Development of a Model for Forecasting Travel Mode Choice in Urban Areas

DONALD M. HILL, Research Analyst, Traffic Research Corporation, New York, N.Y., and
HANS G. VON CUBE, Vice-President, Traffic Research Corporation Ltd., Toronto, Canada

•WITHIN an urban area a great many people travel in pursuit of their daily activities. This large person movement is made mainly with the help of private automobiles and taxis, public transit and commuter trains.

The basis on which people choose among the various means of transportation available in different parts of an urban area is of utmost importance to the transportation planner.

Citywide estimation of potential passengers attracted to a new transit facility is sufficient only for broad planning purposes. With ever increasing cost of operation and construction, the selection of a location and determination of adequate capacity of a new traffic facility requires a reliable framework of references necessary to forecast the probable usage of such a traffic facility.

Hence the objective of the studies reported in this paper was to determine the major factors affecting the travel mode choice and to construct reliable framework of references (modal split) necessary in travel movement forecasting for specific transportation planning purposes. This was done on the basis of empirical evidence of how people actually traveled from origins to their destinations. Such a model has a direct application in the estimation of the relative demand for mass transit and/or expressway facilities, on an area to area basis, area basis or citywide basis.

Basic studies of factors affecting peoples' choice of travel mode were carried out in Toronto in 1960 and 1961. In subsequent studies in 1962 of peoples' travel behavior in Washington, D.C., the established framework of relationships was enlarged and finally corroborated by studies of O-D surveys conducted in Philadelphia.

CONCEPT OF MODAL SPLIT RELATIONSHIPS

The total number of people moving during a certain time period from an origin zone (O) to a destination zone (D), may be thought of as the total travel market existing between the O and D in question. The various modes of travel available for moving from O to D are competing for a share of this market, and each will win a portion of it, depending on its competitive position with the others. In this analysis the comparative advantages and disadvantages of each of the two major types of travel mode (public transit and private automobile) are measured by the time, cost, and convenience criteria. The other criteria, such as economic status and trip purpose, may be thought of as market characteristics which affect user reaction to the first three criteria.

To isolate the effects of the five determinants on market reaction (i.e., relative usage of transit and autos), it is necessary first to calculate the value of relative travel time, relative travel cost, and relative service describing the relative competitive position of public transit and the private automobile between every O-D pair under consideration. It is also necessary to determine the average economic status (income category) of travelers proceeding from O to D. Next the percentage of travelers proceeding from

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O to D using public transit and private automobile is determined for each trip purpose and is related to each of the other four determinant factors.

If these five factors explain completely the modal choice process, one would expect that all O-D pairs with identical values of time, cost and service ratios, and user income level would each display the same percentage of work trips made via public transit. The factors should produce the same percentage of non-work trips made via public transit for O-D pairs with identical values of the factors. However, this percentage would in general be different from the percentage of work trips made via public transit. This is, in general, what is observed, although there is, as would be expected, a scatter in the observations, owing to various sources of random variation.

FACTORS DETERMINING CHOICE OF TRAVEL MODE

The five basic factors considered are as follows:

1. Relative travel time via public transit and private automobile.
2. Relative travel cost via public transit and private automobile.
3. Relative excess travel time via public transit and private automobile (also known as relative level of service or convenience).
4. Economic status of trip makers (income per worker).
5. Trip purpose.

These five factors were selected on the basis of multiple regression analysis as having more independent significance than any others studied, to explain peoples' propensity to use public transit.

Among the factors considered originally were: trip length, population density, employment density, transit seat capacity, and orientation of the trip with regard to the central business district (CBD). However, they were found to be linearly dependent on at least one of the four determinants, time, cost, service, and income. Consequently, the degree of orientation of the trip with regard to the CBD is not included. Previous modal split studies (1) have shown that difference in transit usage of people traveling to CBD and non-CBD areas is adequately explained by differences in the five factors.

Usually there are more than two modes of travel available to most trip makers in urban areas. However, it is believed at this stage of development work, that the division of these travel modes into two main types, public transit and private automobile, is sufficient to account for the basic differences in the properties of the main types. Public transit is characterized by fixed routes and schedules, while private automobiles may be used flexibly whenever desired by the traveler.

Relative usage of alternative submodes within each of the main types (bus, subway, commuter train within the public transit mode; private auto or taxi within the motor vehicle mode) can be shown to depend on similar determinant factors.

Relative Travel Time

Relative travel time is expressed as a time ratio: door-to-door travel time via public transit divided by door-to-door travel time via private automobile. Figure 1 shows how the percentage of trips made to work by transit varies with travel time ratio. Diversion curves of this nature have been developed by a number of research workers for different cities with similar results. Time difference has also been used as a measure of relative travel time, but was not used in this project because the time ratio seems to produce a more well-defined relationship.

Relative Travel Cost

Relative travel cost is also defined as a ratio: the out-of-pocket travel cost via public transit divided by the out-of-pocket travel cost via private automobile (Fig. 2). Transit travel cost in this ratio is defined as the total fare paid during the trip; automobile travel cost is defined as operating cost (gasoline, oil, lubrication), one-half parking cost, and bridge tolls if any. Automobile depreciation, licensing and insurance costs

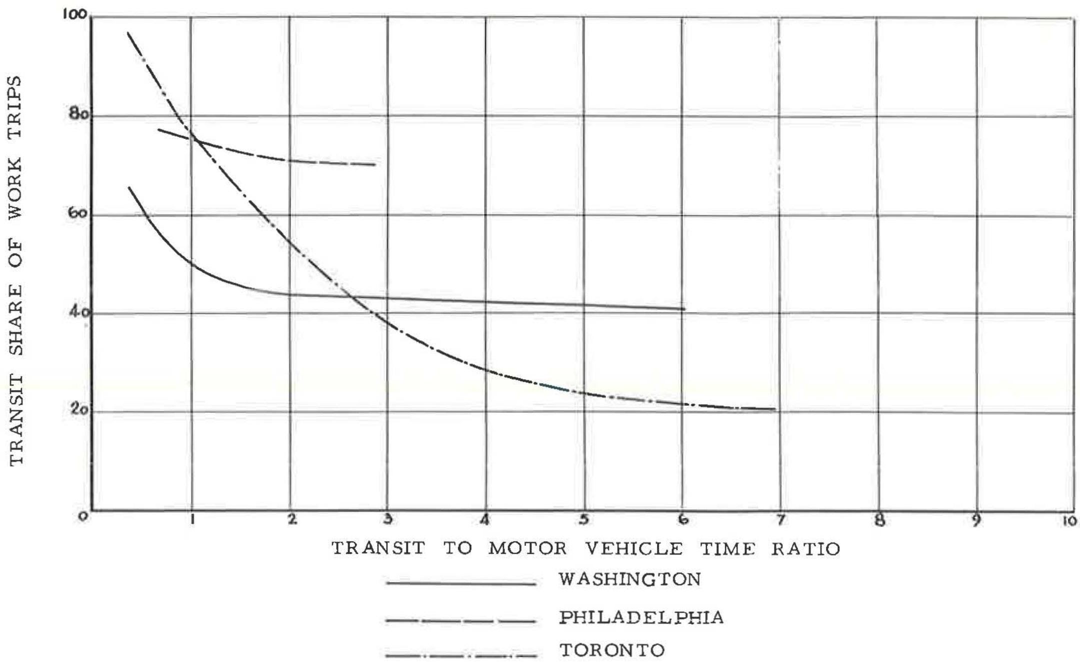

Figure 1. Travel time ratio diversion curve for work trips in peak periods (no. of trips in 1,000's).

