Travel Mode Split in Assignment Programs

D. M. HILL, Research Analyst, Traffic Research Corporation, Toronto; and
NORMAN DODD, Transportation Research Planner, Metropolitan Toronto Planning Board

• DURING THE PAST two years the Traffic Research Corporation of Toronto has been developing and testing an electronic computer "traffic prediction program" (Fig. 1). This is a basic, highly flexible, planning tool that is being used by the Metropolitan Toronto Planning Board to develop a transportation plan comprising road, transit, and rail commuter systems.

To be capable of estimating traffic movements on each system the traffic prediction program must contain a mechanism able to forecast the division of total O-D movements between each of the available travel modes.

This paper deals with the studies carried out to develop this mechanism—referred to as the travel mode split—its incorporation and operation in the traffic prediction program, and finally, the results achieved in the estimation of 1956 traffic movements.

Studies firstly disclosed the factors influencing people's choice of travel mode and their order of importance, and secondly, enabled the establishing of a mathematical model that would represent the mechanism at work when people are confronted with the choice of travel mode.

There are two primary travel modes—travel by public transportation in buses, streetcars, subways, and commuter trains, and travel by private vehicle in automobiles, taxis, and trucks. The distinction between the two modes is characterized by the free movement of the private vehicle, as opposed to that of public transportation which is bound to schedules and routes.

People are influenced by many factors in their choice of travel mode, such as relative travel time, economic motivations, and the regularity and convenience of service. Using regression analysis methods, the influence of each of the factors was investigated separately and trends in transit usage were established.

Once mass human travel behavior was sufficiently explained by various factors, a mathematical model (the travel mode split) was designed to duplicate present behavior. Assuming no changes in human motivations, one can justify its application to future conditions.

The model of travel mode split is an inseparable component of any traffic prediction program. Such a program should contain a direct feedback mechanism using capacity restraints to allow the resultant traffic flow patterns to affect all components of the traffic prediction program including the travel mode split.

The travel mode split was incorporated in a traffic prediction program. It was used to forecast intra-city O-D traffic flows for all modes across various screen lines and on major city roads in metropolitan Toronto for the period of 1956. Close agreements between estimated and observed flows were obtained in most cases.

FACTORS INFLUENCING PEOPLES' CHOICE OF TRAVEL MODE

People are influenced by many factors in their choice of travel mode. These factors will be characteristic of the relative travel time, the social-economic status of the population, the influence of relative costs on the population groups, and the regularity and convenience of service.

Investigations were conducted to establish trends in transit usage with each of these factors. Much of the primary information used in these investigations was obtained from O-D surveys.

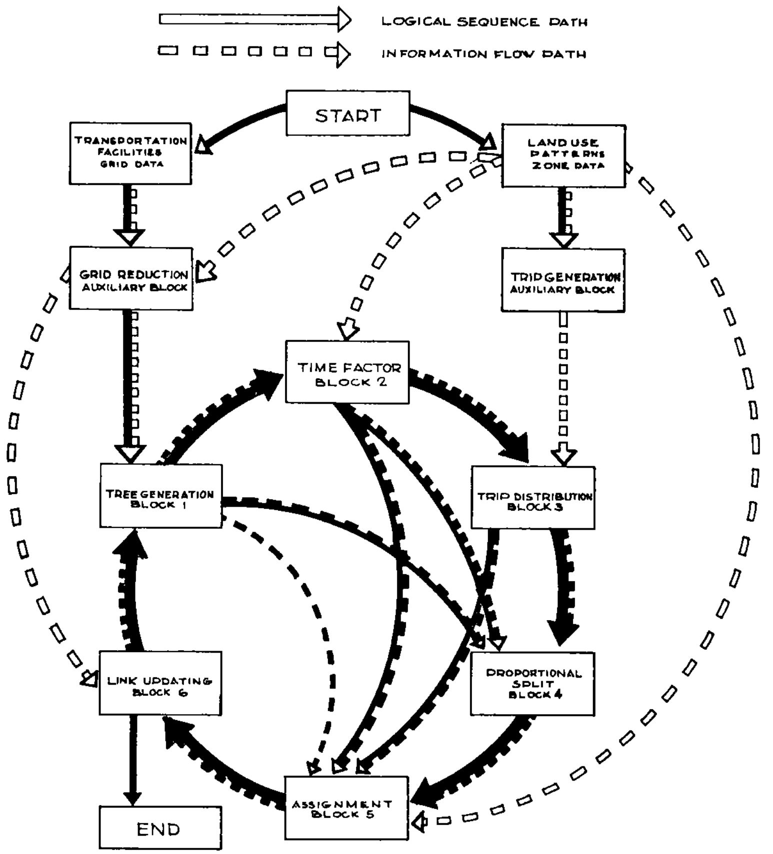

Figure 1. Traffic prediction program.

