICAL RESULTS OF VARIABLE TESTING
(Forming the Model Presented in Table 5)

Trip Purpose	Area	Number of Variables	"t" Values				Beta Values			
			Car Ownership	Density	Accessi-bility	Frequency of Service	Car Ownership	Density	Accessi-bility	Frequency of Service
H-W	Cordon Area	Four	6.82	2.59	1.15	6.00	-0.48	0.21	0.07	0.25
H-NW	Cordon Area	Four Re-run	2.94	3.77	1.06	6.15	-0.23	0.35	0.06	0.36
W-H	CBD Phila., Camden & Trenton	Three	—	1.15	2.77	0.11[a]	—	0.25	0.68	0.02[a]
		Two	—	1.26	3.46	—	—	0.25	0.70	—
	Cordon Area	Three	—	5.80	2.22	5.57	—	0.41	0.16	0.39
NW-H	CBD Phila., Camden & Trenton	Three	—	3.23	0.40	0.36[a]	—	0.83	0.06	0.07[a]
		Two	—	3.45	0.53	—	—	0.80	0.12	—
	Cordon Area	Three Re-run	—	8.10	1.15	3.51	—	0.62	0.07	0.24
NH-NH	Cordon Area	Three	—	7.40	4.05	0.07[a]	—	0.69	0.29	-0.01[a]
		Two	—	7.00	4.19	—	—	0.73	0.24	—

[a]Excluded from the final predictive equation.

as particular simulative and projective capability. Table 5 presents the model in its complete form, together with the statistical yardsticks which indicate its level of reliability. Table 6 gives the values of "t" test of the coefficients and the beta weights of the variables.

Several significant observations can be made on the basis of the findings of the model as given in Tables 5 and 6. First, it can be seen that the car ownership variable varies in significance between home to work and home to non-work trips. In the first instance car ownership appears to be the most significant variable, twice as important as density and frequency of service, and seven times as important as transit system accessibility. In the second instance the car ownership variable appears less important than residential density and even less important than frequency of transit service. Transit system accessibility is again the least important variable for this type of trip.

Second, it can be observed that the residential density or the density of total jobs have a varying degree of significance for the various travel purposes. For instance, one can notice that job density is most closely associated with NW-H trips from the three CBDs of the region, and next with NH-NH trips from the entire region. It appears that proximity to transit lines (which is the essential connotation of the density of development variable) is the primary factor in transit trip production in these two cases. Job density is next found to be closely associated with NW-H trips from the rest of the region and with W-H trips from the non-CBD part of the region. Surprisingly, the model reveals that job density (proximity of transit lines) is least significant for the work to home trips from the three CBDs for which trips transit system accessibility (or the implied speed of transit lines) appears the first and foremost factor. With regard to residential density, it appears that the variable is more important for home to non-work trips than for home to work trips, indicating once more that proximity of service or convenience of using the transit facility is much more important for non-work trips than work trips.

Third, the significance of system accessibility is shown to be different for each type of trip, in absolute and relative measures. For H-W and H-NW trips the absolute contribution of the system accessibility is rather small. Clearly the speed of the transit system has a very small association with the number of H-W or H-NW trips made by transit. For W-H from the three CBD trips, the situation is reversed. It appears that people going home from work and from a CBD area place special emphasis on a fast transit system. This is shown clearly by the beta values and the "t" test of the coefficients. For W-H trips from non-CBD origins, however, the significance of the system accessibility variable is much smaller than either the job density or the frequency of transit service variable. For NW-H trips from the three CBDs of the region or for the same trips originating from the rest of the region, the system accessibility variable is found also to be little associated with the rate of transit trips. Finally, for NH-NH trips, the system accessibility (or speed and cost of transit system) emerges also as a relatively important factor as evidenced by both the pertinent statistical yardsticks.

Fourth, it can be seen that the significance of the frequency of transit service variable is most important for W-H trips from the non-CBD part of the region. For this type of trip the frequency of transit service appears as significant as the job density variable. Next in significance is the contribution of frequency of transit service for the H-NW trips from the region for which frequency of service is at least as important as the residential density variable and of considerably greater importance than the other two variables. Third in line comes the contribution of the frequency of transit service for NW-H and then for H-W trips from the entire region.

It is of interest to notice in the examination of the contribution of each variable that the significance of each variable shifts from case to case and varies both absolutely and relatively. This type of situation suggests that aggregation of trip types can obviously cause significant disparities in simulation and unsatisfactory projections. One might speculate that inappropriate aggregations of trip types in the past could have been, on occasion, the root of controversies in this subject and could have contributed to the unsatisfactory performance of several modal split models developed in the past.

Table 6 also gives the results of the "t" test of the coefficients of each variable for each trip type. For H-W and H-NW trips three variables are above the 1 percent level of significance while the accessibility is significant only at the 25 percent level. For W-H trips from the cordon area, all three variables are found to be above the 1 percent level of significance. For W-H trips from the three CBDs, the frequency of service variable is found to be statistically below any acceptable level of significance and therefore is eliminated. For NW-H trips from the three CBDs the same variable is also found to be statistically below acceptable levels of significance and therefore is also eliminated. For this type of trip the accessibility variable is found to be at a very low level of significance but it has been retained as a variable because it is three times as significant as the frequency of service variable and because of the desire to avoid simple correlations with only one variable. For the NW-H trips from the cordon area, the two variables are above the 1 percent level of significance while the accessibility variable reaches only the 25 percent level of significance. Finally, for the NH-NH trips the frequency of service variable is found to be statistically insignificant (and therefore is eliminated) while the other two variables are above the 1 percent level of significance.

In a more direct form, the model indicates clearly that for H-W trips the car ownership rate, the frequency of transit service, and the density variables play the primary role in that order. For H-NW trips the emphasis is shifted to density and frequency of transit service as primary variables, followed by the car ownership rate variable. For W-H and NW-H trips from the entire region, of primary importance is the job density and frequency of transit service (especially for W-H trips). For NH-NH trips, of primary importance by far is job density followed by system accessibility. For this type of trip as well as for W-H and NW-H trips starting from the three CBDs of the region, the frequency of transit service plays an extremely minute role, if any. Perhaps it should be repeated here that for W-H trips from the three CBDs, the most important variable is by far the system accessibility (indicating, perhaps, the desire of workers to get home as fast as possible) while for NW-H trips from the three CBDs of the region, the most important variable proves to be the job density by a large margin (indicating, perhaps, the desire of close-by, convenient transit lines for this type of trip).