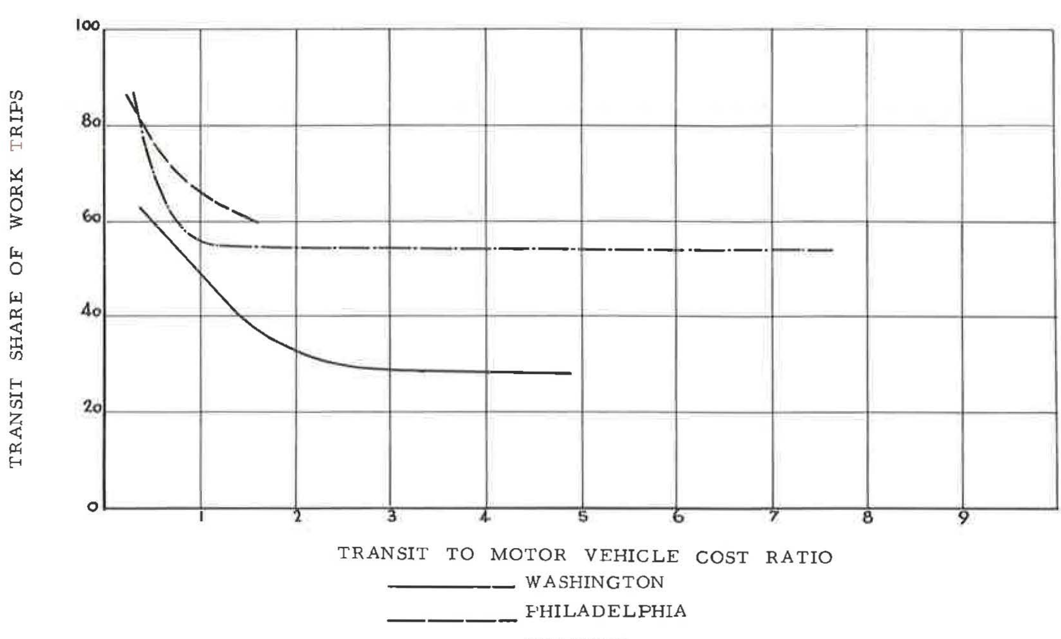

Figure 2. Cost ratio diversion curve for work trips in peak periods (no. of trips in 1,000's).

are not included, on the assumption that most automobile drivers do not consider these costs in connection with each trip made (2). For this study the travel costs via private automobile are divided evenly among all occupants of an automobile, based on the principle of cost sharing which usually exists in car pool arrangements.

Relative Travel Service (Convenience)

Obviously, a number of factors affect the level of service offered by each mode of travel. Among these are a clean bright appearance of the travel vehicle, a pleasant view from the window, a reasonable temperature within the vehicle, a comfortable seat, uncrowded conditions, a smooth ride, flexibility of departure and arrival times to suit the desires of the traveler, and convenient transfers from one vehicle to another, if this should be necessary. Many of these factors cannot be easily or meaningfully expressed in quantitative terms, and cannot therefore be included explicitly in these relationships.

The relative level of service has been expressed as a ratio: the excess time when traveling by public transit divided by the excess time when traveling by private automobile. Excess time is defined as the time spent outside of a vehicle while en route. In the case of public transit this is the time spent walking from point of origin to the nearest transit stop, plus the time spent waiting at the stop for the transit vehicle, plus the time (if any) spent transferring from one vehicle to another during the trip, plus the time spent walking to the point of destination from the nearest transit stop. For private automobile the excess time is the time spent walking to or from the parking place at O and/or D plus the time spent parking or "unparking" the automobile at either end of the trip. Clearly, the ratio of excess times is one measure of the relative convenience of the two modes (Fig. 3).

Another convenience-comfort index which can be expressed quantitatively is the load factor for public transit; that is, the ratio of total passengers in a transit vehicle to the number of seats in the vehicle. It has not been possible to treat this factor explicitly in this study because of the difficulty of obtaining data. When such data become available it will be possible to include the effect of transit load factor directly in the modal split relationships, and therefore in the forecasting process in which they are used. The load factor during peak hours is apparently limited by similar regulations for the three cities. This factor is therefore implicit in the relationships and it can be said that any travel movement forecasts based on the relationships assume such a a load factor level.

Economic Status of Trip Makers

It might be expected that increases in income would increase the elasticity of demand for transit. In the first place, prosperous people expect good service for their money and will tend to avoid a transit system which does not provide good service. Augmenting this is the fact that those with high income can afford the capital outlay necessary for private automobile ownership. The overall effect of trip maker's income (per worker) on relative transit usage (Fig. 4) will become clearer when the stratified relationships are described. It will be seen that high income is not necessarily a deterrent to transit usage, provided the time, cost and convenience are competitive between public transit and private automobiles.

Trip Purposes

For many trip purposes, such as selling to widely separated clients or shopping for week's groceries, the use of an automobile is all but mandatory. For trips, such as work trips of office staff, the choice is open and will depend on other factors. For other trips, such as many school trips, transit is the only choice because of travelers' inability to driver or own an automobile. It is logical to expect, therefore, that modal split relationships based on the four determinant factors described above will vary somewhat, depending on trip purposes.

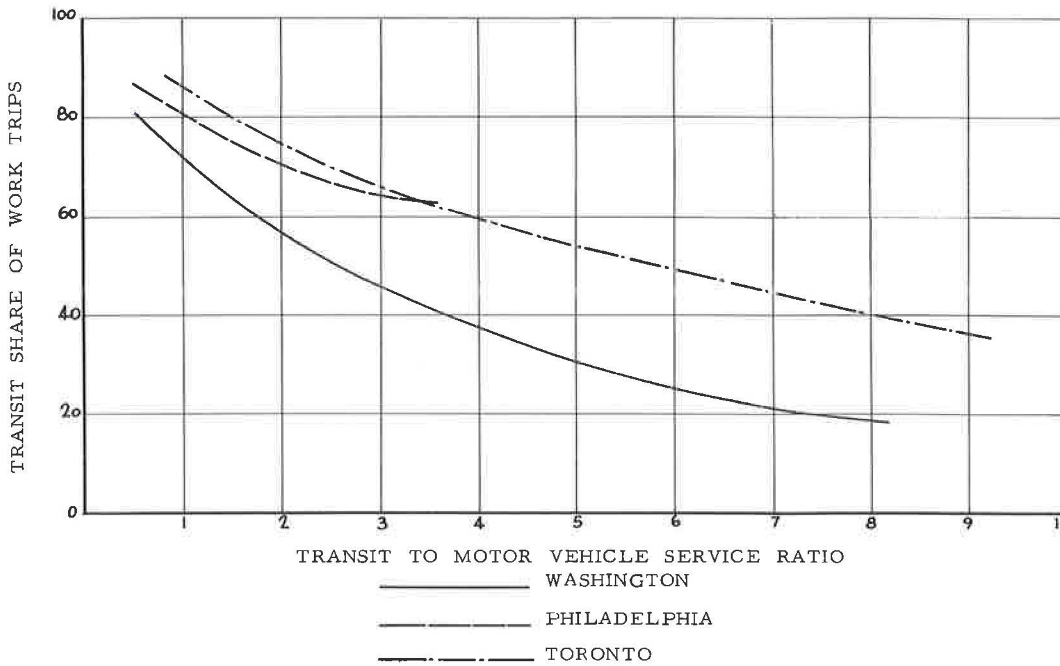

Figure 3. Service ratio diversion curve for work trips in peak periods (no. of trips in 1,000's).

