Application of a Modal Split Model to Travel Estimates for the Washington Area

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•THE National Capital Transportation Agency (NCTA) is an independent Federal agency established in 1959. The Congressional act establishing the agency required that a report be prepared for submission to the President on November 1, 1962 (1) setting forth financial and organizational recommendations for urban transportation in the region.

The Washington Metropolitan Area Transportation Study (WMATS) is a continuing organization sponsored by the highway departments of the District of Columbia, Maryland and Virginia in cooperation with the Bureau of Public Roads.

The Traffic Research Corporation is a private organization which provides consulting services in the fields of transportation planning and traffic research.

In order to maximize the use of technical personnel and techniques and to insure a coordinated technical approach to transportation planning for the region, the technical forces of NCTA and WMATS were combined late in 1961. The major objectives were to prepare forecasts of peak and 24-hr person travel for two land-use plans and to test the modal split implications of various highway and mass transit systems proposed for the two plans. The gravity model method of trip distribution was used for both forecasts (2).

This paper is concerned with the modal split phase of the joint program and more specifically, the application of a model which was developed by TRC (3), under contract to NCTA, for use by the joint group.

Adequate estimation of alternative mixes of transit and highway usage was a critical element in the study of the region's transportation requirements. Washington has a large central area employment with 350,000 today and over 400,000 estimated by 1980. These jobs are situated such that a great majority of them could be served by a rapid transit system. Furthermore, there is evidence that the postwar trend toward low-density development has been arrested. Last year, 62 percent of all dwelling units constructed in the Washington area were in multifamily buildings. These are but two of the several facts that make Washington one of the few American cities which seriously has a wide range of modal mix alternatives. Most other cities are either too small, too dispersed, or already have rapid transit systems receiving heavy use; any of these situations limits the range of future possibilities.

MODAL SPLIT MODEL

The modal split model applied during these studies consists of two parts: (a) empirical relationships describing how travel mode choice behavior is related to basic factors in a number of cities; and (b) a computer program designed to forecast future travel mode choice behavior, based on these relationships.

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Stratified Modal Split Relationships

It is apparent that such a model is a valid forecasting tool only if the relationships on which it is based can be shown to be stable. That is, the relationships must show how propensity to choose one travel mode in preference to another is related to basic motivating factors that are not likely to change over time, or from one city to another. These criteria have been tested for the relationships on which this model rests.

The two travel modes to which the model applied are public transit and the private automobile. These modes have fundamentally different properties. Public transit is characterized by fixed routes and schedules, whereas private automobiles may be used flexibly for door-to-door travel at whatever time the traveler desires. It therefore seems reasonable to assume that travelers' choice of two modes will depend in part on the effects of these different properties, and the evidence bears this out.

Following multiple regression analysis of a larger number of variables, five factors were selected as having more significant correlation with propensity to use public transit than the other variables tested. These five factors are defined as follows:

1. Relative travel time: door-to-door travel time via public transit divided by door-to-door travel time via private automobile.
2. Relative travel cost: the out-of-pocket travel cost via public transit (i.e., the fare) divided by the out-of-pocket cost via private automobile (i.e., gasoline, oil and lubrication costs for the trip plus parking cost, if any).
3. Relative excess travel time: time spent walking to and from transit stops, waiting for vehicles and transferring between vehicles when traveling via public transit, divided by the time spent walking to and from parking areas and waiting to park or "unpark" the auto when traveling via private automobile. (This ratio, also known as the service ratio, provides a measure of the relative level of service or convenience supplied by the two travel modes.)
4. Economic status of trip makers: the income range within which each zone falls, as regards median income of resident workers.
5. Trip purpose: the destination purpose, such as work or school, for which each trip is made.

To isolate the effects of the five determinants on relative use of transit and autos, it was necessary first to calculate the value of the travel time ratio, travel cost ratio and service ratio describing the relative competitive position of public transit and the private automobile between every O-D pair under consideration. It was also necessary to determine the average economic status of travelers proceeding from the O to the D. Then the percentages of travelers from the O to the D using public transit and private automobile were determined for each trip purpose and related to each of the other four determinant factors.

This was done by stratifying the observations for each trip purpose into 80 groups, according to the particular cost ratio, service ratio and economic status applying to each origin-destination pair. The analysis was carried out for two trip purposes (work and non-work) so that 160 groups of data were obtained. For each group, the percentage use of public transit was plotted against the travel time ratio for each O-D pair in the group. The final result was 160 transit-use diversion curves, each one showing how relative use of public transit varies with relative travel time for the travelers experiencing a particular level of cost ratio, service ratio, economic status and trip purpose.

Five O-D surveys, for the years 1954, 1955, 1960 and 1961, were analyzed in this manner during the model development and it was found that the derived modal split relationships were similar from one year to another during this period. These surveys represented travel data from three cities, Washington, Toronto and Philadelphia, and again it was observed that the modal split relationships were quite similar from one city to the next.

Comparison of the three sets of Washington work trip relationships showed that, when all three sets were expressed in terms of 1961 Washington dollars, the stratified relationships were similar enough to allow amalgamation of the three sets of data, producing one composite set of Washington modal split relationships for work trips (Fig. 1). A similar set was developed for non-work trips. The Toronto and Philadelphia sets of modal split relationships for work trips, also expressed in terms of 1961 Washington dollars, were then compared with the composite Washington work trip relationships, both visually (Fig. 1) and statistically. It was shown that the modal split of work trips in the three cities is strongly similar when stratified by the four factors, time, cost, service, and income.

A word of caution is necessary, however, regarding the application of modal split relationships developed in one city for forecasts in another city. Comparison of the Washington curves of Figure 1 (solid lines, with dotted lines where the curves have been extrapolated to low and high travel time ratio values) with the curves from Philadelphia (dashed lines) and from Toronto (dash-dot lines) shows that some significant differences occur for some of the curves. It would therefore be unjustified, considering the present state of knowledge in this field, to use curves developed in one city for forecasts in another, except for the roughest estimates of modal split. The Philadelphia and Toronto curves were not used directly in the Washington forecasts, but were derived rather to corroborate the Washington relationships and to provide evidence for the extrapolation of Washington curves. General similarity from city to city is very pronounced; however, any city contemplating the use of this model for detailed forecasts should carry out some analysis of local travel data as the primary basis for modal split relationships, rather than applying the Washington relationships without verification for local conditions.

Each of the 20 graphs in Figure 1 shows transit use diversion curves as a function of travel time ratio (TTR) for all trips in the city which fall within a certain range of travel cost ratio (CR), economic status level of travelers (EC), and travel service ratio (L). All five graphs in each vertical column of Figure 1 pertain to one value of CR. Similarly, all four graphs in each horizontal row pertain to one value of EC. Finally, within each of the 20 graphs there are four separate curves for Washington, each referring to a particular level of L. (There are fewer than four curves in each graph for each of the other two cities because of lack of data for some levels of service.) The ranges of values defined by each level of CR, EC and L are given in Table 1.

Examination of Figure 1 indicates the effects that the various factors have on propensity to use transit. First, the curves within each graph show the effect of relative travel time: as the time ratio increases, transit use decreases. Second, the effect of cost ratio is indicated by comparing each column of graphs with the next: generally, as cost ratio increases (moving from left to right) transit use decreases. Third, the effect of economic status is indicated by comparing each row of graphs with the next: generally, as user income increases (moving from top to bottom) transit use becomes more sensitive to poor service. And fourth, the four Washington curves in each graph indicate the effect of service ratio: as service ratio increases (moving from L_1 to L_4) transit use decreases. When interpreted in the light of the four factors, it can be seen that these effects appear to be entirely reasonable, strongly suggesting rational modal choice behavior on the part of the traveling public.

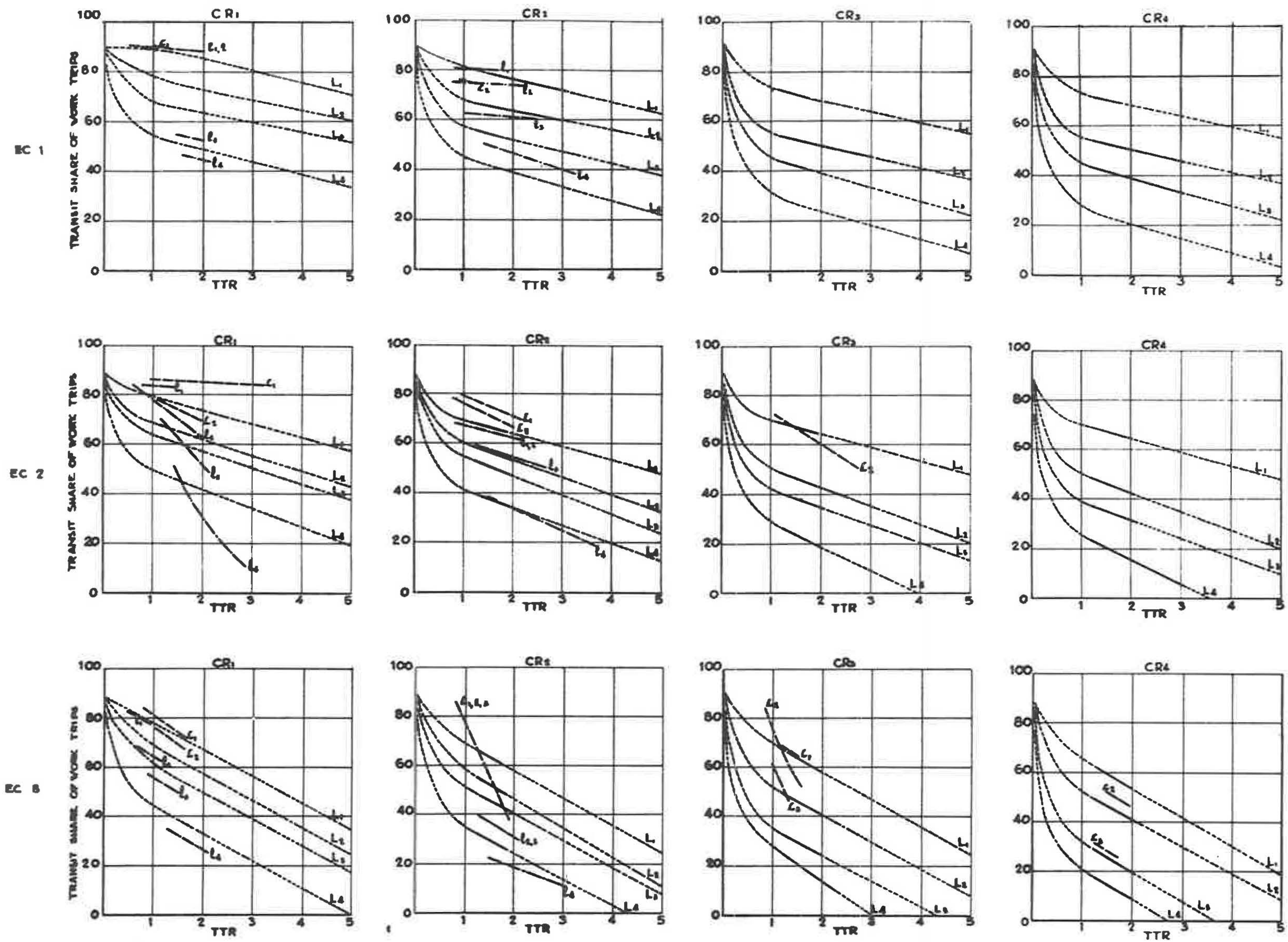
The details of the modal split analysis, its statistical validity, and the compar-