In conclusion, according to PJ findings, transit H-W trips depend primarily on car availability and then on frequency of service; transit H-NW trips depend primarily on proximity of transit line and then on frequency of transit service; transit W-H trips depend primarily on proximity of service and then on frequency of service when these trips originate from non-CBD parts of the region but they depend primarily on travel speed and cost when the same trips originate in the three CBDs of the region; transit NW-H trips depend primarily on proximity of service and then on frequency of service when these trips originate in non-CBD parts of the region but they depend almost exclusively on proximity of service when they originate in the three CBDs of the region; finally, transit NW-NH trips depend primarily on proximity of service and then on travel speed and cost.

SIMULATION OF 1960 TRAVEL PATTERN

The tests of the quality of the model took several forms. The first and most generalized measures of accuracy in the simulation process were the generally used statistical yardsticks of correlation analysis. As seen in Table 5, the correlation coefficients of the equations varied from 0. 807 for non-work to home trips to 0. 914 for work to home trips from the three CBDs of the region. The standard error of estimate of the equations varied from 4. 3 percent to 21 percent of the mean values of NH-NH and NW-H trips, respectively. The F statistic is also significant in all cases and the values of betas and of the "t" test verify the contribution and the significance of each variable taken into account. Obviously, statistical stability of the coefficients of the equations may also be expected for projection purposes.

Additional tests of accuracy of simulation were carried out by purpose of travel, sector of trip origin and total trips in the region. In terms of trips by purpose (Table 7),

TABLE 7

COMPARISON OF SIMULATION RESULTS OF 1960 O-D TRANSIT TRIPS
(By Purpose of Travel)

Category	H-W		H-NW		W-H		NW-H		NH-NH		Total	
	Trips	Percent Diff.	Trips	Percent Diff.	Trips	Percent Diff.	Trips	Percent Diff.	Trips	Percent Diff.	Trips	Percent Diff.
Actual 1960	336, 278	—	265, 489	—	323, 252	—	261, 582	—	86, 821	—	1, 273, 422	—
Original simulation	277, 709	-17. 42 (-7. 5)	246, 462	-7. 17 (-1. 0)	315, 372	-2. 44 (-1. 1)	205, 730	-21. 35 (-2. 9)	99, 086	+14. 13 (+0. 8)	1, 144, 359	-10. 14 (-1. 9)
Model simulation with accessibility	326, 199	-3. 00	234, 078	-11. 83	359, 947	+11. 35	216, 314	-17. 31	100, 763	+16. 06	1, 237, 301	-2. 84
Model simulation with accessibility plus frequency of service[a]	333, 532	-0. 82	246, 391	-7. 19	336, 726	+4. 17	270, 733	+3. 50	100, 763	+16. 06	1, 288, 145	+1. 16

[a]The numbers reported in this line represent the simulation of all the transit trips in the region, by individual purpose. The specific simulation errors of the equation corresponding to only the districts included in the equations vary slightly from the above and are correspondingly -0.82, -7.19, +4.17, +3.50 and +16.06.

Note: Percent estimates within parentheses represent the simulation error of the trips expressed on the basis of auto trips in each trip purpose.

the results indicate that for total home to work trips the simulation produces less than 1 percent overall error. Non-work to home trips from the region present the greatest difficulty in simulation with an overall simulation error of the districts forming the equation of -11. 25 percent. However, when the simulation is expanded to cover the entire region, the simulation error is reduced to only +3. 50 percent. The reverse is observed with regard to the NH-NH trips, for which the districts of the equation produce only 4. 82 percent simulation error, but when the equation is expanded to cover the whole region, the simulation error rises to 16 percent of actual total trips.

In order to ascertain the degree of simulation of the various parts of the region, the total area was divided into 12 sectors (Fig. 16). Six of these sectors include the Philadelphia area, three sectors include the Pennsylvania suburbs and three sectors include the New Jersey areas. The results are shown in Table 8. One can notice that individual sectors frequently have simulation errors well above the overall simulation error of the five trip purposes combined. The difficulty in achieving higher accuracy by each individual sector is manifest in all modal split models attempted in this as well as in other studies. If uniformity, consistency, and theoretical foundation is to be retained in a modal split model, individual differences by areas are bound to be greater than the overall simulation discrepancies in any trip purpose. In our case the differences frequently counterbalance each other by purpose of trips and by sector in the same vicinity. In most cases they are also well within acceptable design limits in terms of volume of trips or percent error, or both. The remaining few rather large differences are found in sectors with small volumes in 1960 and low sample accuracy. Finally, in terms of the overall simulation error for all trip purposes and the entire region, the discrepancy is found to be less than 2 percent of the actual number of trips.

Tables 7 and 8 also give the results of the two previous simulation efforts of mass transit trips. The original simulation presents the results of the transit trips as