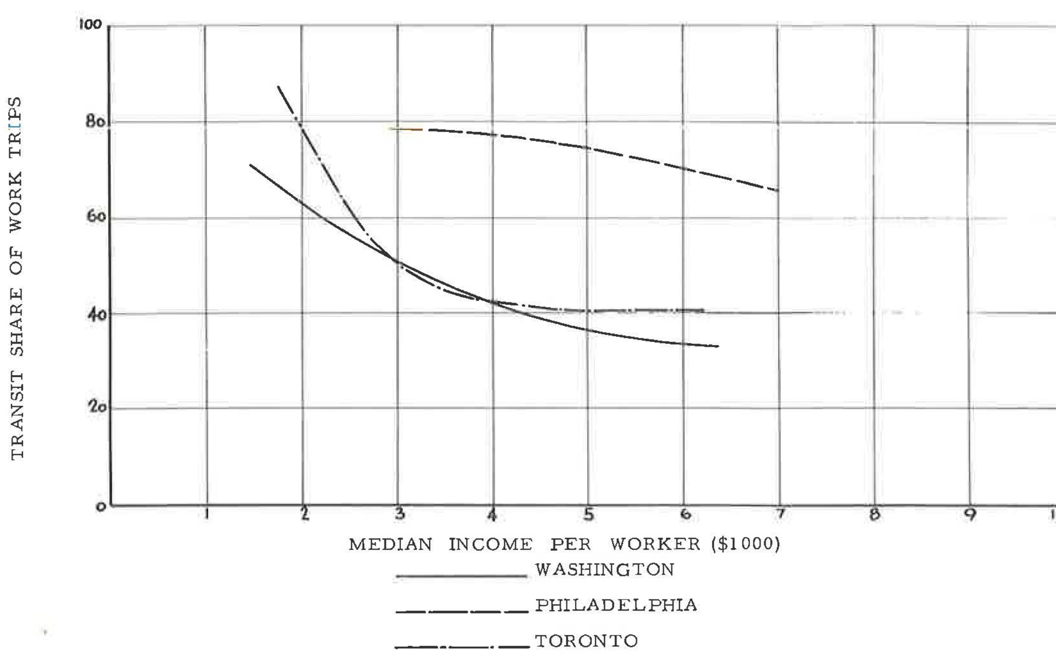

Figure 4. Income diversion curve for work trips in peak periods (no. of trips in 1,000's).

Figures 1 to 4 show the unstratified relationships determined from the three-city work trip data. Differences in slope and intercepts of the relationships are generally due to the interactance of the remaining factors which vary from city to city, i.e., low transit fares in Toronto and Philadelphia relative to auto costs, compared to higher transit fares in Washington relative to auto costs and the effect that rapid transit facilities have on modal choice behavior in Philadelphia and Toronto, but not in Washington, due to an entire bus-streetcar system. The relationships once stratified by the remaining factors demonstrate less significant differences.

SOURCES OF DATA

The major source of information concerning travel mode in metropolitan areas was O-D surveys, reporting how people actually traveled from their origin to trip destination when faced with the relative time, cost and convenience of competing modes of travel. The analysis was not based on interviews asking people how they would like to travel.

To relate the observed travel mode to the five determining factors, supplementary data of parking surveys, published mass transit route schedules outlining headways and fares, and the census providing population and household characteristics were necessary to augment the O-D survey data. Although supplementary information was obtained from independent sources it was generally considered representative for the sample trip interchanges, where the survey sample was chosen according to random selection procedures.

The following surveys were the major source of data for each of the three metropolitan areas:

1. Toronto journey to work survey, 1954: a survey reporting how workers actually traveled.
2. Washington home-interview O-D destination survey, 1955: a survey reporting how people traveled, their trip purpose, trip start and arrival time and type of parking facility used by auto drivers.
3. Philadelphia home-interview O-D survey, 1960: a survey reporting how people traveled, their trip purpose, trip start and arrival time, type of parking facility used by auto drivers, toll bridges crossed and trip maker's income.
4. Washington Federal employee journey to work survey and Washington private employee journey to work survey, 1961: surveys reporting how workers traveled to CBD areas, trip start and arrival time, transit fare of transit passengers, parking cost to auto drivers, walking times at the trip O and D and income grade.

Generally, survey trips are reported for the individual modes of travel, or combinations of the following: (a) auto driver, (b) auto passenger, (c) railroad, (d) elevated subway, (e) bus, (f) streetcar or trolley, (g) taxi passenger, and (h) truck passenger. Trips involving transfers between different modes were linked and assigned the mode code of highest priority. The mode priorities were as follows: (a) railroad, (b) elevated subway, (c) streetcar and subway, (d) bus, and (e) auto, auto passenger.

The mode stratifications were different between surveys. However, this was disregarded where the basic distinction between the two main types of travel mode was maintained. Grouping of travel modes reported in the surveys were made in order to comply with the two main types of travel modes.

Transit share of O-D traffic was calculated from the data thus grouped for the three metropolitan areas. The transit share expressed as percent of the total O-D interchange volume was correlated with the basic determinants which were calculated using the survey or supplementary information.

Travel Times

Departure and arrival times were reported for each trip of the surveys with the exception of the Toronto survey, thus providing all the information needed for the time determinant for both mass transit and motor vehicular trips. Portal-to-portal travel times of the two modes were calculated by differencing the two times.

In the case of Toronto, procedures were implemented to estimate the travel times by mode from each zone centroid to all other centroids. Knowledge of the relationships between travel speeds and prevailing traffic flows was used to estimate travel times by auto for each O-D worker movement. Travel times on the public transportation facility, not including waiting or transfer times, were based on scheduled speeds as recorded by the Toronto Transit Commission for their service in operation in the Metropolitan Toronto Area. Using a minimum path algorithm, travel times were calculated for each O-D interchange. Terminal times were added to the travel times to provide an estimate of the portal-to-portal time.

Travel Costs

Mass transit fares were generally determined from transit fare schedules. In those cases where different fares applied for railroad and other transit travel, weighted average fares were computed which were dependent upon the observed percent usage of the submodes. In the single case of the 1961 Washington journey-to-work trip surveys, the costs of transit trips were reported and therefore could be used as the source.

Automobile operating costs were calculated based on empirical formulas derived by Bevis (3) and May (4) which show average fuel consumption as a function of average speed. Average speed for each O-D pair was based on average travel distance data and automobile running time data (portal-to-portal minus estimates of terminal time). Appropriate cost per gallon of fuel was determined for each city to give fuel costs. To the fuel costs were added the proportion of oil and lubrication costs determined for a motor vehicle trip.

Average automobile parking costs were obtained for zones comprising the study areas by determining the average rates of commercial, private (government if applicable) and street facilities and the utilization thereof. The average parking costs were computed by weighting the rates of facilities according to the number of drivers serviced by each facility. With the exception of the 1961 Washington journey-to-work surveys where parking costs were reported, parking costs were derived in this manner. Since one-way trips were the basis of the study, parking costs were divided by two to give one-way parking costs.

In the case of Philadephia, toll charges were a component of some motor vehicle trip costs. When calculating motor vehicle trip costs, therefore, a toll cost for crossing the Delaware River was included. An average toll cost per O-D motor vehicle interchange was determined by combining information of percent usage of each bridge and the toll cost.

Thus the average automobile travel cost for each O-D pair was obtained by summing the (one-way) parking cost at the O or D, bridge tolls and the one-way operating cost based on average travel time and distance, and dividing this cost by the average automobile occupancy figure for the O-D pair in question, as reported by the survey.

Taxis and truck passenger trips were a small proportion of total motor vehicle trips. Consequently, automobile costs were assumed as representative of the costs of the general motor vehicle. Any discrepancies due to taxis and truck passenger trips were considered to be negligible.