TABLE 1

STRATIFICATION LEVELS FOR COST RATIO (CR), ECONOMIC STATUS (EC) AND SERVICE RATIO (L)

CR_1	= 0.0 to 0.5
CR_2	= 0.5 to 1.0
CR_3	= 1.0 to 1.5
CR_4	= 1.5 and over
EC_1	= $0 to $3,100 per annum
EC_2	= $3,100 to $4,700 per annum
EC_3	= $4,700 to $6,200 per annum
EC_4	= $6,200 to $7,500 per annum
EC_5	= $7,500 per annum and over
L_1	= 0 to 1.5
L_2	= 1.5 to 3.5
L_3	= 3.5 to 5.5
L_4	= 5.5 and over

Note: TTR is plotted as a continuous variable, the abscissa of each graph in Figure 1.


EC 1
EC 2
EC 8
CR1
CR2
CR3
CR4
TRANSIT SHARE OF WORK TRIPS
TTR

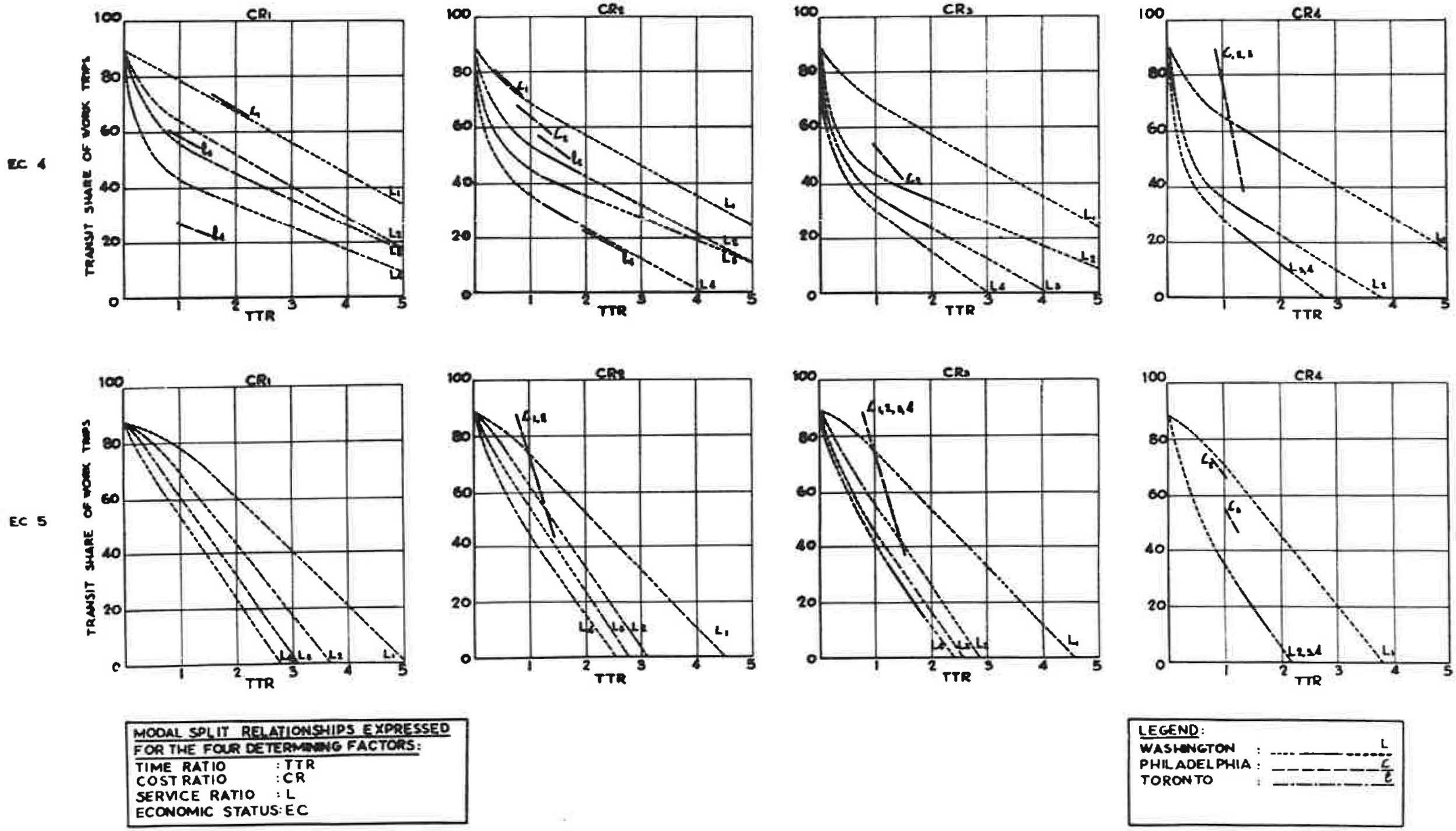


Figure 1. Work trip modal split relationships for Washington, Philadelphia and Toronto.

Figure 3. NCTA transit system.

Figure 3 also shows the assumed transit frequency of operation. In general, trains were assumed to run each 90 sec downtown with 6-min headways being common at the outer ends of the lines (these headways were applied for peak hours only). Express bus lines were assumed to operate at varying headways, in the 30- to 60-sec range, depending on passenger demand. The one commuter rail line had 10-min headways.

A local bus transit network was assumed to be in operation to serve those "close in" residents living within 5 to 6 miles of the city center and to provide feeder service to the rapid transit lines. Though the local lines are not shown in Figure 3, the lines were located in a pattern similar to the existing bus lines except for reorientation so as to intercept rapid transit stations. Local bus speeds and frequency of operation were assumed to be similar to those of existing peak-hour bus operations.

Figure 4 shows the major elements in the test highway system, consisting of 140 miles of urban freeways, and limited-access parkways, plus a connecting network of expressways, arterial streets and local streets. The most difficult element of the highway system was the determination of future assumed peak-hour operating speeds. The problem was solved by use of an iterative process as follows:

1. A judgment estimate was made of the percent of all peak-hour trips to downtown which would be by transit (62 percent) and the percent of all non-downtown destined trips by transit (20 percent).

2. The total person trip interzonal peak-hour volumes for 1980 were factored by the auto share of these trips, 38 percent for downtown and 80 percent for non-downtown trips. The resulting trips were assigned to the highway system. The assignment program used was the WMATS-BPR "all-or-nothing" process (5). Speeds assumed for this assignment were similar to the "average daily speeds" which have been used to

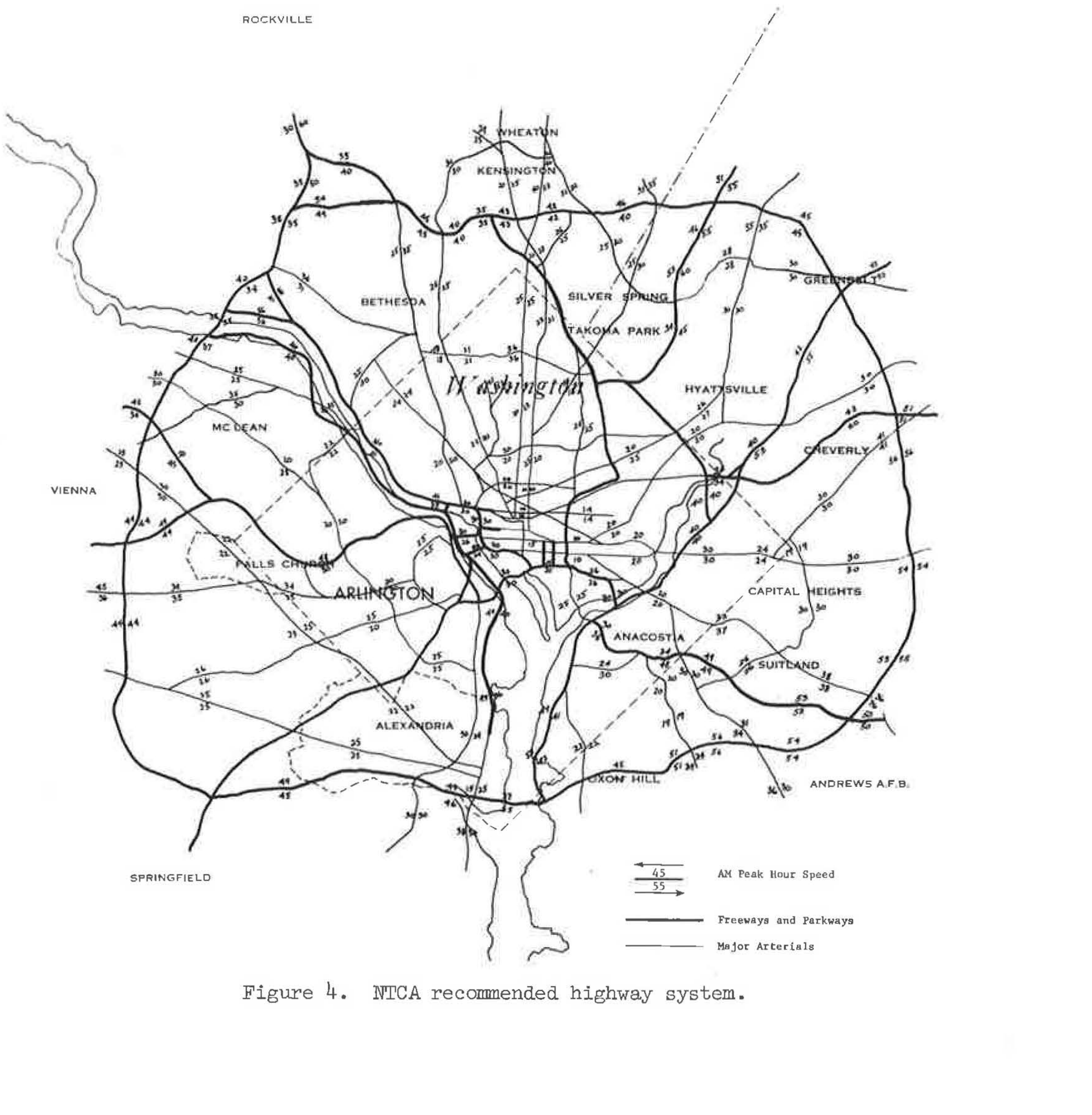


Figure 4. NTCA recommended highway system.

calibrate a similar highway network for the Washington Area. Volume capacity ratios were calculated for key links of the system.