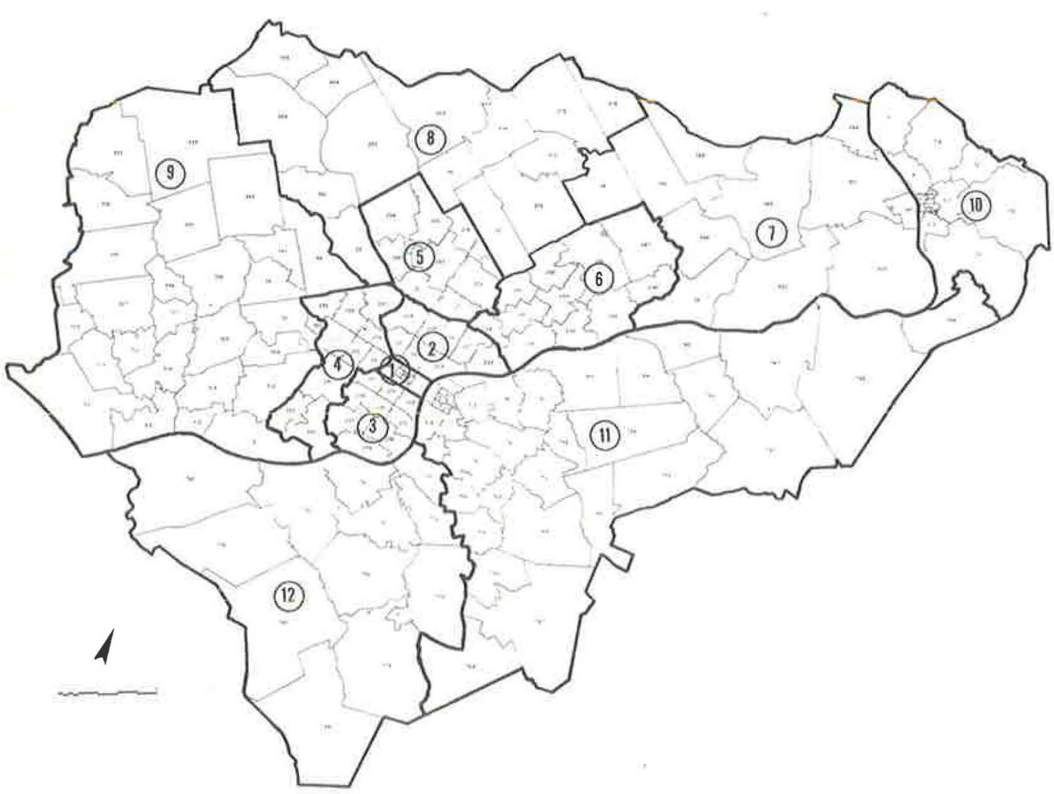


Figure 16. Twelve sectors for modal split tests.

TABLE 8

COMPARISON OF SIMULATION RESULTS OF 1960 O-D TRANSIT TRIPS
(On Basis of 12 Sectors)

Sector	1960 Actual Trips	Originally Simulated		Model Simulation With Accessibility		Model Simulation With Accessibility and Frequency	
		Trips	Percent Diff.	Trips	Percent Diff.	Trips	Percent Diff.
1	229,689	207,342	-9.73	227,280	-1.05	232,412	+1.19
2	221,076	185,688	-16.01	193,062	-12.67	212,629	-3.82
3	98,820	91,843	-7.06	90,139	-8.78	100,689	+1.89
4	180,847	129,430	-28.43	160,296	-11.36	179,867	-0.54
5	165,159	114,993	-32.02	126,193	-25.40	148,210	-12.38
6	111,466	88,602	-20.51	92,486	-17.03	98,030	-12.05
7	9,059	21,429	+136.55	14,523	+60.32	10,384	+14.63
8	38,425	48,883	+27.22	49,374	+28.49	44,393	+15.53
9	104,010	102,142	-1.80	123,785	+19.01	120,953	+16.29
10	24,834	53,661	+116.08	60,305	+142.83	41,516	+67.17
11	71,510	82,223	+14.98	81,933	+14.58	81,185	+13.53
12	14,527	18,123	+24.75	17,925	+23.39	17,877	+23.06
Total	1,273,422	1,144,359	-10.14	1,237,301	-2.84	1,288,145	+1.16

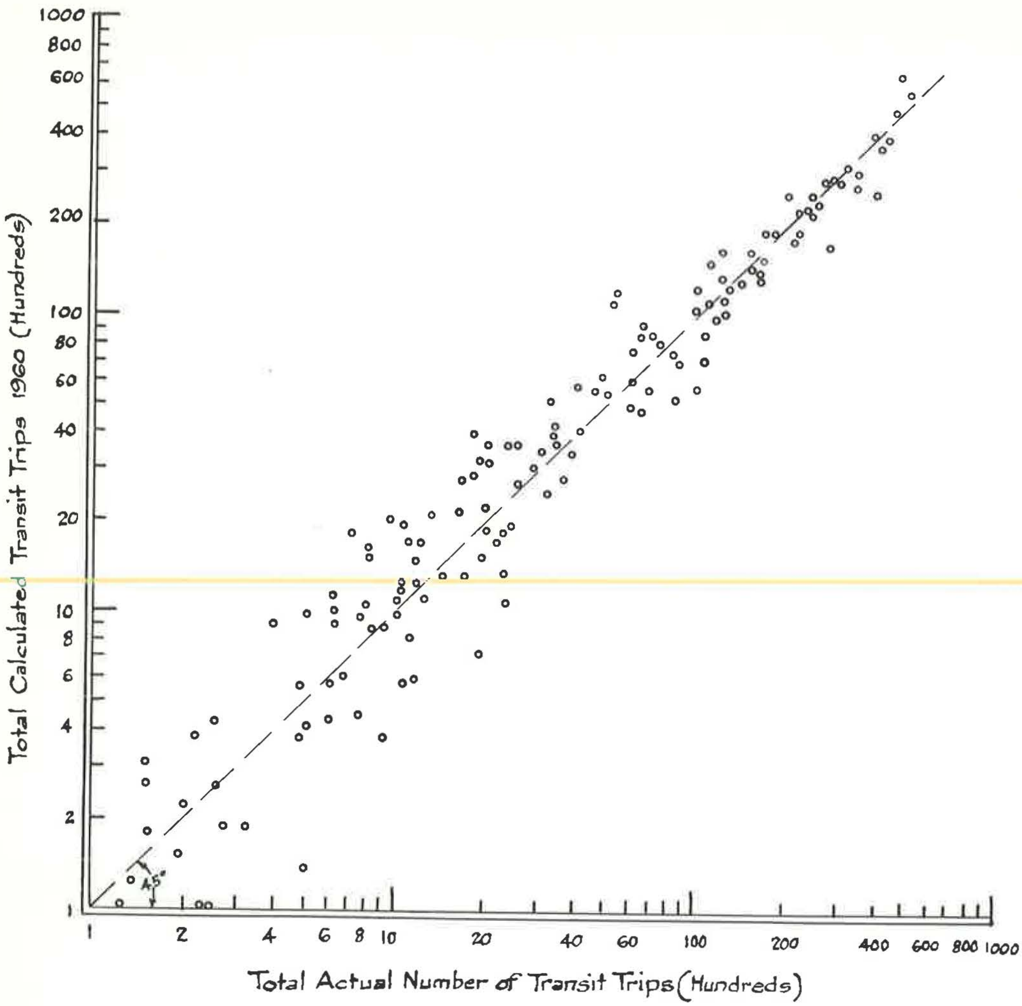
produced by subtracting auto trips from total person trips. The second effort presents the results of the modal split model without the use of the frequency of service variable. The comparison points out the improvements of the completed model in terms of total trips, trips by purpose, and trips in each of the twelve test sectors. The final results by sector, for all trip purposes combined, indicate that the model reaches an acceptable level of simulation even though it is not capable of producing results always below the 5 percent level of accuracy which is usually the acceptable error in simulation of other parts of the travel demand analysis. Trips by each individual district are frequently, of course, found to carry much greater simulation error. However, even in these cases, when trips from all trip purposes are taken together, the total simulation error decreases in most cases to very reasonable levels. Figure 17 shows the satisfactory degree of the simulation discrepancies on the district level.