Service Times

With the exception of the 1961 Washington journey-to-work survey, no information about excess transit times (walks, waits, and transfers) was reported. Walk times were reported in the particular Washington survey, but other excess times (waits and transfers) were not given and had to be computed by reliable estimating procedures.

Average wait and transfer times were determined by a procedure of tracing O to D transit routes and computing average times from the many route combinations. Experts of the transit system generally considered the results representative of the actual situation. Average walking times to and from transit stops in each zone were determined in a systematic manner based on geometric formulas. The formulas were based on the postulation that the average walking distance to transit stops was related to the following factors:

1. Developed land area serviced (acres);
2. Number of miles of transit routing;
3. Stop spacing (miles); and
4. Location of transit in developed area with respect to population centers.

Walking times to parking facilities plus the delay at the facilities were taken as a measure of convenience of motor vehicle travel. Such times were considered negligible at the home end of the trip but significantly important at the non-home end of the trip. Walking times were generally determined from the available O-D survey data. Average walking times were obtained by converting walking distance data of a parking survey, on the basis of a walking speed of 3 mph. Estimates of parking delay times were generally based on knowledge of lot and garage operation. These aggregate totals were considered representative of the total excess time for travel by auto.

Economic Status

Income-per-worker data were derived from population and household statistics of the 1950 and 1960 censuses (1951 in case of Toronto). This derivation was employed in the case of Washington and Toronto. However, income data for Philadelphia were taken from the home-interview survey and converted to income-per-worker data.

Comparative analysis of modal choice behavior in various cities necessitated expressing income data in terms of the real buying power in a base city. The Washington dollar of 1961 was chosen as the basis. Both Philadelphia and Toronto income data were adjusted to express incomes in terms of 1961 Washington constant dollars; i.e., real buying power as compared to the buying power of a dollar in Washington.

DERIVATION OF MODAL SPLIT RELATIONSHIPS

The comparative analysis of modal choice behavior in different cities was conducted exclusively with work trip data. The conclusions reached concerning the three-city work trip relationships generally should apply in the case of non-work trips, excluding school trips. The modal split of school trips will be governed by the policy of school boards with regards to location of schools to population centers and provision of school bus service. The modal split described for work trips naturally does not take such extraneous factors into account.

All types of non-work trips (excluding school), if considered, would be grouped together as one category, because the peak-hour period of time is of immediate interest for travel movement forecasting studies and such trips make up less than 25 percent of total trips at that time.

Relationships must be determined from trips made in a specific period of the day, either the rush hour or off-rush hour, as travel time and transit services differ significantly between the two periods. It is expected that differences in travel mode choice are completely explained by the differences in these two determining factors, therefore, either may suit analysis purposes. However, the rush-hour period is most suitable because of the concentration of work trips in that period. Time ratio diversion curves stratified for the remaining factors were determined for the AM rush hour (7:00 to 9:00 AM) from the three-city data, to demonstrate trends of transit usage among workers.

Stratification of Data

The unstratified curves in Figures 1 to 4 would be unsuitable for travel movement forecasting purposes because they show on a given curve the effects of one determinant only, while the effects of all other determinants are submerged in each curve. These unstratified curves are useful to indicate the overall effect of each determinant, but for forecasting purposes it is necessary to stratify the observations further so that the effects of each determinant may be seen explicitly.

In order to stratify the modal split relationships based on these data properly, it was necessary to define meaningful ranges of the factors which were to be stratified. These ranges were chosen such that each covered a roughly equal variation of the factor in question.

The cost ratios were subdivided in the following 4 ranges: (a) transit trip is cheaper; (b) equal trip costs; (c) transit is more expensive; and (d) transit is 50 percent more expensive.

The service ratios were divided into the following 4 ranges: (a) equal service time; (b) transit service time is higher by a factor of 4; (c) transit service time is higher by a factor of 6; and (d) transit service time is much higher.

The economic status was subdivided into the following 5 ranges: (a) low income; (b) intermediate income; (c) moderate income; (d) high; and (e) very high.

O-D data were stratified for each type of trip, into 80 categories, depending on which range of each of the three stratified factors applied to each O-D pair. Then for each group, a curve was determined by regression analysis and plotted showing percentage use of public transit as a function of travel time ratio. For each city data, there is a set of about 80 time ratio transit diversion curves, one curve for each combination of cost ratio, service ratio and economic status.

Grouping of Data

Individual stratified O-D observations were not plotted. A grouping procedure was carried out to remove random scatter in the data before determining the modal split curves.

Upon grouping O-D observations which fell into equidistant time ratio intervals, weights were assigned according to the total interchange volume, and the weighted average transit usage was calculated for the average point in each time ratio interval. Next, the grouped data were plotted on graph paper. Linear, and in a few cases curvilinear, curves were drawn as best fit through the plotted data, which generally agreed with the least squares fit to the ungrouped data.

In a few instances the best fit to the grouped data did not agree with the least squares fit to the ungrouped data. However, the least squares fit to the grouped data was within the confidence limits of the relationships based on ungrouped data. Also the fit to the grouped data was more consistent with known trends as indicated by data from the same source and by data of other cities. Consequently, it was concluded that the best fit to the grouped data would be more reliable in travel movement forecasting.

Observed Modal Choice Behavior

Figures 5 to 9 show observed modal choice behavior among workers, expressed for the four determining factors. Relationships based on selected survey data from each sample survey and for each metropolitan area are demonstrated.

Within each set of stratified relationships the effects of time, cost, service, and income can be seen quite clearly. Generally, it can be seen that the slope of the curves increases for increasing values of cost ratio, service ratio and economic status. That is, as public transit becomes relatively less and less competitive in terms of travel time, demand for its use falls off more quickly among prosperous people and those paying relatively low transit fares continue to use transit in fairly large proportions. By the same token, these curves show that high percentages of travelers are using public transit for trips in which it is fairly competitive with the private automobile in terms of travel time and excess time, even though transit is relatively expensive and/or the travelers in question are of high economic status.

STATISTICAL VALIDITY OF RELATIONSHIPS

Most of the points comprising the curves (Figs. 5 to 9) have a number beside them representing the number of thousands of observed trips on which each point was based. Points with no number were based on fewer than 500 observed trips. Points representing large numbers of observed trips have more statistical significance than points representing small numbers of trips, and the more significant points have been given more weight in drawing the curves. Each point shown actually represents the average of a number of points which were grouped together when they fell within a small range of the independent variable of the curve (time ratio).