3. Consideration was given to existing peak-hour speeds, to existing volume capacity ratios, to increments in capacity planned for each corridor, and to increments in the assigned volume above existing volume. A curve relating freeway volume to speed (Fig. 5) was also used as a guide. This curve was a composite of freeway operation experience in numerous urban areas. Speed estimates were prepared for each freeway link and critical arterial links. Secondary and local street speeds were assumed to be unchanged from today's speeds.

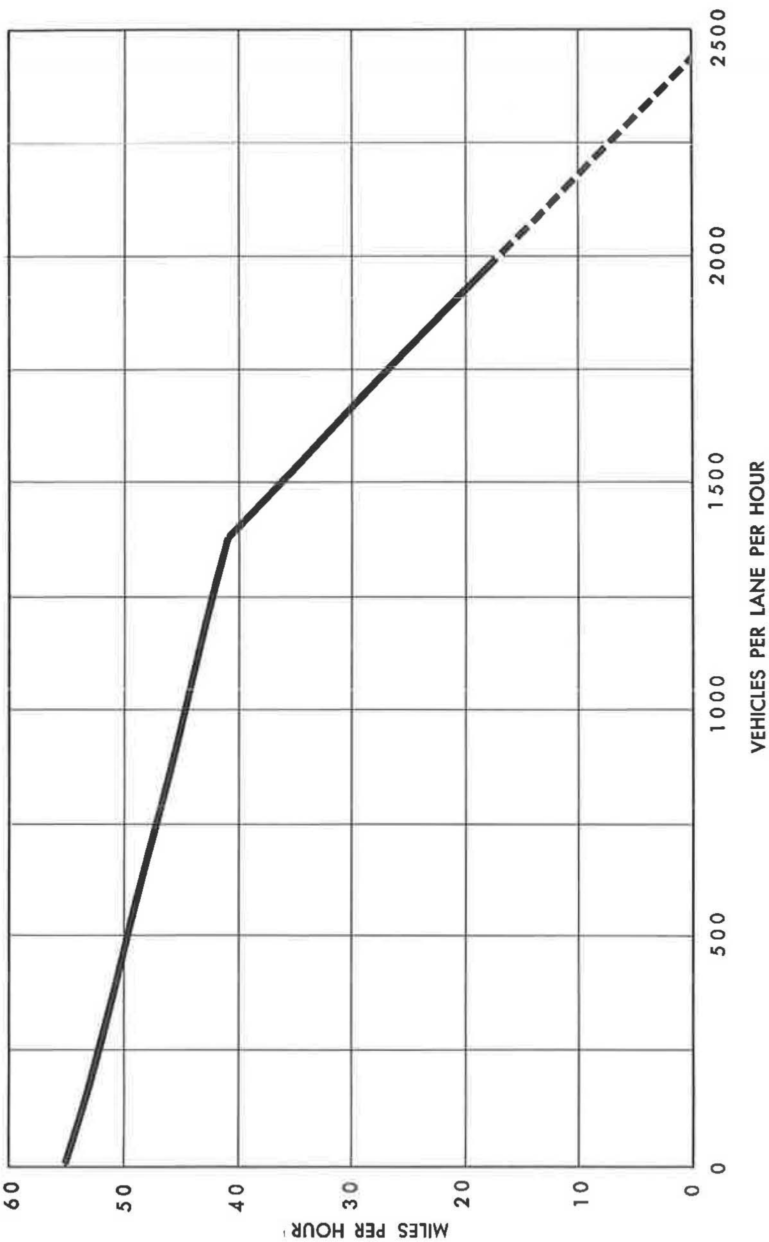


Figure 5. Relationship of speed and lane volume on urban freeways used in NCTA split analysis.

4. These speeds were introduced onto the network and new auto interzonal travel times were computed.

5. The modal split computer program was run. Resulting highway volumes were assigned and steps 3 and 4 repeated. The computer program was run again and steps 3 and 4 repeated again. This process was continued until the assumed speed on each link was consistent with its assigned volume and capacity.

The preparation of peak-hour speeds was a time-consuming and tedious operation. The time was spent because it was believed that auto speeds were critical in the final modal split calculations particularly within a 2- to 3-mi radius of downtown where highway capacity deficiencies were most likely to occur. Experience with the model has demonstrated that the travel mode split is not nearly so sensitive to fluctuations in these close-in highway speeds as was initially assumed. Sample manual calculations of typical interzonal movements confirm this.

The use of a capacity restraint program would have obviated the need for this manual process, but programming difficulties did not allow the automated procedure to be developed within time limits imposed on this project.

APPLICATION OF MODEL TO TEST SYSTEM

Figure 2 above shows the input data necessary for running the modal split program. A matrix of interzonal total person trips (without travel mode designation) is required as well as interzonal travel times by auto and transit and various parameters related to individual zones. The output includes a matrix of transit trips, a matrix of auto trips, and additional data (such as transit revenues) useful for analysis.

Figure 6 indicates the flow of data from initial assumptions to final calculation of modal split. Some of the process occurs as part of the modal split program; other steps are performed by use of intermediate programs; others are manual preparations. Modal split (Box D-21) is determined by the value of the travel time (Box D-17), cost (Box D-19) and service ratios (Box D-18) plus the income of the rider (Box D-20). (The fifth variable, trip purpose, is established by the interzonal person trips input, i.e., either work trips or non-work trips.) The travel time ratio is dependent on the time by transit (Box D-11) and time by auto (Box D-12). The auto travel time is a function of: (a) auto running time (Box C-7), and (b) auto parking delay (Box 4-5). The auto running time is a function of the speeds coded into the highway system (Box B-3) as previously described. Figure 6 can be used to relate any of the fundamental modal split determinants to the initial input.

Initial Assumptions

Some initial assumptions had to be made before the model could be used.

1. Truck traffic would be unaffected by the presence or absence of a rapid transit system.

2. Trips which have one end outside the Washington Metropolitan Area will not be diverted to transit. Actually, some 7,000 motorists (drivers and passengers) came across the boundaries of the metropolitan area during the three heaviest morning hours bound for downtown for work in 1961. It is likely that some of these will become rapid transit riders in the future by parking their cars in outlying station parking lots. Savings of downtown parking costs and avoidance of central city congestion would probably motivate them in the same way as residents living within the study area. However, to remain conservative, it was assumed that all of these travelers will continue to use their autos in the future.

3. The modal split relationships would not apply to passengers now using taxis. Taxis fill a somewhat unique transportation function in Washington. Considered on a 24-hr basis, over 10 percent of all internal trips were made by cab in 1955 (internal trips exclude trips with one or both ends outside the 1955 urbanized area). For 1980, it was estimated that 23,000 taxi trips would be made in the AM peak hour assuming no rapid transit system to be in operation. Of these, 72 percent were estimated to begin or end (or both) within "Sector 0." It would be reasonable to assume that many of