ALTERNATIVE TRANSIT TRIP PROJECTIONS FOR 1975

The satisfactory simulation of the 1960 travel pattern on the basis of a set of general principles and consistent mathematical relationships made possible the projection of the 1975 transit travel pattern in the PJTS area on the same basis.

The projection process usually starts by projecting the independent variables which enter in the projection model. In our case the independent variables were five: car ownership rate for each district in the region, to be used with H-W and H-NW trips; residential density in each district, to be used with H-W and H-NW transit trips; system accessibility, to be individually projected for each district and for each transit trip purpose and combination of highway and transit system; transit service frequency, to be projected for each district and for each of the three transit alternative plans and to be uniformly used with all five transit trip types; and total job density for each district, to be used with W-H, NW-H and NH-NH trips.

Car ownership rates for each district in the region were projected on the basis of the relationships developed for 1960 and using a projection of average family income, residential net density and size of households. Although at a later stage of analysis a relationship was found between the rate of cars per household and transit system accessibility of a district, no such relationship was put to use in the projection of car



Figrue 17. Total calculated vs total actual transit trips on district-to-district basis.

ownership rates for the 1975 plans. Also, due to the rather short period of time between 1960 and 1975, the problem of car ownership saturation rates did not emerge to any significant extent.

Residential net density in each district was projected on the basis of trend extension and consideration of the growth patterns evidenced in the various parts of the region. In general, a slight reduction of density in the densely developed residential parts of the region and a moderate increase of residential net density in the largely undeveloped parts of the region were frequently projected.

The system accessibility for each of the five travel purposes was estimated using 1975 person trip destinations (by trip purpose) in each district and a pair of the proposed highway and transit systems. The estimations were completed for three combinations of system—the minimum highway and maximum transit systems (system 82), and the maximum highway and the minimum transit systems (system 83-A). Figures 18 to 22 present the overall trends of system accessibility for each trip purpose and according to a classification of the districts on the basis of their distance from the Philadelphia CBD. It is of special interest to notice that for all five trip purposes the system accessibility results essentially in substantial gains of accessibility for those

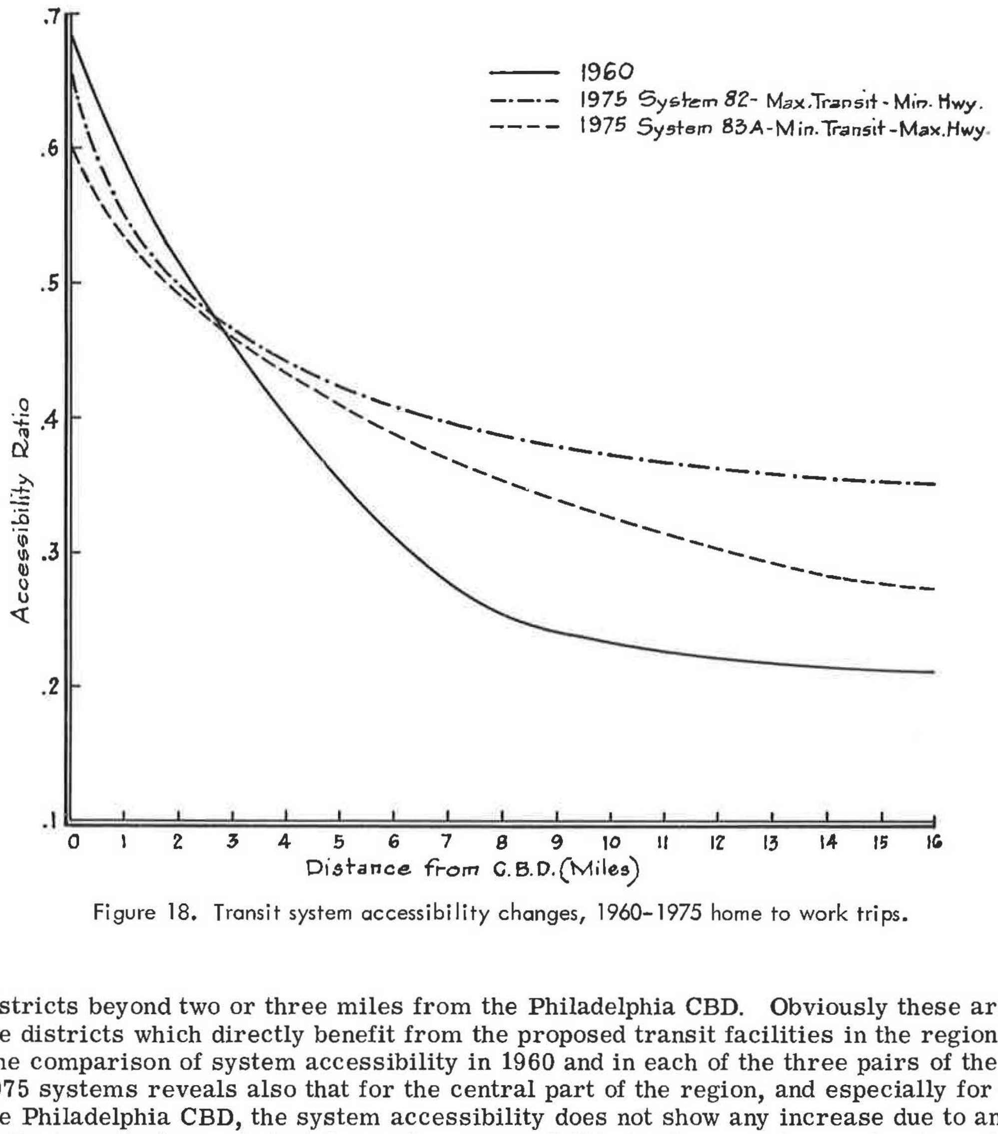


Figure 18. Transit system accessibility changes, 1960-1975 home to work trips.