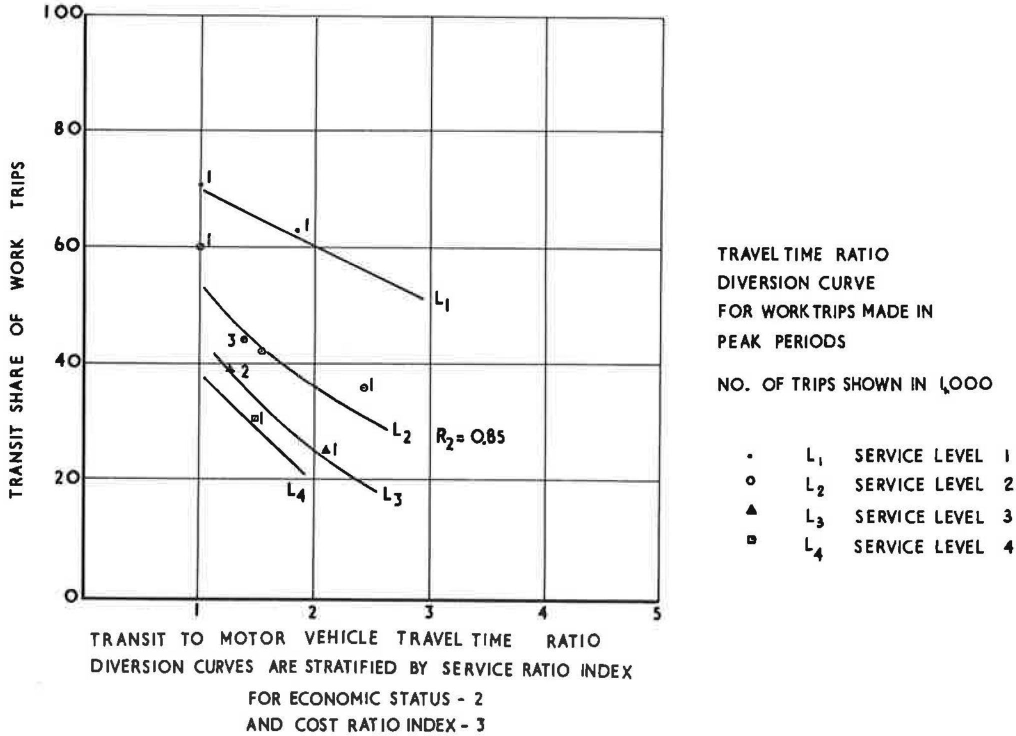

Figure 5. Home-interview survey data, Washington Metropolitan Area Transportation Study, 1955.

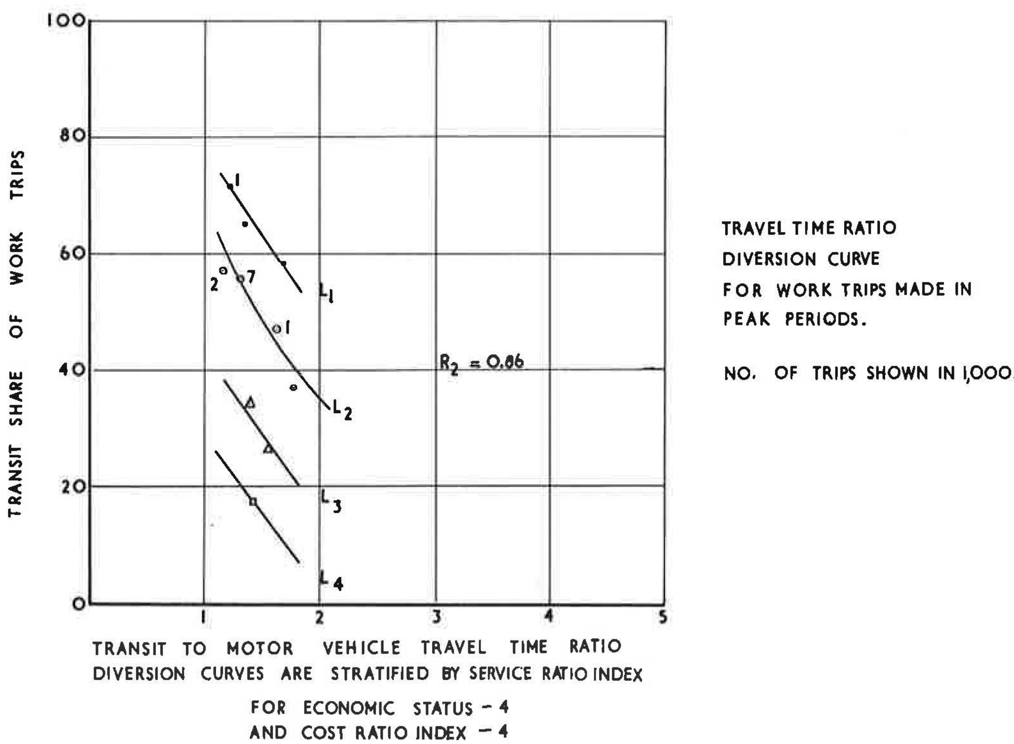

Figure 6. Federal employee parking and transportation survey data, 1961.

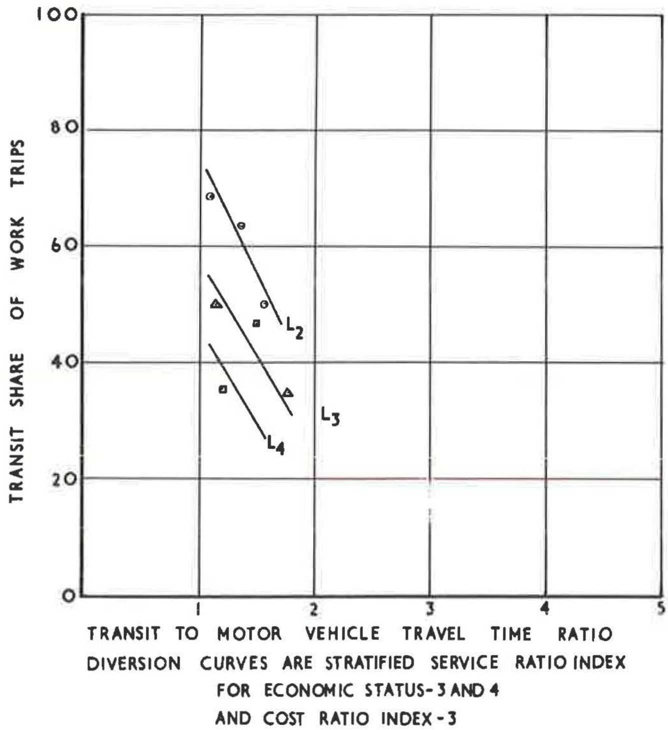

Figure 7. Private employee work trip survey data, National Capital Transportation Agency, 1961.

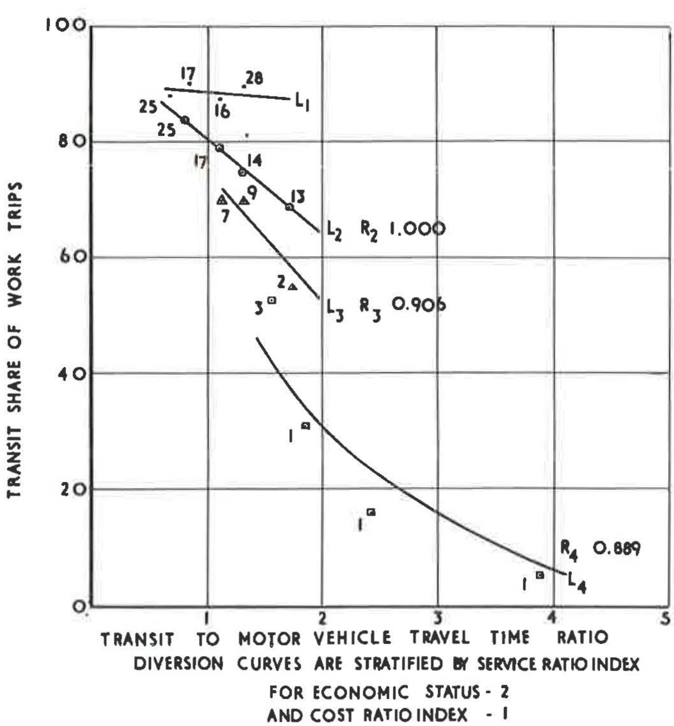

Figure 8. Worker survey data, Metropolitan Toronto Planning Board, 1954.