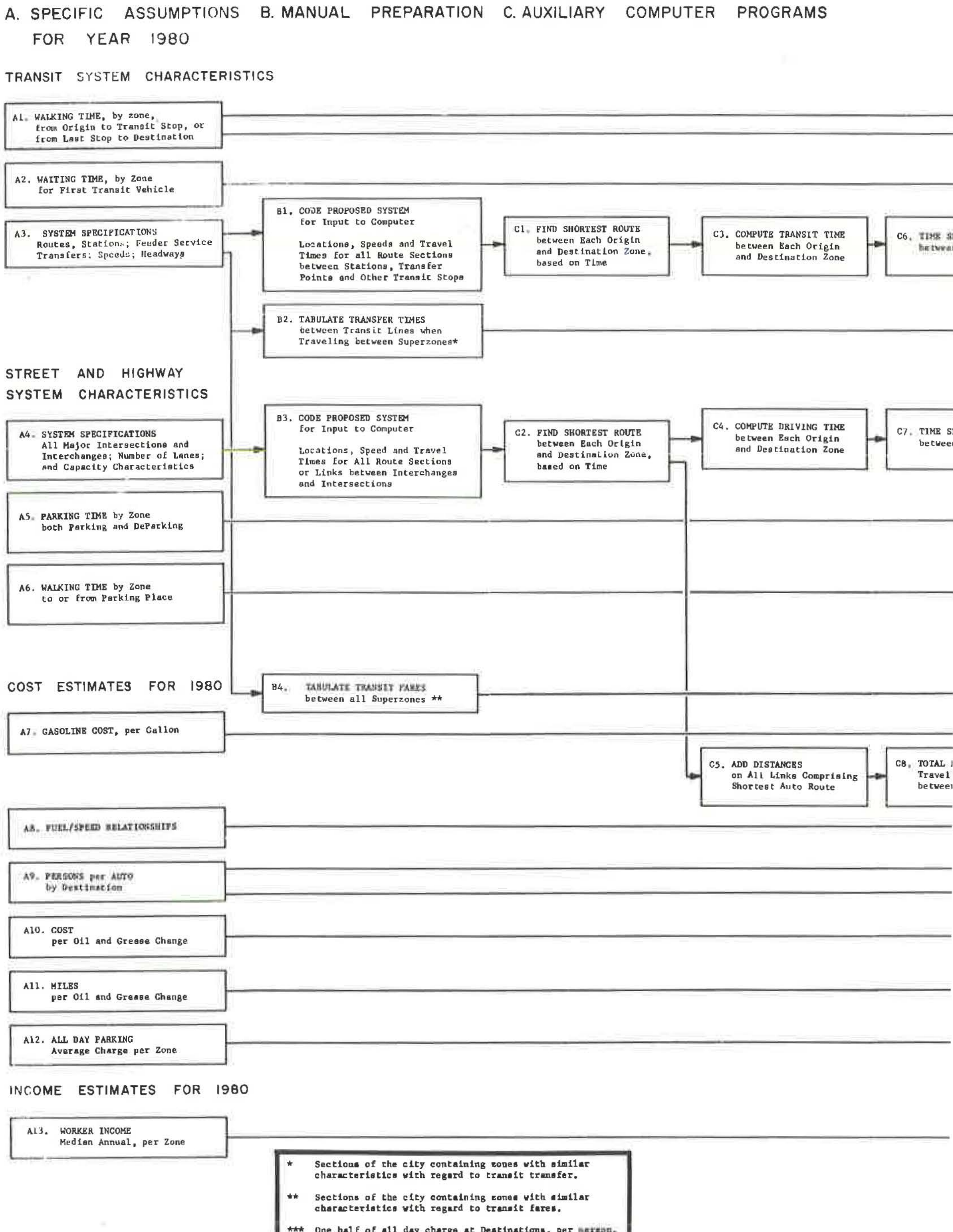
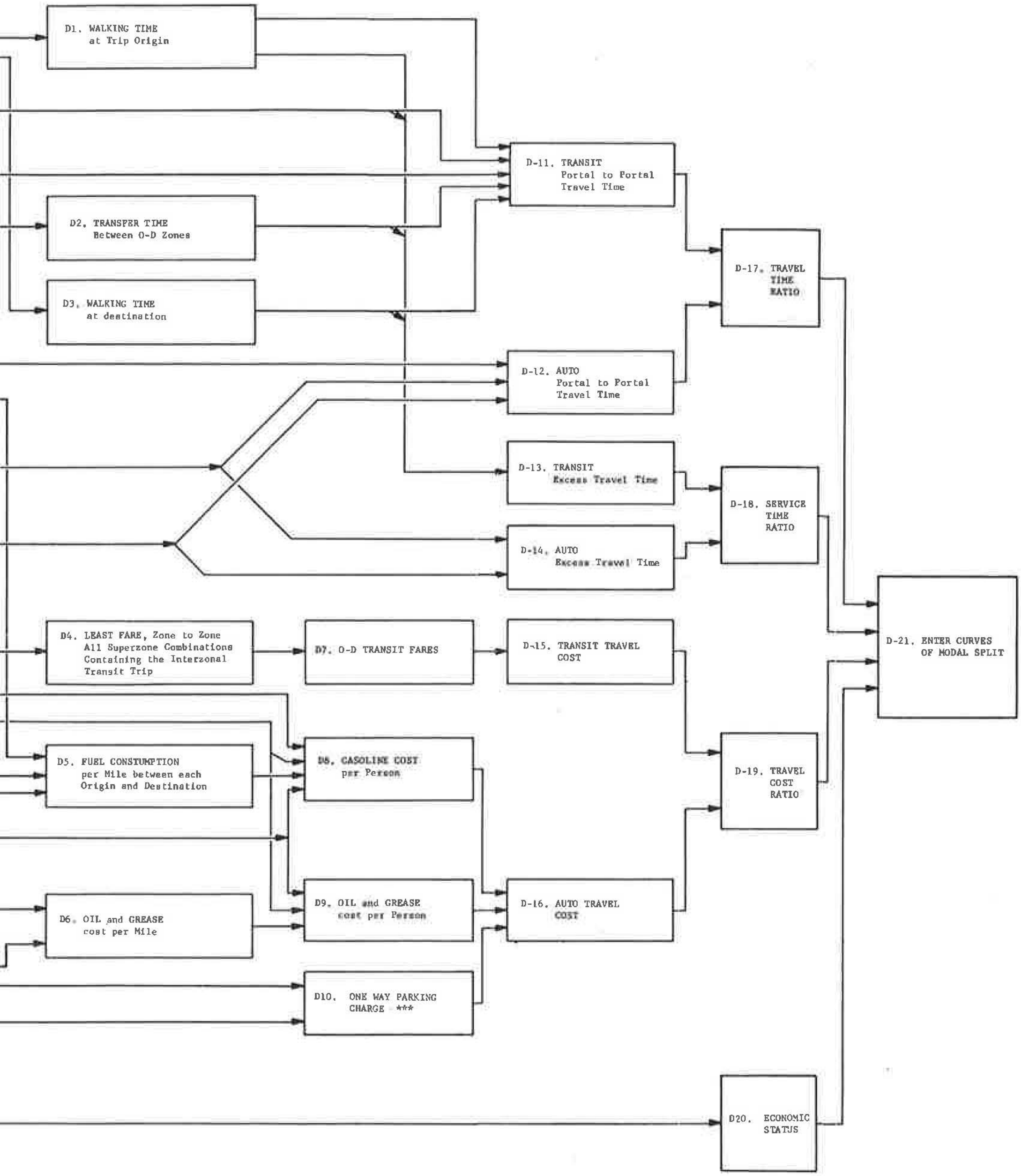


Figure 6. Process diagram for

D. MODAL SPLIT PROGRAM



analysis of modal choice.

these peak-hour trips to Sector 0 will be made by rapid transit in 1980 given the wide coverage of the proposed downtown subway system. For this reason, it was assumed that 25 percent of all peak-hour 1980 taxi trips would be diverted to rapid transit.

4. Persons making trips to school are not influenced by service and cost considerations in choosing their mode of conveyance in the same manner as persons making trips for other purposes (this was confirmed by analysis of 1955 school trips). This is probably due to the preponderance of children making these trips. Many are too young to drive and few have cars available to them. Probably the most important determinant of mode of school trips is the local school board policy on transportation. For example, Fairfax, Montgomery, Arlington and Prince Georges Counties provide school buses for public school children who live above a stated distance (usually 1 to 1⅓ miles) from their schools. On the other hand, the District of Columbia operates no school buses and Alexandria only a few. Students making school trips in the latter two areas make considerable use of public transit. For purposes of future estimates, it was assumed that all AM peak-hour trips from home to school (except those students walking to school) with destinations within the District of Columbia and Alexandria will be by public transportation. No school trips with destinations in Arlington, Fairfax, Montgomery and Prince Georges County were assumed to use transit.

5. Persons making trips to work or other purposes (except school) would, in 1980, be influenced in their choice of travel mode in accordance with modal split relationships such as shown in Figure 1. These relationships were derived from five different surveys made in three different cities over a span of seven years (1954-1961). Generally speaking, the relationships derived from each survey showed few significant differences. Inasmuch as the three cities had widely varying characteristics in terms of density, transit facilities available, street capacity, transit fares, income, etc., it is reasonable to assume that the modal split relationships represent basic and fundamental determinants of modal choice.

Procedures

Figure 7 shows the procedures used in this study for determining the modal split of trips made during the AM peak hour. These procedures incorporate the previously stated assumptions. The modal split program was run twice for each peak-hour test, once for work trips and once for non-work, non-school trips. Inputs for each run included a matrix of interzonal total person trips, interzonal travel times by transit and auto, and other inputs (Fig. 2). The matrix of interzonal auto trips output from each run was added to peak-hour taxi, truck and external auto trips. The summed trip table was then assigned to the highway system. Examination was then made (Fig. 7) of the resulting highway volumes to see if assumed link speeds were compatible with assigned volumes. The feedback loop illustrates the iterative procedure for bringing future highway speeds into line with estimated volumes.

The transit volumes resulting from each run (Fig. 7) were added together with diverted taxi trips and school trips. The summed transit volumes were assigned to the transit system.

Preparation of Inputs

Individual input items are reviewed to indicate the character of input data used in this test. Complete details of all items are not included, in the interest of brevity. Figure 6 shows the relationship of each input item to the modal split process.

1. Interzonal auto driving time (Box C7, Fig. 6): The test highway system was coded into the format required for the WMATS-BPR assignment program (6). A least time path through the network for each interzonal movement was found and its time value calculated by the computer.

2. Interzonal auto driving distance (Box C8, Fig. 6): Using the coded network, the computer calculated the distance along each minimum travel time route for each interzonal path.

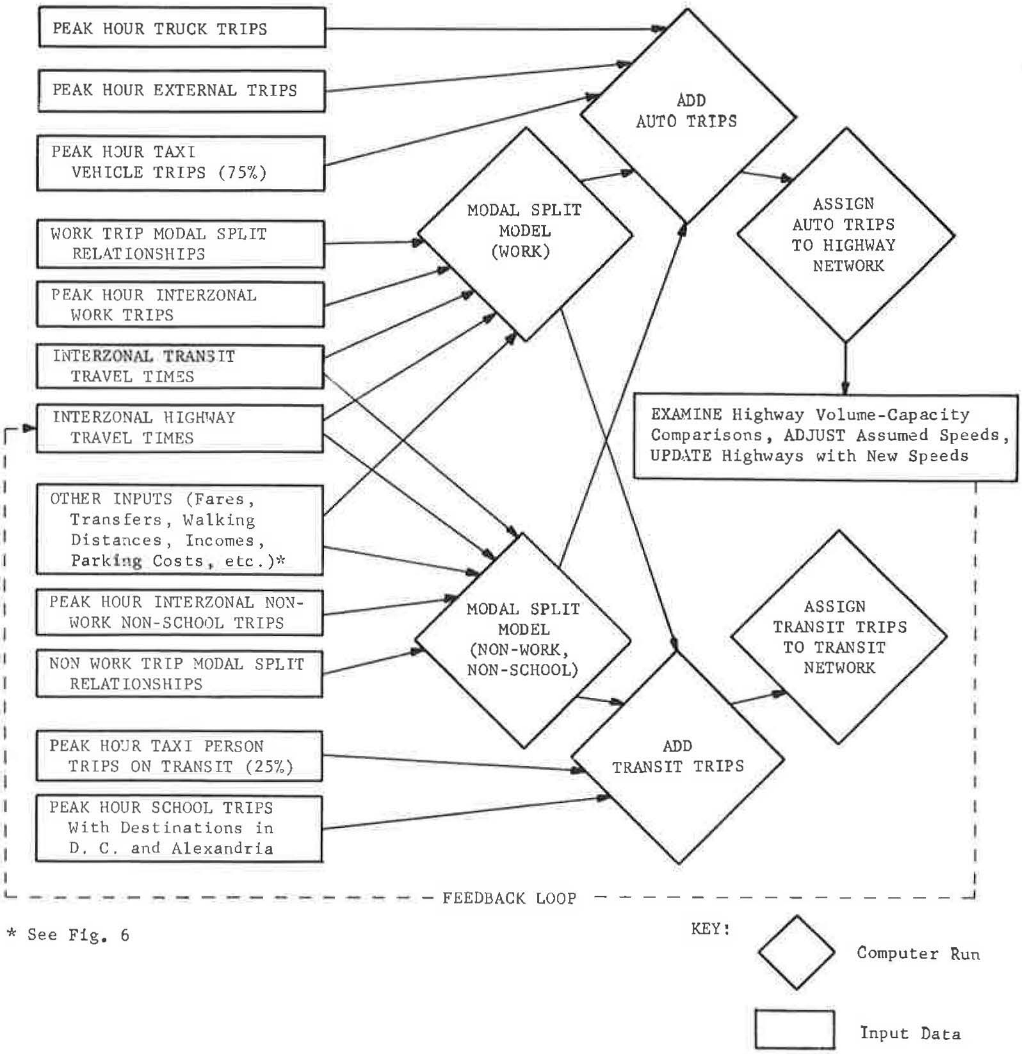


Figure 7. Procedures used in application of modal split model.