districts beyond two or three miles from the Philadelphia CBD. Obviously these are the districts which directly benefit from the proposed transit facilities in the region. The comparison of system accessibility in 1960 and in each of the three pairs of the 1975 systems reveals also that for the central part of the region, and especially for the Philadelphia CBD, the system accessibility does not show any increase due to any of the transit plans. In fact the system accessibility is shown as decreasing from 3 to 10 percent for the various travel purposes.

The projection of the frequency of transit service followed a uniform approach by accepting a policy determination that in 1975 the maximum transit plan will include a 25 percent increase in the frequency of service, uniformly experienced in all major lines of the region. For the minimum plan the present-day frequency of transit service was accepted in each line. New lines will have a frequency of service comparable to similar lines of today. For special districts, in which particular developments were expected, the frequency of service was projected accordingly.

Total job density for 1975 was accepted to be essentially similar to that prevailing in 1960. Special districts, where particular policy considerations or developmental plans were in existence or expected, were adjusted accordingly. For the rest of the region the projected effective job density was accepted as primarily determined by the dominating density of present development in each district.

On the basis of these projected variables, the 1975 alternative transit trip projections for the entire region were carried out for two pairs of systems, the system with

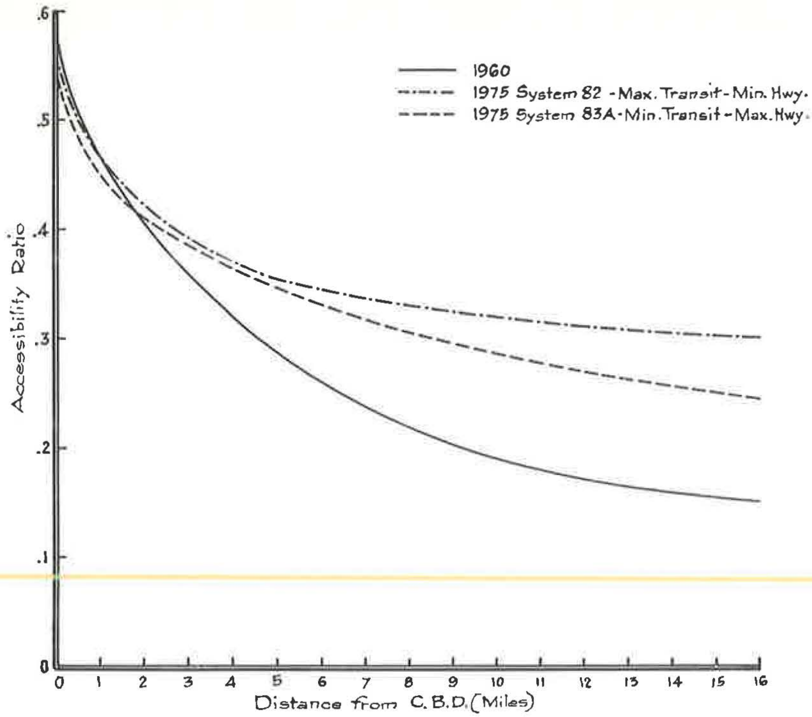


Figure 19. Transit system accessibility changes, 1960–1975 home to non-work trips.

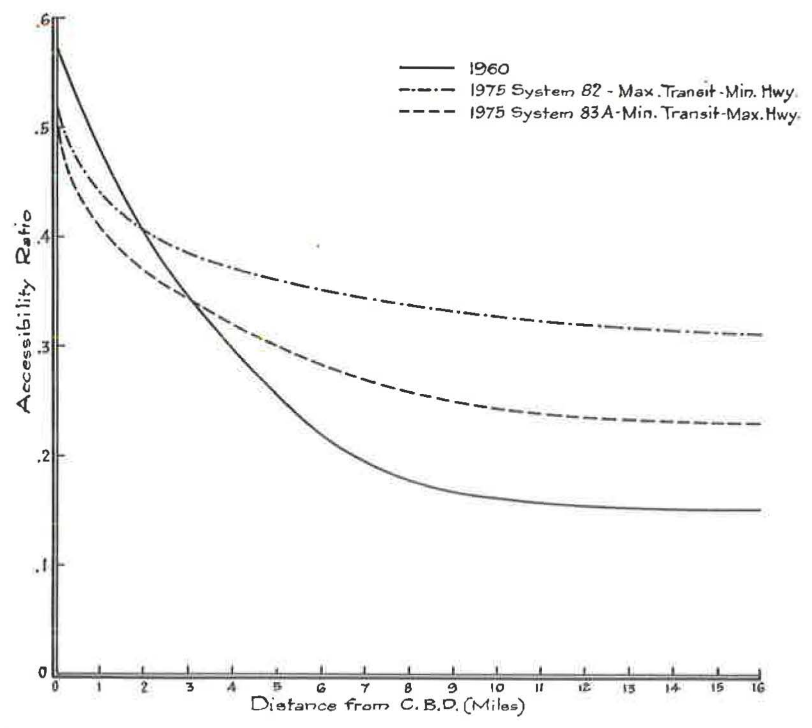


Figure 20. Transit system accessibility changes, 1960–1975 work to home trips.