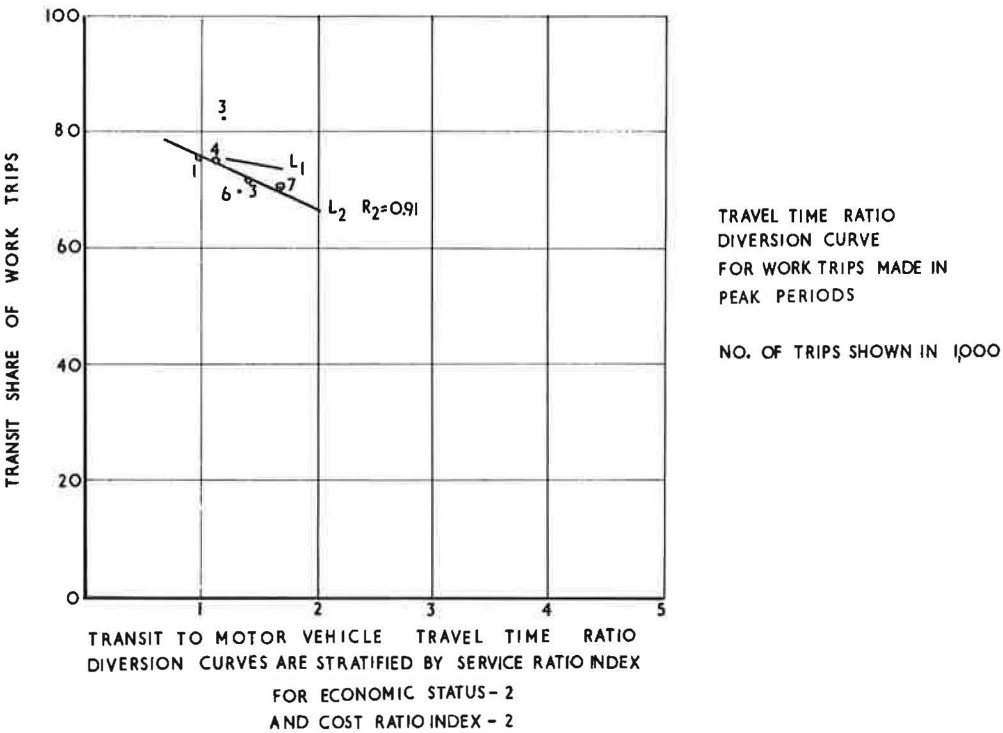

Figure 9. Home-interview survey data, Penn-Jersey Transportation Study, 1960.

Individual observations were subject to random variances. The random variances were mainly due to two factors: survey sampling error and the effect of zone size.

Survey Sampling Error

The magnitude of sampling error is a function of the observed number of person interchange trips. The more people who report trips, the greater is the confidence that the sample is representative of the whole population. Consequently, survey sample size regulates the magnitude of this component of random variation. A theoretical approach to estimating this error is based on the theory of the binomial probability distribution.

For the case of a 1-in-20 sample survey, Table 1 shows the dependency of one standard deviation of percentage usage on differing expanded trip interchange volumes V and different mean usage P.

TABLE 1

ONE STANDARD DEVIATION FOR VARIOUS VALUES OF V AND P
(Sample Size of 1-in-20)

V \ P	10	25	50	75	90
40	21	29	35	29	21
80	14	20	24	20	14
160	10	14	17	14	10
200	9	12	15	12	9
320	8	10	12	10	8
400	7	9	11	9	7
600	6	7	9	7	6
800	5	6	8	6	5
1,000	4	5	7	5	4

Effect of Zone Size

In order to simplify data handling, trip ends are grouped into O and D zones or districts which are in some cases of considerable size. The travel time, cost, and service between a pair of such zones must, of necessity, be average values which describe the trips between them as well as possible. However, the average values of these determinants will be lower than the values for trips starting and ending at extreme opposite sides of the two zones and higher than the values for trips between the near edges of the two zones. This will cause the trip makers to split between travel modes in different proportions than will average travelers between the two zones, leading to scatter in the observations. Similar scatter will be caused by the fact that inhabitants of most zones are not homogeneous as regards income, and yet must be treated as if they all had the average income for each zone.

These two sources of error are to some extent in conflict because a reduction in zone size, to decrease averaging errors, leads to an increase in sampling errors unless the relative sample size is increased substantially. Although there is a scatter in the observations when O-D pairs with like determinants are grouped together, the scatter is within expected limits, and the relationships between modal choice and the five determinants show up clearly.

The standard deviation of the ungrouped points around the grouped point, with regard to the dependent variable, is a good indication of the validity of the grouped point. The standard deviations of these groups have been calculated and have been found, in general, to be less than what was expected from the two sources of random variation. Clearly, each of the grouped points in Figures 5 to 9 are truly representative of actual travel behavior.

The next step in assessing statistical validity was to examine the degree of correlation, as shown by the grouped points, between the percent transit usage and the time ratio.

For each curve based on more than three grouped points, a value of R, the coefficient of correlation, is given. This quantity is defined as follows:

$$R = \sqrt{\frac{\sum_{n} (y - \bar{y})^2 - \sum_{n} (y - Y)^2}{\sum_{n} (y - \bar{y})^2}}$$

in which

y = observed percent transit use as shown by a grouped point for a given value of the time ratio;

$\bar{y}$ = average percent transit use of all grouped points for curve in question (i.e., for all values of time ratio);

Y = fitted percent transit use from curve itself, for each value of time ratio for which a grouped point exists; and

n = number of grouped points on which curve is based.

The coefficient of correlation provides a measure of the relative portion of the variation in the values of the percent transit use which is explained by dependence on time ratio. That is, if y remains nearly constant for all values of time ratio, the coefficient of correlation R will be small or zero. If, on the other hand, y varies clearly and systematically with time ratio, and there is little scatter of the observed points around the fitted curve, then R will be close to 1.00, its highest possible value.

Figures 5 to 9 show that R is generally high enough to show a clear dependence of percent transit use on the various determinant factors.

COMPARISON OF MODAL SPLIT RELATIONSHIPS FOR THE THREE CITIES

Investigations of modal choice behavior within a metropolitan area and between metropolitan areas demonstrated a similarity of trends of transit usage.

Submodal choice behavior was shown to be similar when expressed by the five basic determining factors. These findings supported the statement that the various modes of travel can be divided into two main types. Such evidence appears to be sufficient for travel movement forecasting where empirical observations of travel behavior are based on small sample surveys.

The use of transit for CBD and non-CBD oriented travel, use by government and private employees, and use by workers over a six-year period (1955 to 1961) were shown to be statistically similar. This further confirmed that no differentiation has to be made for CBD and non-CBD oriented travel other than to reflect the differences in time, cost and service. Most important, the relationships apparently demonstrate a stability between types of workers and especially a stability over a period of time.

Statistical tests and visual comparisons of modal split relationships conclusively showed that transit use by workers in the three cities was similar when expressed by the four determining factors.

Statistical Tests of Significance

The student t-test was used to test the similarity between the corresponding sets of data. For each set, the slope of the line of best fit and its intercept on the vertical axis were calculated and compared with the slopes and intercepts of other sets. The level of significance of the difference between sets of data was obtained from t-distribution tables. The assumption is made here in conducting these tests that there is a linear fit to the data. Generally, a linear fit to the three-city data seemed to apply; in a few dissenting cases where curvilinear fits were indicated because of points with small weights at opposite ends of the scale. such data were deleted before the statistical comparisons.

The general form of the t-ratio was

$$\frac{m_1 - m_2}{\sqrt{s_1^2 + s_2^2}}$$

in which

m = the variate to be tested; and
s^2 = the variance of each set of data.

Because of the heterogeneous nature of the survey data, it could not be presumed that each set of data would have equal standard deviations. In applying the formula, and in calculating the corresponding degrees of freedom, solutions were incorporated which make provision for this heterogeneity (5, 6, 7).