3. Interzonal transit travel time (Box C6, Fig. 6): The test transit system, both local and rapid, was coded into the format required by the WMATS-BPR assignment program. Minimum time paths between all zones on the transit system were calculated by the computer.

The problem of coding the transit system so that it would accurately represent the test system was a complex one that cannot be described in detail. One of the most perplexing problems concerns the choice of the mode of travel used to get to the rapid transit station at the home end of transit trips (submodal split). There are conceivably four modes available for some passengers: (a) walking, (b) driving an auto, (c) being driven as an auto passenger, and (d) feeder bus. Each of these has different associated travel times and costs. For such zones, there is no unique value of either cost or time for an interzonal transit trip. An acceptable solution was found by making logical estimates of the submodal split, determinating cost and time values for each submodal trip from home to station, and applying a weighted average time and cost to that link. The scope of this problem was reduced somewhat by assuming that zones more than one-half mile from transit stations would have no walkers; that zones with less than three dwelling units per acre would have no feeder bus; and that time and cost of auto passenger or auto driver trips were the same. Although these assumptions were sufficient for many zones there were others which required more detailed estimates of the submodal split. A computer program was devised to compute systematically these estimates in accordance with the method devised. While this process was approximate, the range of values of time and cost on the submode are limited such that the overall modal split calculation was not compromised by these estimates.

4. Interzonal transit transfer time (Box D2, Fig. 6): Ideally, transit transfers should be coded into the transit system. However, time deadlines required the use of a less refined transfer procedure. Transfer "superzones" were established which incorporated all traffic zones having the same transit transfer characteristics. For example, Figure 8 shows a simplified transit system consisting of two transit lines. Superzones are drawn enclosing the area served by each line. A transfer superzone matrix can then be prepared (Table 2). This matrix shows the transfer time as one-half the vehicle headway on the line to which the transfer is made. Since superzones X or Y can include any number of traffic zones, a "table of equivalents" relating the superzones to zones must be prepared. The computer can then calculate the interzonal transfer times. The superzone transfer matrix used for the test system was 20 × 20.

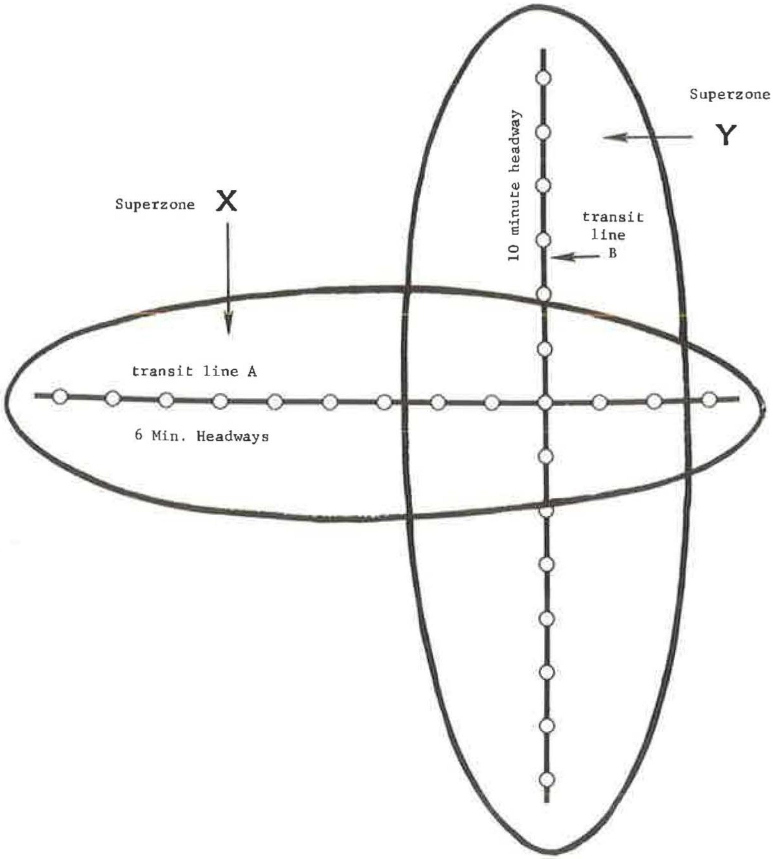


Figure 8. Transit transfer superzones.

5. Interzonal transit fare (Box D7, Fig. 6): Any transit fare scheme can be used in the model. For this test, a zone fare system was established (Fig. 9). Representation at this fare structure was accomplished by the establishment of fare superzones and a matrix of inter-superzone fares, along with a table of equivalents, similar to the method used for transit transfers. The fare matrix consisted of 625 entries (25 × 25).

TABLE 2

EXAMPLE OF TRANSIT TRANSFER TIME SUPERZONE MATRIX

Superzone	X	Y
X	0	5 min.
Y	3 min.	0

6. Zonal transit walking time (Box A1, Fig. 6): The estimated walking time to the transit stop (or station) is a component of both the service ratio and the travel time ratio. All transit riders originating or arriving at a given zone were assumed to have the same walking time. The average walking time was estimated as follows: (a) zones inside the 10-mi square: average

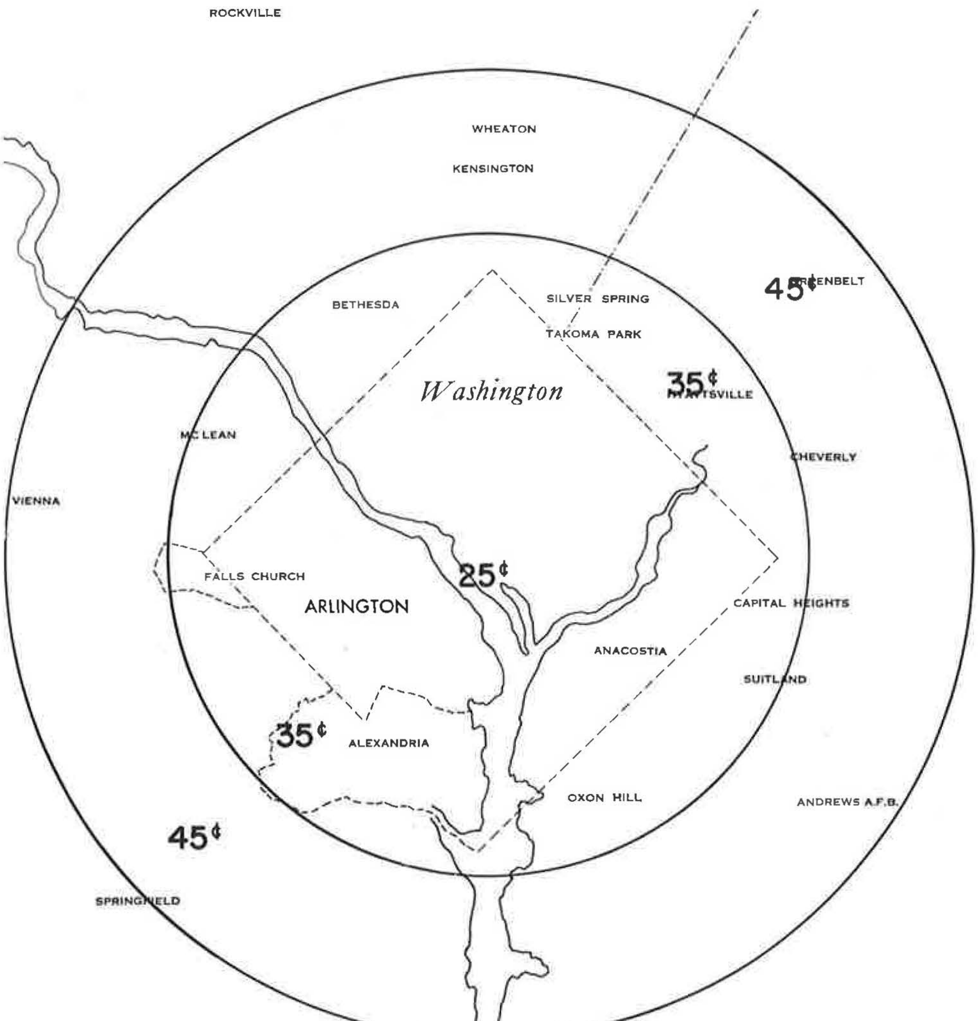


Figure 9. Transit fare structure.

walking time was estimated by examination of the transit route location and the development pattern in the zone; and (b) zones outside 10-mi square: walking time to local bus stops was assumed to be similar to average walking times in zones with similar density today.

7. Zonal transit waiting time (Box A2, Fig. 6): Transit waiting time is a component of both the service ratio and the transit time ratio. All transit riders originating in a given zone were assumed to have the same transit waiting time. It was estimated as follows: (a) zones inside the 10-mi square: average waiting time was estimated by the proposed frequency of service on transit lines serving the zone—generally, the waiting time was taken as one-half the transit headway; and (b) zones outside 10-mi square: average waiting at local bus stops was assumed to be similar to average waiting time in zones with similar density today (waiting time for rapid transit was estimated as for zones inside the 10-mi square).

8. Zonal parking delay (Box A5, Fig. 6): Time spent in parking or unparking is a component of both the service ratio and the travel time ratio. Delay was assumed to occur only at the trip destination. This delay was assumed to be 1 min except in downtown areas where delays of 1 or more minutes were used, depending on the proportion of all parking estimated to be in commercial garages.

9. Zonal walking time (from parking to destination) (Box A6, Fig. 6): Zonal walking time to and from parking facilities is a component of both the service ratio and the travel time ratio. It was assumed to occur only at trip destinations. It was generally assumed to be 1 min outside downtown except at some large employment centers with big parking lots. For downtown destinations, walking times were estimated from those reported in a recent comprehensive parking study. Times ranged from 2 to 5 min.

10. Zonal car occupancy (Box A9, Fig. 6): Car occupancy is a factor in computing the average auto passenger (or driver) trip cost, because total interzonal vehicle trip costs were assumed to be equally shared by the cars' occupants. Car occupancy was assumed to remain the same in 1980 as today. All auto trips into a zone were assumed to have the same average occupancy. Occupancy rate assumptions for the AM peak hour varied from 1.3 persons per car for trips to outlying zones to 1.8 per car for some downtown zones.

11. Zonal median worker income (Box A13, Fig. 6): Average income per worker is one of the variables in the modal split calculation. For some combinations of the other variables (travel time ratio, etc.) lower incomes show higher transit use. However, for some combinations, particularly those representing good transit service, high income riders use transit more frequently. (This may be observed on some high quality commuter rail service in operation today.) Based on median annual income per worker, each zone was classified into one of five income categories (Table 1).