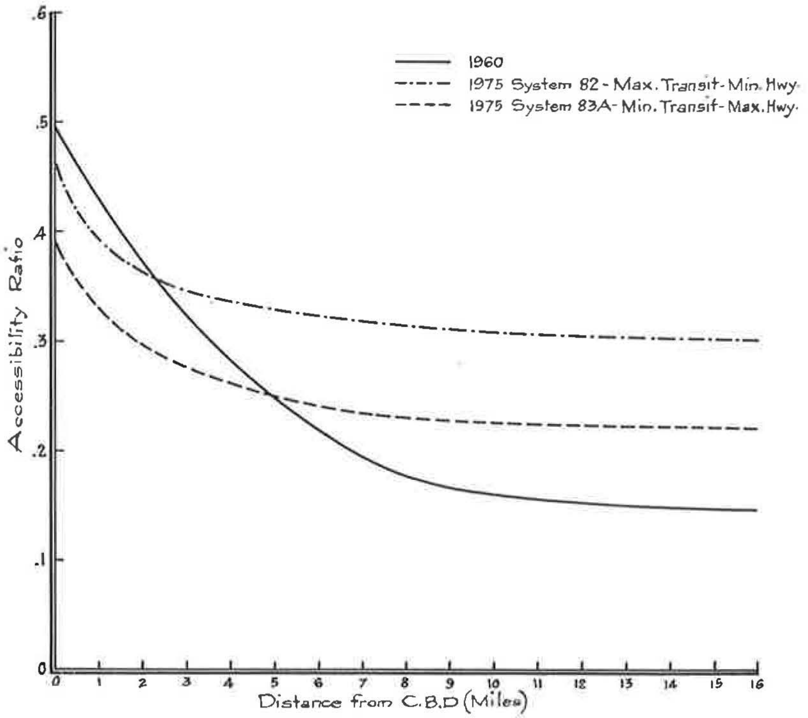


Figure 21. Transit system accessibility changes, 1960-1975 non-work to home trips.

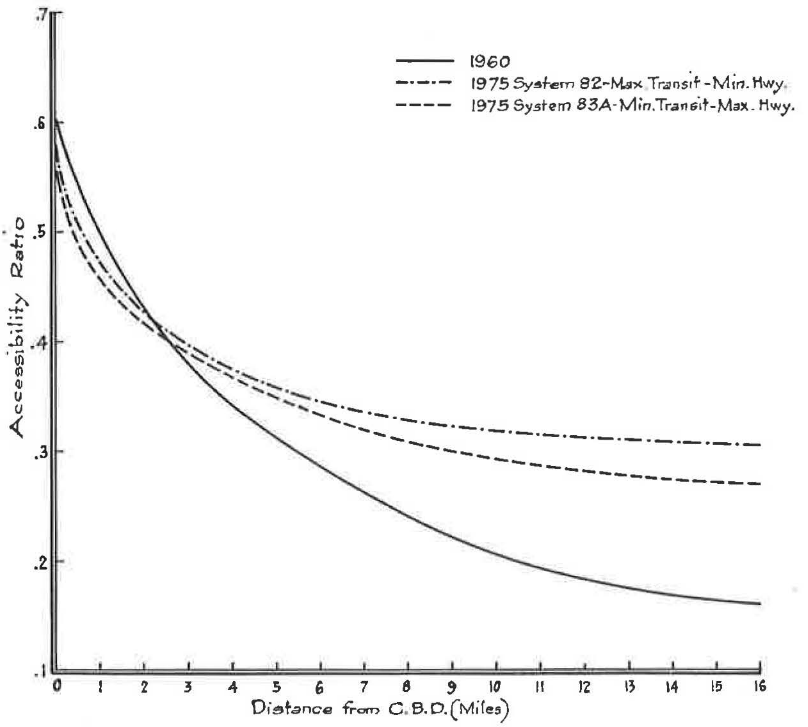


Figure 22. Transit system accessibility changes, 1960-1975 non-home to non-home trips.

TABLE 9

ALTERNATIVE TRANSIT TRIP PROJECTIONS, 1975
(By Trip Purpose)

System	H-W		N-NW		W-H		NW-H		NH-NH[a]		Total	
	Trips	Percent Change From 1960	Trips	Percent Change From 1960	Trips	Percent Change From 1960	Trips	Percent Change From 1960	Trips	Percent Change From 1960	Trips	Percent Change From 1960
Actual 1960	336,278	—	265,489	—	323,252	—	261,582	—	86,821	—	1,273,422	—
Original 1975 projection	360,925	+7.33	197,811	-25.49	360,737	+11.60	252,962	-3.30	121,928	+40.44	1,294,363	+1.64
Model projection (system 83-A)	339,018	+0.81	322,852	+21.65	342,378	+5.92	330,750	+26.44	162,486	+87.15	1,497,484	+17.60
Model projection (system 82)	357,349	+6.27	328,447	+23.71	363,016	+12.30	339,225	+29.68	175,996	+102.71	1,564,033	+22.82

[a]Excluding L.U. O for NH-NH.

TABLE 10

ALTERNATIVE TOTAL TRANSIT TRIPS PROJECTIONS, 1975
(By Sector)

Sector	1960[a] Trips	Original 1975 Projection		Model Projection			
				System 82		System 83-A	
		Trips	Percent Growth 1960-1975	Trips	Percent Growth 1960-1975	Trips	Percent Growth 1960-1975
1	229,689	272,974	+18.85	249,450	+8.60	232,915	+1.40
2	221,076	164,805	-25.45	254,791	+15.25	245,602	+11.09
3	98,820	75,936	-23.16	117,033	+18.43	115,492	+16.87
4	180,847	140,181	-22.49	214,656	+18.69	209,098	+15.62
5	169,159	120,315	-28.87	183,296	+8.36	177,686	+5.04
6	111,466	104,611	-6.15	128,436	+15.22	122,220	+9.65
7	9,059	20,713	+128.65	21,889	+141.63	21,495	+137.28
8	38,425	73,012	+90.01	59,354	+54.47	57,329	+49.20
9	104,010	135,305	+30.09	149,147	+43.40	143,790	+38.25
10	24,834	61,933	+149.39	40,732	+64.02	40,069	+61.35
11	71,510	97,623	+36.52	116,414	+62.79	107,518	+50.35
12	14,527	26,955	+85.55	28,835	+98.49	24,270	+67.07
Total	1,273,422	1,294,363	+1.64	1,564,033	+22.82	1,497,484	+17.60

[a]Excluding L.U. 0 for NH-NH.