The criteria for evaluating the results of the t-tests were:

1. A level of significance equal to or greater than 0.05 indicated no significant difference between the sets of data.
2. A level of significance between 0.05 and 0.01 was inconclusive of whether any significant difference did or did not exist.
3. A level of significance less than 0.01 indicated that there was a statistically significant difference between the sets of data.

Tests of Significance of Submodal Behavior

It has been stated that the relative use of alternative submodes within the public transit mode is also dependent on similar determinant factors: time, cost, service, and economic status. Using Philadelphia data, a statistical evaluation was carried out to offer some insight to this consideration.

All railroad trips were assigned appropriate time, cost, service, and economic status data for the calculation of representative determinant factors. Likewise the determinant factors were calculated for public transit trips, referred to here as transit not involving travel by railroad. In each case the usage of the submode was shown as a percentage of total O-D trip interchange. Consequently, the use of submodes was directly comparable.

Where sufficient comparable data were available T-tests of coincidence were conducted for the submodal relationships. In all but one case the tests showed that differences in slopes and intercepts were insignificant at the 5 percent level. In one case the level of significance was greater than 1 percent, hence the results were inconclusive as to whether any difference did exist (Table 2).

TABLE 2

PUBLIC TRANSIT SUBMODAL TIME RATIO DIVERSION CURVES DATA STRATIFIED BY EC, CR, SR
(Rail vs Transit)

EC	CR	SR	Slope t-Ratio	Level of Significance	Intercept t-Ratio	Level of Significance
3	2	1	0.81	0.40	0.32	0.70
3	2	2	1.62	0.10	0.20	0.80
3	3	2	0.47	0.60	2.15	0.03*
4	2	1	2.02	0.10	2.05	0.10
4	2	2	0.18	0.80	0.54	0.50
4	3	2	0.11	0.90	0.62	0.50
4	3	3	2.91	0.05	3.10	0.05

*Inconclusive results.

Similarity of Modal Choice Behavior Within a Metropolitan Area

The similarities of modal choice behavior between CBD oriented and non-CBD oriented travel, between government and private employees and between workers over a 6-yr time period were confirmed by statistical tests of significance, based on survey data of the Washington Metropolitan Area.

1. 1955 CBD Work Trips vs 1955 Non-CBD Work Trips (Table 3a). —In all cases tested, the level of significance between these sets of data was greater than 0.05, indicating that on a statistical basis there was no significant difference between the sets of data.

TABLE 3

SIMILARITY OF MODAL CHOICE BEHAVIOR WITHIN A METROPOLITAN AREA

E	C	L	Slope t-Ratio	Level of Significance	Intercept t-Ratio	Level of Significance
(a) 1955 CBD Work Trips vs 1955 Non-CBD Work Trips						
1	3	2	1.19	0.25	1.46	0.10
2	3	2	0.33	0.70	0.60	0.50
2	3	4	0.41	0.60	0.16	0.80
3	3	4	0.28	0.70	0.16	0.80
3	4	4	0.84	0.25	0.46	0.40
(b) 1955 CBD Work Trips vs 1961 Federal Survey						
3	3	3	1.88	0.05	2.13	0.05
3	4	2	1.45	0.10	1.08	0.25
3	4	3,4	0.10	0.90	0.10	0.90
(c) 1961 Federal Survey vs 1961 Private Survey						
3,4	2	2	0.54	0.60	0.86	0.40
3,4	2	3	1.03	0.40	1.23	0.40
3,4	2	4	1.24	0.20	0.93	0.30

2. 1955 CBD Work Trips vs Federal Survey (Table 3b). —In all cases tested, the levels of significance between the paired data were in the range that indicated no statistically significant difference existed between the sets of data.

3. 1961 Federal Survey vs 1961 Private Employees Survey (Table 3c). —In all cases tested, the comparison indicated no significant difference between the sets of data.

Similarity of Modal Choice Behavior Between Metropolitan Areas

T-tests of concidence of relationships were employed to determine if significant differences of modal choice behavior (for work trips) existed between metropolitan areas which were not explained by the four major determinants. The tests generally showed that differences were statistically insignificant at the 5 percent level and were otherwise generally inconclusive at the 1 percent level. On the basis of such tests, it was concluded that the relationships were statistically similar. Any dissimilarity was definitely less than the variation within the survey data. Either large sample surveys or special market research type surveys would have to be carried out to disclose the nagnitude of dissimilarities, if they do exist.

It was not possible to make a comparison between all O-D trip data of each metropolitan area because of a different distribution of data over the time, cost, service ratio and economic status scales. The median worker income for Toronto was in the range of the second economic status level, whereas the median incomes for Washington and Philadelphia were in third economic status level. Although there were ample data for low cost ratios in the case of Philadelphia and Toronto, there were no such data in the case of Washington. Large variations of service ratio existed in all three cities, so that direct comparisons were possible for service ratios over the complete range.

Of the 17 groups for which comparisons were made, 11 indicated no significant differences for either slope or intercept. One comparison indicated significant differences and the remainder were inconclusive on the slope comparison and or intercept comparison (Table 4).

TABLE 4

TIME RATIO DIVERSION CURVES; GRAPHS STRATIFIED BY EC, CR, SR

Comparison	EC	CR	SR	Slope t-Ratio	Level of Significance	Intercept t-Ratio	Level of Significance
Philadelphia	2	1	1	1.05	0.30	0.61	0.50
vs	2	1	2	1.25	0.40	1.23	0.40
Toronto	3	1	1	1.96	0.10	1.61	0.10
	3	1	2	2.87	0.01*	2.38	0.025*
Washington	2	2	1	0.64	0.50	0.86	0.40
vs	2	2	2	0.10	0.90	0.91	0.30
Philadelphia	3	2	1	3.72	0.005**	3.99	0.01*
	3	2	2	3.77	0.001**	4.51	0.001**
	3	3	2	0.38	0.70	0.18	0.80
	4	3	3	0.88	0.40	0.12	0.90
Toronto	2	2, 3, 4	1	0.50	0.60	0.51	0.60
vs	2	2, 3, 4	2	2.22	0.02*	0.60	0.50
Washington	2	2, 3, 4	3	1.62	0.10	0.17	0.80
	2	2, 3, 4	4	2.39	0.02*	1.60	0.10
	3	2, 3, 4	1, 2	1.86	0.05	2.28	0.02*
	3	2, 3, 4	3, 4	1.73	0.05	0.43	0.60
	4	2, 3, 4	3, 4	0.19	0.80	0.15	0.80

*Inconclusive results.
**Significant differences are apparent.