The effect of income is evident in the modal split relationships. However, it is not so evident whether the median worker income is the real determinant or whether this is simply an indirect measure of another more fundamental but less measurable variable such as relative social or economic status. If the latter is true, the overall income increases between now and 1980 will not affect region-wide transit riding. In any case, the assumption of significant average regional increase in worker income must also be reflected in increases in transit fare, parking costs and vehicle operating costs. The econometric relationships between these elements are complex and obscure. For these reasons the average worker income was assumed to hold constant until 1980. At the same time no increases in transit fare, parking rates or vehicle operating costs were made to account for wage increases. However, individual zonal incomes were increased or decreased (while holding the regional average constant) to account for areas expected to decay or those where urban renewal or other influence are expected to affect income.

12. Zonal parking costs (Box A12, Fig. 6): Parking cost is the major component of out-of-pocket costs for motorists who are CBD bound. Parking costs outside the CBD were assumed to be zero. Since the model was applied only to AM peak-hour trips, only one-half of the assumed parking cost was allocated to the trip to downtown; the other half, by implication, being related to the return trip. All-day parking costs were assumed for work trips and one-half day costs for non-work trips.

Average downtown commercial parking rates were assumed to increase by about 60 percent by 1980, due to the higher intensity land use associated with higher downtown employment. The average all-dayparking cost for all vehicles was assumed to increase even more because of: (a) a reduction in the all-day street parking; (b) a significant reduction in the amount of free government space; and (c) higher land values resulting from an assumed 16 percent increase in downtown employment.

RESULTS OF TESTS

Figure 10 shows the passenger volumes assigned to the rapid transit system. These volumes were obtained by following the procedures indicated in Figure 7; they include all morning peak-hour trips. Once the matrix of transit trips was obtained, it was assigned to the transit system using the same assignment procedure used for the highway network, i.e., all or nothing to the least time path. Since local transit was coded into the transit network, those transit trips beginning close in and between the rapid transit corridors were routed to their downtown destinations without using the rapid. Volumes shown in Figure 10, then, are only for rapid transit.

Maximum 1980 load point volumes are estimated to range from about 25,000 peak-hour passengers coming in from the north (B and O Rockville line) to about 1,400 passengers on an express bus line serving a low-density area to the west (Cabin John line).

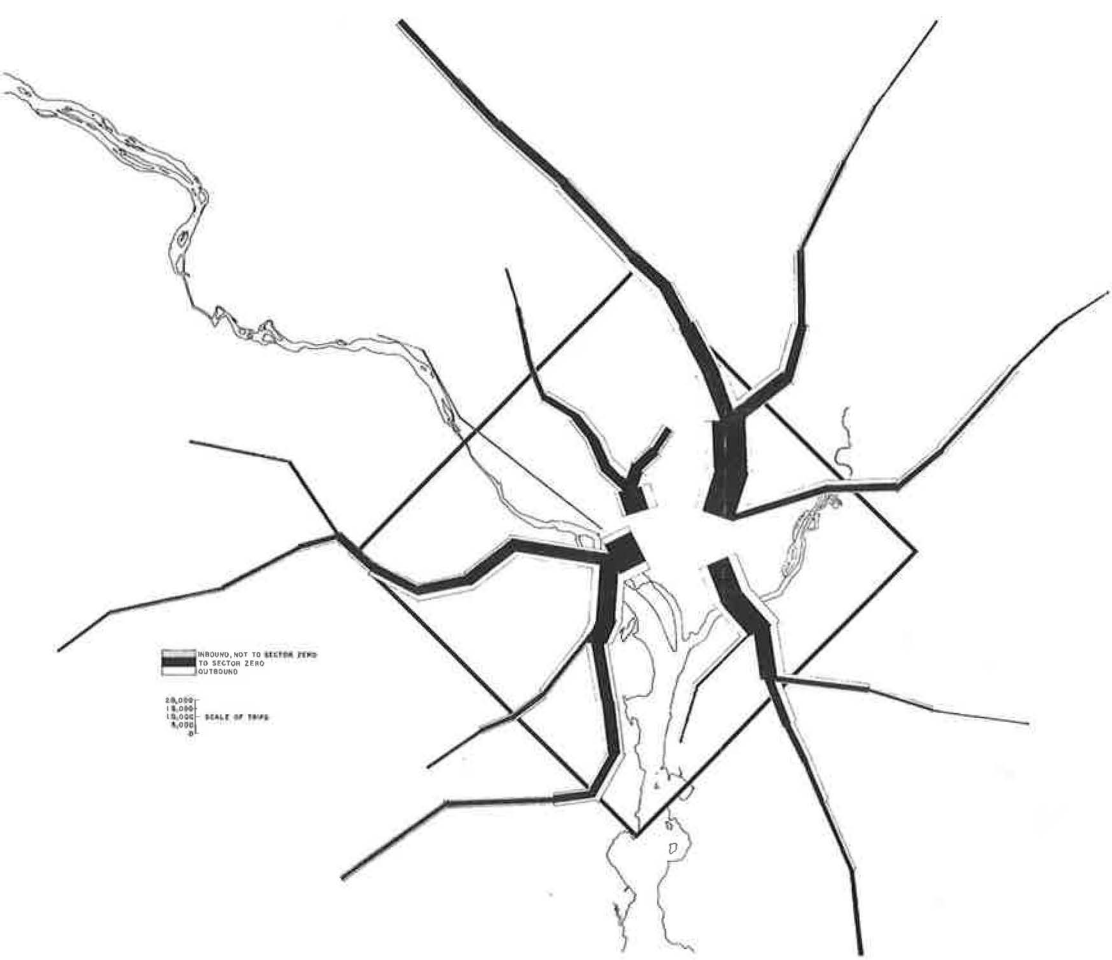


Figure 10. Transit traffic flow for NCTA recommended system.

Table 3 summarizes the shift in mode implied in these results as far as downtown oriented travel is concerned. The proportion of all peak-hour trips to the CBD by transit in 1955 was 46 percent. The model estimates that 64 percent of an increased number of trips would use transit by 1980. A 29 percent reduction in trips by auto to downtown from 68,000 to 48,000 was estimated. On the other hand, a general increase was estimated for non-downtown oriented travel by auto.

Table 4 shows modal split results for the entire metropolitan area. Twenty-five percent of all peak-hour trips are estimated to be performed via transit in 1980, compared to 33 percent on transit in the smaller urbanized area in 1955. Of 449,000 trips not going downtown in 1980, 87 percent are estimated to be by auto.

TABLE 3

COMPARISON OF AM PEAK MODAL SPLIT TO CBD: 1955 OBSERVED VS 1980 ESTIMATED

AM Peak Person Trips to CBD	1955 (Actual)	1980 (Model)
All modes	124,700	140,000
Transit (local and rapid)	57,000	90,000
Auto	67,700	50,000
% Transit	46	64

Note: Excludes trips from outside study area and taxi trips; CBD is defined as Sector 0.

Of the total estimated 153,000 peak-hour transit trips, 60,000 or about 39 percent will be to non-downtown destinations (Table 4). However, of an estimated 108,000 peak-hour work trips on transit, 80 percent will have downtown destinations. A high proportion of the non-downtown transit trips are school trips. Figure 10 shows that about 27 percent of all rapid transit trips entering the CBD will be destined beyond the CBD. Since these non-downtown volumes appear high compared with experience of some rapid transit lines, the non-downtown riding was reduced for revenue calculations by NCTA. Since making the analysis, however, it has been concluded that the model overestimated non-downtown trips owing to the manner in which the modal split curves were extrapolated for high travel time ratios. In the light of this experience, the extrapolated regions of the curves were adjusted as described in the following.

The modal split relationships (Fig. 1) were drawn so that transit riding diminished to zero at a travel time ratio of ten. Closer examination of the data for Washington and Philadelphia indicated that almost no data were available on transit riding for travel time ratios >5 in these cities. Toronto had a few cases showing some transit riding with ratios of 6 or 7, probably for short trips. Since transit use for travel time ratios >5 is almost non-existent in all three cities, new curves for work trips (Fig. 11) and for non-work, non-school trips (Fig. 12) were drawn which more nearly fit the data. Some of the non-downtown trips shown on transit in Figure 10 and Table 4 are

TABLE 4

ESTIMATED 1980 AM PEAK MODAL SPLIT FOR DOWNTOWN AND NON-DOWNTOWN DESTINATIONS

Trips	All Destinations	Downtown Destinations	Non-Downtown Destinations
All modes	606,000	157,000	449,000
Transit trips (local-rapid)	153,000	93,000	60,000
Auto person trips	453,000	64,000	389,000
% Transit	25	59	13

Note: Downtown defined as a somewhat larger area than the CBD in Table 3; all trip volumes exclude trips with one end outside the metropolitan area, taxi trips or truck trips.

oriented between adjacent or nearly adjacent radial corridors, which can be served only by very circuitous transit routing with consequent high time ratios. It is therefore believed that non-downtown trips will be estimated more accurately when new runs are made using the adjusted curves. It should be noted that downtown trips will be little, if at all, affected by use of the new curves.

MODEL SENSITIVITY

One of the greatest benefits that may accrue from the development of this model is insight into the interrelationship between modal split determinants which may be gained by its use. The great interest in the problem of modal split has included a number of experiments and studies on the subject in recent years. Some of these are theoretical, while others, particularly recent HHFA demonstration tests, produce empirical results. Interpretation of the conclusions of these various studies is difficult because they often seem to conflict. For example, reduced fares and increased service on commuter railroad lines in Philadelphia have increased riding by as much as 400 percent on some lines, whereas others have shown little increase (7). Increased service frequency on a bus line in Detroit produced 5 percent to 25 percent increases in riding during different periods of the day (8). On the other hand, Northwestern University recently conducted a theoretical study of data obtained from 5,000 Chicago commuters which indicated that it might require cash payments to commuters to get them to shift from auto to transit (9).