TABLE 11

PROJECTION OF TOTAL TRANSIT TRIPS, 5 PURPOSES
(By Area of Dominant Transit Line Influence)

Area Served by Subsystem	1960 Total Transit Trips	Total Transit Trips, 1975		
		Original Projection	Model Projection for System 82	Model Projection for System 83-A
Philadelphia CBD	229,689	272,974	249,450	232,915
Camden CBD	19,632	17,462	24,717	22,691
Trenton CBD	6,867	13,670	8,204	8,132
Area of Market Street Subway[a]	374,499	393,369	431,517	406,948
Area of Frankford Extension[a]	415,135	434,210	466,652	440,343
Area of Jenkintown Extension[a]	458,841	430,098	497,126	472,561
Area of Northeast Max. Plan	466,723	443,445	528,420	505,434
Area of Northeast Min. Plan[a]	519,631	484,801	586,528	560,419
Area of Broad Street Subway[a]	444,096	420,234	498,717	477,528
Area of Kirkwood Line[a]	51,038	62,479	74,893	70,556
Area of Woodbury Line[a]	45,741	51,741	63,295	56,135
Area of Moorestown Line[a]	34,638	39,629	49,468	43,768

[a]Several districts are taken into account for more than one line.

minimum highway and maximum transit investment and the system with maximum highway and minimum transit investment (systems 83-A and 82).

The results of these projections are given in Tables 9, 10, and 11. In all three tables a comparison is made among the 1960 actual trip estimates, the projections carried out with the original and simplified modal split procedure, and the two 1975 trip projections using systems 82 and 83-A.

Table 9 gives the results on a region basis for each of the five travel purposes, and for total transit trips. In all cases it becomes clear that significantly different transit trip projections are derived. The contribution of each system on transit trip production becomes evident for each travel purpose. Differences in this contribution are also apparent. Clearly, H-NW and NW-H trips appear to be the most sensitive to transit system improvements. Also NH-NH trips appear to be the type of trips with the greatest percent increase due to transit system improvements and to job increases in the region.

Table 10 gives the results on a sector-to-sector basis for all five trip purposes. Examination of this table reveals that the transit trip growth is expected to vary greatly by sector. According to the 1960 relationships and the projections of the independent variables, the greatest need and use for the mass transit system exist (or will be) in the suburban areas of the PJTS region. Whereas the City of Philadelphia demonstrates as a whole a stability or a relative inelasticity in the transit trip demand, the suburban area indicates a capacity to double or triple the present-day transit trips, if appropriate transit improvements are established there. Table 10 also shows that the difference of transit trips by sector between the two alternative projections has a relative consistency in terms of the area and the magnitude of trip changes. Clearly, a change in the transit system does not produce radical results in individual sectors—only incremental changes, positive or negative, are registered in each sector, although particular small districts within the sector may register a far greater rate of change than their sector as a whole.

Table 11 presents the results on a line-by-line basis. Each proposed line of system 82 or 83-A has been assumed to affect a number of individual and neighboring districts. The changes in the number of trips in each of these districts were taken into account in establishing the potential changes which each line might serve and/or induce. Note again that the significant changes occur mostly in the lines which serve suburban areas of the region. Of interest also is the substantial increase of transit trips appearing within the CBD of the City of Camden, which is expected to be the convergence point of three new transit lines from Philadelphia to the New Jersey areas.

All three tables also present a comparison of trip estimates reached on the basis of the original method. The comparison indicates clearly that the total understatement of trips in the region as well as the biased estimation of trips in the central area of the region and of its suburbs was clearly carried on to the projection phase of the work. The produced total understatements and consistence biases are especially evident for the City of Philadelphia. The differences between this set of projections and the ones achieved with the completed model of modal split are apparent by purpose of trips, by sector of trip origin and, of course, at the estimation of total trips. In all cases the previous imperfections have been eliminated.

An interesting aspect of this modal split model and its application for projection purposes is the fact that the basic form of the model indicates clearly that the relationships are addressed exclusively to the forces which affect the transit trip generation of each trip purpose. Nothing compels each set of relationships to produce estimates of one type of transit trip origins in the region equal to estimates of any other type of transit trip origins in the region. Accordingly, the use of this model for projection purposes would clearly produce estimates responsive to the various changes of the pertinent variables but also estimates which might or might not be in any type of equilibrium. For instance, home origin transit trip projections would reflect trip estimates according to the effects which changes in car ownership, residential density and job accessibility would have on home origin transit trips. In contrast to this, projections of W-H and NW-H trip estimates would reflect the effect which changes in job density and home accessibility would have on non-home origin transit trips. These effects might very well not be coincidental or, in other cases, conflicting; e.g., increases of car ownership would clearly tend to decrease home origin transit trips while increases of job density would tend to increase the non-home transit trip origins. The result in arithmetic terms would be that the projected estimates of H-W and H-NW transit trips would be lower than the projected estimates of W-H and NW-H transit trips. In reality the total number of transit trips from and to home will be the result of the combined influence of conditions at home as well as at the non-home trip origin. In essence, therefore, the average influence of the forces affecting the transit trip at its origin and destination should be taken into account when projections of this type of trip are undertaken. This approach is followed in our 1975 estimates in producing the final transit trip projections for the region.

CONCLUSIONS

The completion of this phase of the modal split model in the PJTS area makes possible the derivation of several conclusions of direct relevance to this study and perhaps to other similar efforts. Among them the following six should be stressed.

1. The selection of five transit trip types to be analyzed, simulated, and projected has produced satisfactory and reasonably reliable results. In essence this classification of trips reveals that other types of transit trips, formed on the basis of land use types at the origin or destination of trips, might not be necessary and that a classification of trips on the basis of the purpose of travel is both feasible and revealing of the different factors which influence transit trip generation. In our case the classification of trips into home origin and non-home origin, and into work and non-work trips proved to be of direct significance in achieving high correlations, low simulation errors, and reasonable projections.