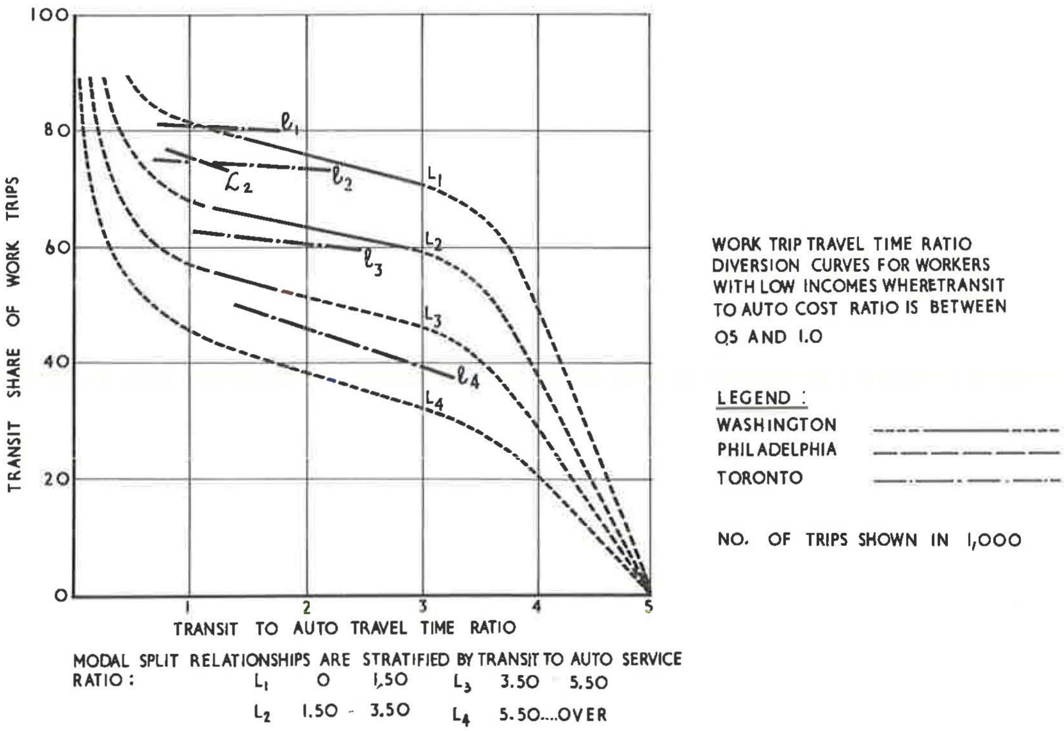

Figure 10. Direct comparison, Philadelphia, Washington and Toronto.

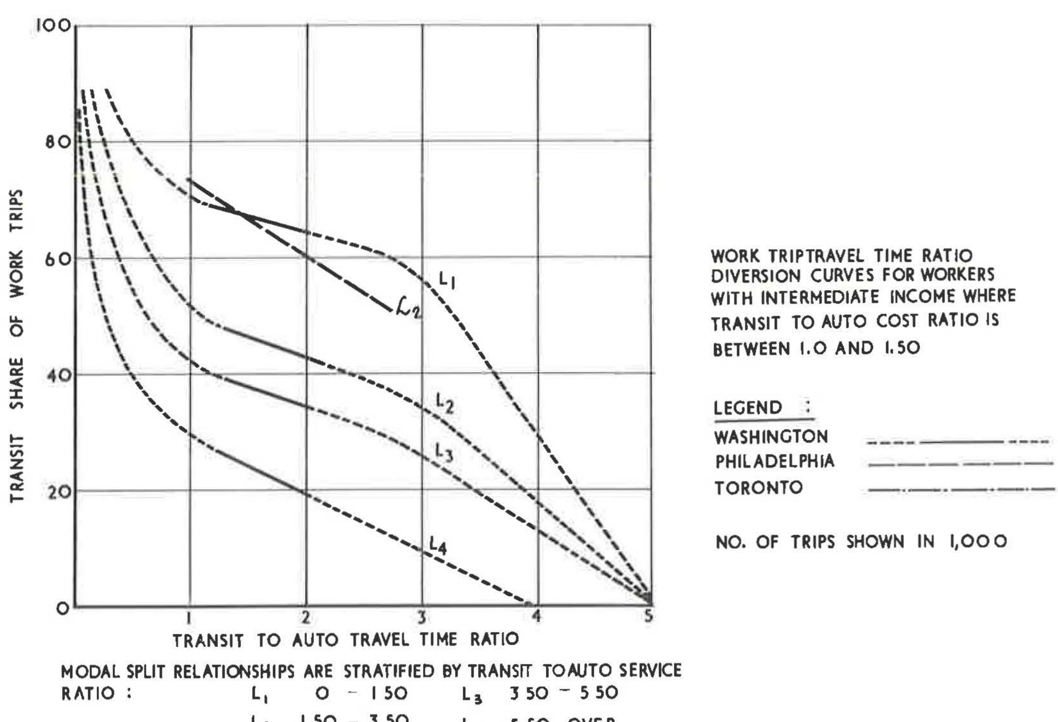

Figure 11. Direct comparison, Philadelphia, Washington and Toronto.

The findings were encouraging, as modal choice behavior was apparently similar between cities. Modal split relationships of cities such as Philadelphia and Toronto can be employed to augment the Washington relationships for those situations where no local supporting survey data are available, etc. This does not mean a direct substitution of relationships, but only an extrapolation of known trends in the most probable direction of occurrence as indicated by corroborative data from the other cities.

In addition to the statistical comparisons, this conclusion is borne out by visual comparison of the three city relationships (Figs. 10 and 11).

CONCLUSIONS

Based on the above comparisons it may be concluded that travel mode choice behavior for trips to work, as related to the four basic factors, time, cost, service and income, is stable over time and is similar in Philadelphia, Washington and Toronto.

A major difficulty in these comparisons is that stratification of data into 80 groups, although necessary to isolate the effects of the determinant factors, has the result of reducing the number of survey reported trips in some of the stratified groups to levels for which statistical sampling variance can be quite large (Table 1). Comparisons between data for three cities have removed most of these uncertainties because similar trends have been established for the three cities. Similar reassurance may be gained from the fact that forecasts using these relationships will focus attention mainly on heavily traveled corridors where the large numbers of trips involved tend to cancel out statistical variances. Further analyses and comparisons of travel mode choice behavior, based if possible on large sample surveys, are desirable to increase knowledge in this important area. Meanwhile, modal split relationships derived for each metropolitan area and verified by comparative analyses for the remainder, may be used with confidence for urban travel movement forecasting studies.

In particular the relationships have been incorporated into a modal split model which is being used for travel movement forecasting in Washington (8) and in Toronto (9).

Relationships for non-work trip purposes were derived from the Washington data and were a component of the Washington model. Although, unsupported by other city data at that time, they were considered adequate for the purpose of travel movement forecasting.

Although the comparative analyses have demonstrated statistical similarity between the modal split relationships for Washington, Philadelphia and Toronto, the transportation planner who may choose to use directly these relationships for travel movement forecasting in another city is cautioned concerning their direct use. Ten percent differences in absolute usage exist in some cases between the three sets of relationships. These differences are probably due to random variation, inherent in the data of small sample surveys, and perhaps also due to other factors characteristic of the population and or transportation system, which have not been included in the model. Since a measurable range of random variance is expected in the survey data which generally exceeds the 10 percent difference between curves of the three cities, it is difficult to determine other sources of difference from the basic data alone. Special large sample surveys or surveys of a market research type are required to determine these sources.

This 10 percent difference in absolute usage reflects a significant difference between estimates of demand for a transportation system. The differences could influence a transportation decision regarding the number of freeway lanes or capacity requirements for public transportation facilities.

It is recommended that some analysis of survey data for a city be conducted to determine precisely the intercepts and positioning of the curves on the usage scale. Although the slopes should generally agree with those of Washington, Philadelphia and Toronto, the intercepts may disagree by 10 percent. The derivation of new relationships from sample survey data and comparative analyses with other city data will give the transportation planner the assurance he requires to apply modal split relationships in travel movement forecasting.

The investigations described in this paper have been essential and exploratory research into the factors which motivate people in their choice of mode. The finely stratified data presented here in the form of time ratio diversion curves lend themselves to careful scrutiny of partial effects and comparison with data from different sources.

Following the careful examination of the role of the determinants in mode choice and the numerous interrelationships, investigations are now proceeding to determine whether mathematical functions will adequately describe modal choice behavior as explained by the stratified diversion curves.

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