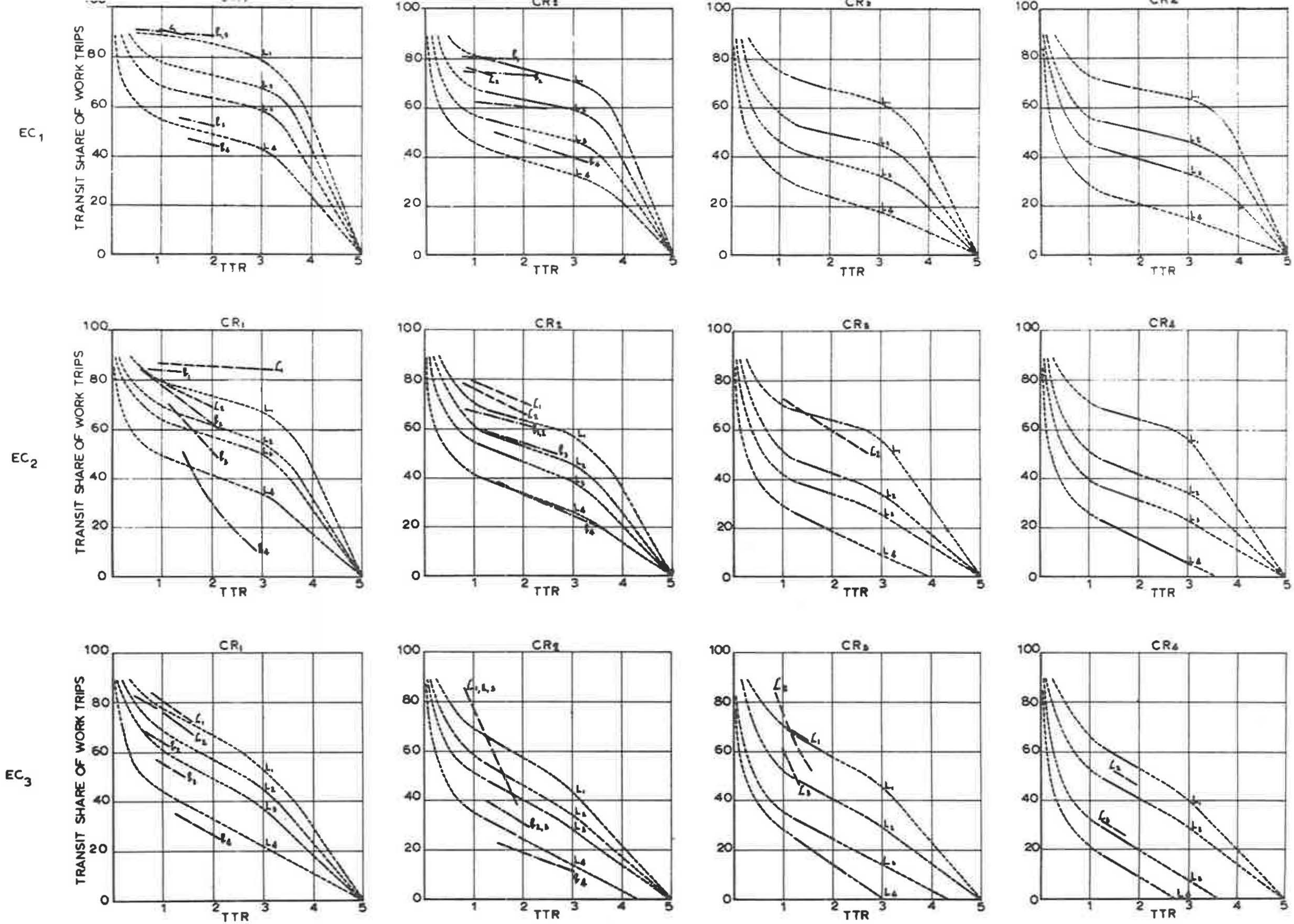
Actually all of these conclusions may be perfectly valid and also compatible. For example, analysis of the modal split relationships in Figure 1 reveals that doubling or tripling transit frequency can affect modal split significantly or not at all depending on the combination of other modal split determinants which are extant in a particular case. A 50 percent decrease in transit fares will produce dramatic changes in patronage in one instance but little or no change in others. Some understanding of the interrelationships between the modal split variants must be achieved before adequate interpretation of modal split tests can be made.

It is not proposed that all the many variables are accounted for in this model. It was noted for example that the model shows little sensitivity to the effect of extending a rapid transit line farther out into low-density suburbs. With adequate parking facilities assumed at most or all suburban stations, the downtown oriented suburban commuter who drives his car to the station may park at the station nearest his home, or, if there is a good highway in the corridor, park at a station several miles closer to town. In either case his costs or travel time or convenience is not substantially different. The net result is that the rapid transit line attracts the same number of riders whether it ends 10 miles from downtown or 12 miles. (Further shortening of the line would eventually affect riding as indicated by the model, because higher density areas, closer in, with substantial walking or feeder bus access to the stations would get poorer travel time ratios.) The unanswered question here concerns whether transit patronage in such cases is really unaffected by length of line or whether the model is simply insensitive. Perhaps another variable need be introduced and examined, namely, the "usage ratio": the proportion of the total O-D transit trip distance that is actually performed on transit.

Several sensitivity checks have been performed using the model. The data for the sensitivity checks are taken from some preliminary results of a more thorough test of the model now under way by the Bureau of Public Roads. These tests are based on the NCTA transit and highway system and other inputs as presented in this paper. The conclusions presented here are those of the authors alone. Although not enough checks have been run to provide comprehensive conclusions, several of the more interesting ones follow.

Increase in Transit Fare

For the proposed NCTA zone fare structure (Fig. 9), the basic fare is \$0.25 with additional increments of \$0.10 for traversing each of three fare zone boundaries. To check the results of an across-the-board fare increase of \$0.15, i.e., \$0.15 added



EC1
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TRANSIT SHARE OF WORK TRIPS
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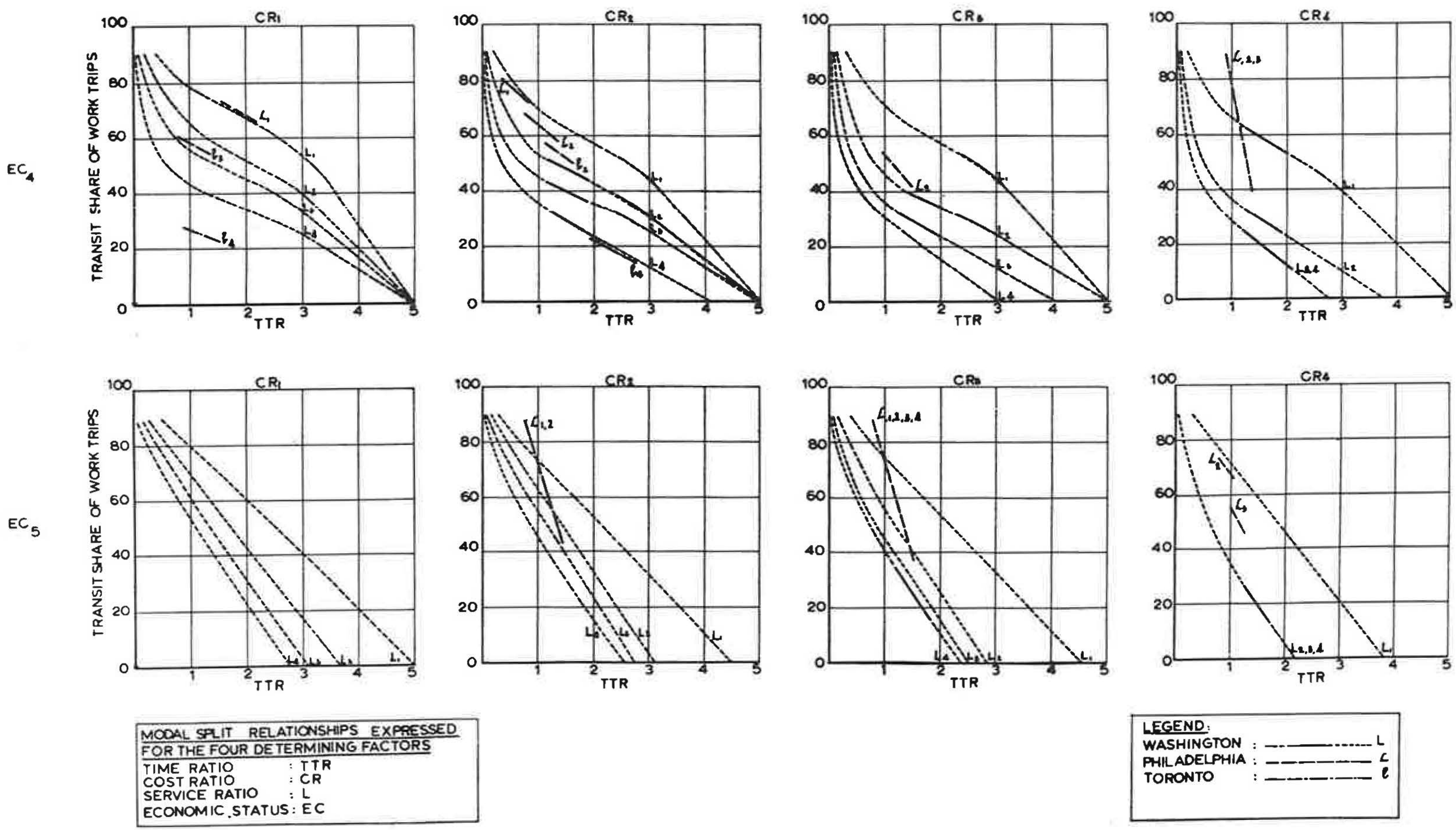
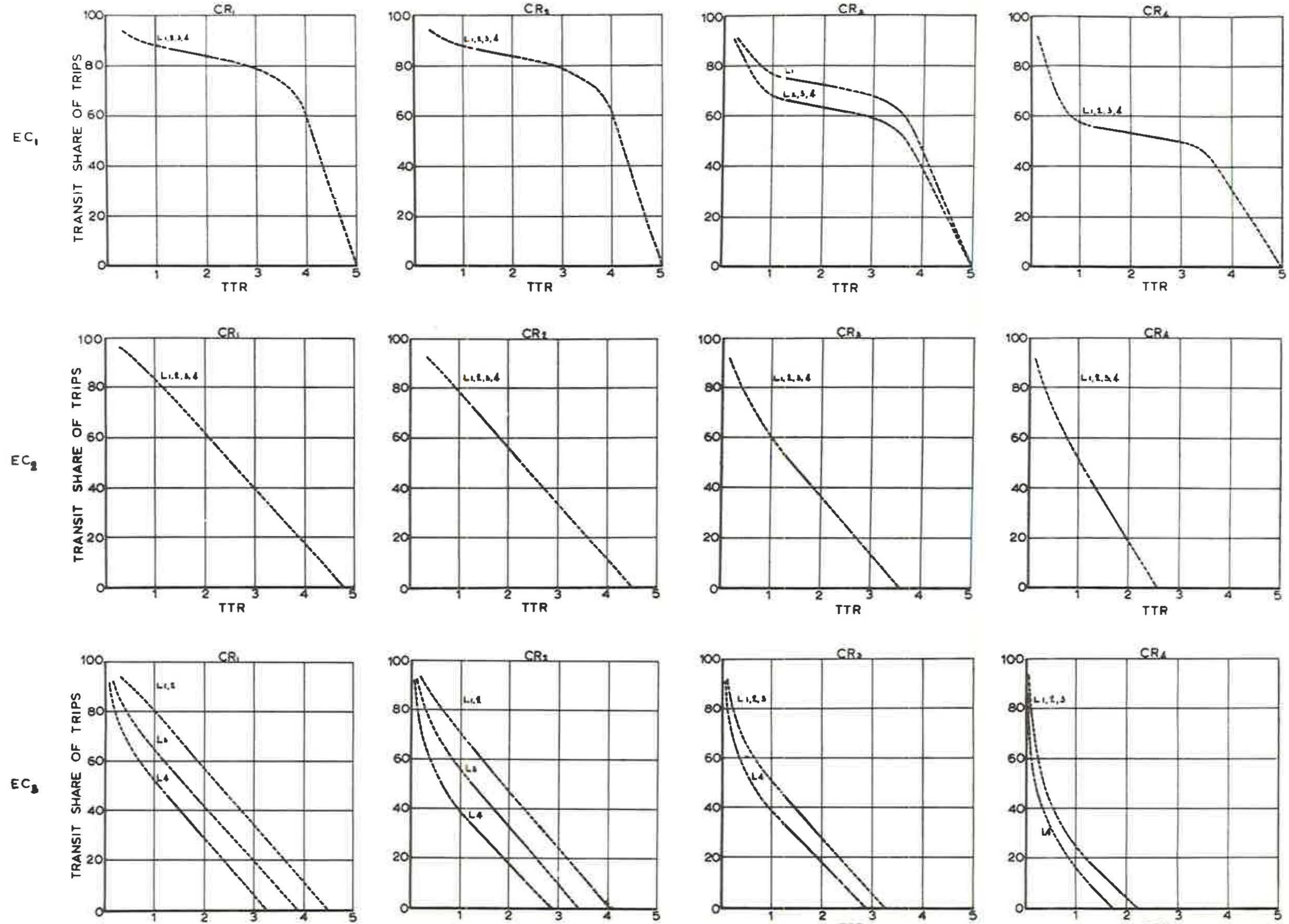