2. The modal split model incorporates simultaneously one variable descriptive of the rider, another variable descriptive of the area of trip origination, and two variables directly descriptive of the systems serving the area and the region. The simultaneous incorporation of the effect of these variables is considered of significance and contributes to the reliability and accuracy of transit trip projections in the region. Of special significance is the incorporation of system variables to those non-system ones. The simultaneous incorporation of variables diminishes the significance of the question of whether one or another factor affects transit trip generation in advance of the other variables and at the same time increases the level of confidence of the resulting equations by permitting a greater number of observations to form the statistical basis of the formation of the predictive equations.

3. The system variables selected for this modal split model are essentially three. The first one is the implied density (or proximity) of transit lines in a measure of residential or job density in a district. On the basis of present-day experience, this implied association by density of development and density of transit lines is clearly justifiable. Transit lines are indeed more numerous and more frequent in areas with higher developmental density than in areas with low developmental density. The second system variable is the system accessibility, as previously defined. This variable combines three different features of the highway and transit system in addition to two area features. It combines the physical existence of a facility, as well as the travel speed and the associated costs (tolls, fares, etc.) for each highway and transit system. The area features it combines are the amount of relevant destinations included in each district within the metropolitan complex. The third system variable is the frequency of transit service which is descriptive of the availability of transit service in a district. This variable permits the recognition of the difference between a line with a few vehicles serving a district and another line with frequent and extensive service serving another district.

The need or desirability of incorporating additional system variables in a modal split model has frequently been pointed out in the literature. Although such need or desirability is generally recognized, the actual incorporation of variables expressing comfort or convenience has not been possible in the present modal split model. It appears that it would require, first, an objective, quantitative and meaningful definition of the concepts of comfort and convenience before their effective incorporation can be achieved. Additionally, data from "before" and "after" actual experiments will be required before detailed conclusions can be formed with regard to the extent of influence such variables may have on travel mode selection.

4. Closely related with the previous observations is the finding that each of the five trip purposes indicates a particular dependence on only one or two of the five variables incorporated in the model. Thus, if one desires to associate each of the five trip purposes with the one or two most important variables in explaining the district-to-

district transit trip variation, one can cite the following major associations: H-W transit trips with car ownership and frequency of transit service; H-NW transit trips with frequency of transit service and proximity of transit service (density variable); W-H and NW-H transit trips from the region at large with proximity of transit service (density variable) and frequency of transit service; NH-NH transit trips with proximity of transit service (density variable) and transit system accessibility; W-H transit trips from the CBDs of the region with transit system accessibility and proximity of transit service (density variable); and, finally, NW-H transit trips from the CBDs of the region with proximity of transit service (density variable). Implicit in these findings appears to be an understanding that any major change in each of the variables will have its most direct effect on the type of transit trip with which the variable is most closely associated. Of course, changes of transit trips at any future date will also have to be associated with changes in the variables which are directly associated with the complementary type of each transit trip purpose.

5. The verified relationships between transit trips and car ownership, density of development, and system variables open new possibilities for policy consideration in planning future transportation systems in an urban area. The formulation and testing of alternative transportation systems thus takes on additional meaning. Variations in the extent of facilities in the transit or highway system, variation in highway speeds, highway tolls, and transit fares, or variations in the frequency of transit service in each line can be directly reflected in the projection of transit trips produced in a region, just as planned or expected changes in the future car ownership rate and in the residential or job density in the various districts of a region can be directly incorporated in the projection process of transit trips in the region.

6. Another significant observation is in regard to the sensitivity and range of applicability of this model. Examination of the equations and of the means of deriving accessibility measures indicates that individual changes of each variable have limited impact on the final results. The projection of two transit trip estimations on the basis of a common land use plan but with two distinctly different transportation systems presents a good indication of the sensitivity of the model to various sets of transportation facilities. The two system variables, which respond directly to system variations, have produced most of the differences observed between original projections and final projections, as well as all of the differences between systems 82 and 83-A. Clearly, a transportation system should include substantial changes before any real effect on transit rates would become significant. The model itself also has a restrictive characteristic on the effect of any of the variables. It is apparent that although the model is directly responsive to variations in the transportation system and density of development, these variations should be of significant magnitude and extent before any appreciable impact will register in the number of transit trips produced in the particular sector(s) and in the region in general. Thus, individual facilities can seldom be expected to produce changes of the required magnitude and therefore such facilities could seldom be expected to register any region-wide effect, beyond the effect on a few districts through which they might pass and thus serve directly.

Finally, it should be pointed out that the flexibility acquired with the modal split process should not foster unreasonable application of the model. Although the relationship between each variable and the transit trip rate is already conditioned by the parameters of the predictive equations, there is still need for cautious application of the model within reasonable limits of change of each variable. It would be, for instance, an unreasonable application of the model if a multiple increase of each variable were assumed for the sake of experimentation and a corresponding increase of transit trips were expected. Incremental increases or decreases of present rates should be considered as the proper objective of the modal split model. Radical changes in the travel patterns and preferences in urban regions, as well as in the transportation systems, are not usually subject to the predictive capacity of one or of a handful of variables derived and correlated within the present-day set of circumstance. No predictive model based on manifest present-day behavior and on existing trends and circumstances should be expected to project radical changes or to anticipate any fundamental reversal of preferences and situations.

REFERENCES

1. Campbell, E. M. Transportation Quality: Research Challenge and Promise. Traffic Quarterly, pp. 395-407, July 1963.
2. Claffey, P. J. User Criteria for Transit Planning. Jour. Urban Planning and Develop. Div., Proc. ASCE, p. 4029, Sept. 1964.
3. Moses, L. N. Economics of Consumer Choice in Urban Transportation. The Dynamics of Urban Transportation National Symposium, Oct. 1962.
4. A Model for Estimating Travel Mode Usage in Washington, D. C. Traffic Research Corp., 1962.
5. Hill, D. M., and Von Cube, H. G. Development of a Model for Forecasting Travel Mode Choice in Urban Areas. Highway Research Record 38, p. 78, 1963.
6. Schofer, J. L., and Voorhees, A. M. Modal Split Model. Paper presented at HRB 43rd Annual Meeting to Committee on Origin and Destination.
7. Schmidt, J. W. Modal Split Rationale.
8. Basmaclyan, H., and Schmidt, J. W. Development and Application of a Modal Split Model for the Puget Sound Region. Staff Rept. No. 12, Puget Sound Regional Transportation Study, May 1964.