Figure 11. Work trip modal split relationships with adjusted extrapolations.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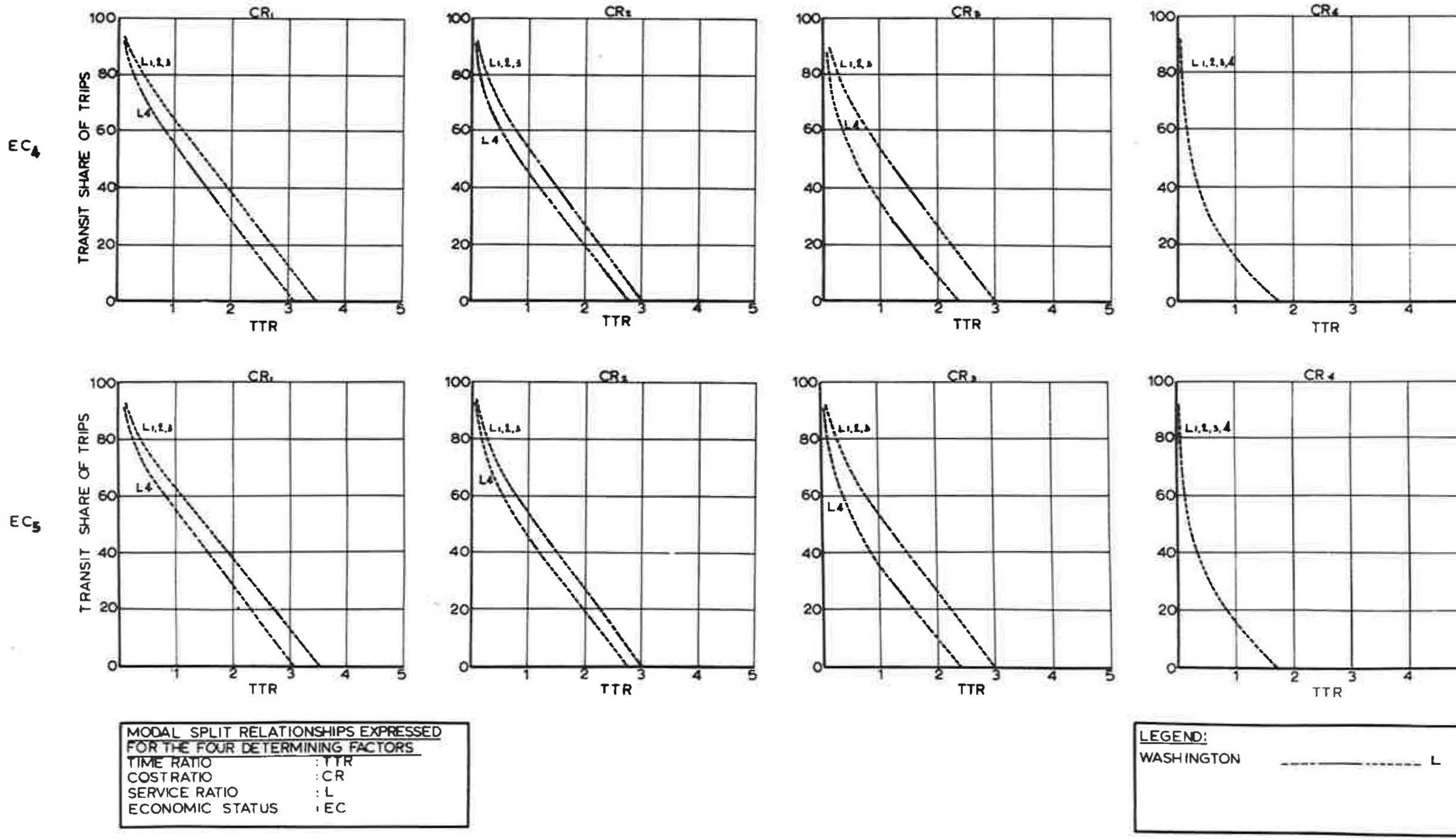

Figure 12. Non-work, non-school trip modal split relationships with adjusted extrapolations.

to the fare in each zone, making the basic fare $0.40, the program was run only for work trips. Total transit trips dropped from 108,200 to 102,700 or about a 5 percent drop in passengers. Non-downtown travelers experienced the greatest drop, about 8 percent.

Increase in Parking Costs

Holding transit fares and other inputs to those previously described, the parking costs were increased by a factor of 2. Since zones outside downtown had no parking cost assumed initially, this factor influenced only downtown riding. Transit riding for work trips increased from 108,200 to 114,900 for a 6.2 percent increase. It is likely that this test resulted in cost ratios of 0.1 or less for trips to some downtown zones. Since cost ratios of 0.15 or less were only rarely observed in any of the cities from which the curves were developed, the model is probably not sensitive to the full effects of such an auto trip cost increase. Cost ratios of 0.001 are treated the same as cost ratio 0.01 or 0.1, simply because these values lie outside the range of observed data. A general conclusion is warranted here: any output from the model which results from inputs outside the range of observed data should be treated with caution.

Increase in Worker Income

NCTA assumed that the median worker income for the metropolitan area as a whole would not change by 1980. This led to speculation of the effects on total transit riding if incomes were assumed to increase substantially. Such an increase would of course have a variable effect on other fiscally related items that are input into the model, such as parking costs, transit fares and gasoline costs. However, to gain some insight into the problem, median worker income was assumed to increase by 50 percent, without corresponding increases in the other variables.

This dropped transit work trips from 108,200 to 103,300, a 5.4 percent decrease. Figure 1 shows that income level has very little effect on transit riding where service is good (e.g., travel time ratios 1.25 or less and service levels L_1 or L_2) and in some instances where travel time ratios are less than 1.0, higher income travelers show a higher propensity for transit riding. However, where service is poor (e.g., travel time ratios 1.25 or more and service levels L_3 and L_4), dramatic differences are revealed depending on income. This is confirmed in this test. Whereas overall riding dropped 5.4 percent, downtown riding (where transit service is best) dropped only 1,600 transit work passengers or 1.9 percent. Non-downtown riding (where transit service is not as good) dropped 15 percent.

Increase in Parking Delay and Walking Time

The great attractiveness of the automobile is its convenience. Nevertheless, in crowded downtown centers inconveniences are associated with auto travel. One of these inconveniences is delay in parking a car, particularly the wait for a car in an attended parking facility. The scarcity or high cost of downtown parking also often requires parking some distance from the real trip origin or destination.

All NCTA tests held auto walk-wait time the same as had been assumed when the curves were developed, from 4 to 8 min for downtown zones and two minutes for non-downtown zones. (This time was applied to the destination end of trip only; thus trips from residential areas into downtown did not have any auto walk-wait time assessed at the trip origin.)

The sensitivity test for this variable consisted of adding 2 min to the auto walk-wait time or an increase ranging from 25 to 100 percent. This rather drastic reduction in auto convenience increased transit riding by 33 percent. Downtown trips (where the auto walk-wait time increase was 25 percent for most trips) increased by only 10.4 percent. For non-downtown trips, where the increase in auto walk-wait time was 100 percent, the increase in transit riding was 122 percent. Several conclusions might be drawn from this:

1. Auto convenience is its most attractive feature in attracting use.
2. No conceivable condition is likely to cause a 100 percent increase in auto parking delay outside downtown.
3. The whole test is subject to question since it contains inputs of auto delays which are outside the range of observed values.

Increased Transit Walk, Wait and Transfer Time

Time spent walking to the transit stop (or station), waiting for the transit vehicle, and, in some instances, transferring is one of the inherent characteristics of transit service. NCTA assumed frequent rapid transit service ranging from 1½- to 6-min headways. Local and feeder bus service was assumed somewhat similar to today's service. Walking and waiting times for each zone were estimated on this basis.

This check, then, was to test the effect of increasing the walking, transferring, and waiting time for transit by 50 percent. This resulted in a 15 percent decrease in transit riding, 13 percent for downtown riders, 29 percent for non-downtown riders.

CONCLUSION

It is believed that the modal split model is an operational tool which produces results with accuracy similar to other techniques and procedures used in urban travel forecasting. Although the model requires many assumptions and estimates of future conditions, it is believed that the problems of estimating the input parameters are not significantly more difficult than those associated with other travel forecasting requirements.

Possibly the greatest gain from the model in the long run will be the insights and knowledge gained concerning the interrelationships between the various modal choice determinants. In this regard, a great deal can be learned by further research, specifically: (a) developing modal choice relationships in other cities to see how consistent the relationships are in a wider range of population density, service levels, etc.; (b) comparing this approach to modal split determination with other approaches being developed, such as the multiple regression model now under way at the Penn-Jersey Transportation Study; (c) development of additional factors for representing transit service in a model, automated feedback procedures for restraining highway speeds, and more research generally into the effect of the development of highway and transit systems on total travel demand.

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