SOURCES OF INFORMATION

Surveys

Workers' Survey.—In the metropolitan Toronto area approximately 25 percent of establishments employing at least 30 people were surveyed in 1954. The questionnaire distributed was designed to establish the location of the worker's home, his place of employment and his mode of travel. Following the expansion of all reported trips and the processing of this information, a complete record was available of the total movements of this group of workers between zones by mode of travel.

Home Interview Survey.—Approximately 1 ½ percent of all households in metropolitan Toronto were surveyed in 1956. The interviews were conducted to obtain information about the number of persons per household, number of cars per household, and the occupants' travel behavior, i.e., how many trips were made by the occupants, the purpose of the trips, the mode of travel used, the place of departure and arrival, etc. By expanding the survey and processing of the results much information was available about such factors as population density, car ownership density, and trip characteristics.

Land-Use Survey.—Tables of 1956 existing land uses (in acres) were prepared from data derived from field surveys and aerial photographs. Land use was classified by such categories as residential (single dwelling units), residential (multiple dwelling units), hotels, commercial establishments, institutions, utilities, parking lots, transportation (railways), roads, open spaces, and vacant lands.

Some of the supplementary information was taken from the 1951 and 1956 Census Report of the Dominion Bureau of Statistics. In addition, information not available from the sources mentioned but essential for establishment of factors influencing people's choice of travel mode such as relative travel time and level of O-D transit service, was derived from transit schedules, transit route maps, and maps of the road layout. The data thus synthesized were carefully checked before implementation. The procedures of derivation used are discussed in their respective sections.

For the purpose of reducing the volume of survey data on hand the metropolitan Toronto area was subdivided into zones. The boundaries of the zones were made identical in all surveys so that they coincided with the zone layout used by the Dominion Bureau of Statistics.

For the purpose of further simplification a "center of gravity" was established for each zone, thus all trips are recorded as trips to and from fixed points—the centroids of the zones. Using a grid superimposed on the city map the centroids of zones were assigned coordinates where the X-axis of this coordinate system was taken parallel to the direction of the main east-west streets. This is especially justified in cities with a rectangular road layout.

There is a small sampling error inherent with a high percent sample, consequently the workers' survey is used in the regression analysis to establish most trends in transit usage. The other surveys are used to supply the necessary supplementary information.

STUDIES OF FACTORS

The relative importance of factors identified from the survey data is described in detail in the subsequent paragraphs. Only the major factors are mentioned, such as time, economic motivations, regularity and convenience of service. Other factors were eliminated from further investigations, once shown to be highly correlated with the major factors.

Travel Time

People are conscious of time elapsing while traveling, consequently they are likely to choose the mode of travel that keeps this time to a minimum. The choice may be related to the difference between travel times of the two modes; however, such an approach overlooks the relative importance of this difference as travel time increases. For example, a 10-min difference between travel times of 10 and 20 min is more critical than between travel times of 20 and 30 min. At this time the best approach seems to be to represent the time difference as a percentage of one of the travel times. This is equivalent to saying people's choice of travel mode is related to the ratio of the travel times.

Travel times for the O-D movements reported in the workers' survey were not available. Consequently, steps were taken 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 implemented to estimate rush hour 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 rush hour service in operation in the metropolitan Toronto area on October 24, 1955.

To establish stable trends of travel behavior, a systematic grouping of all observations is necessary. The grouping of information tends to eliminate extraneous influences, and discloses the primary influence of a selected factor. The system of grouping requires that the entire spectrum of time ratio be divided into ranges, each of fixed length.

On grouping observations in this manner, the average transit share of all person-trips was calculated for each group and plotted on graph paper with the average travel

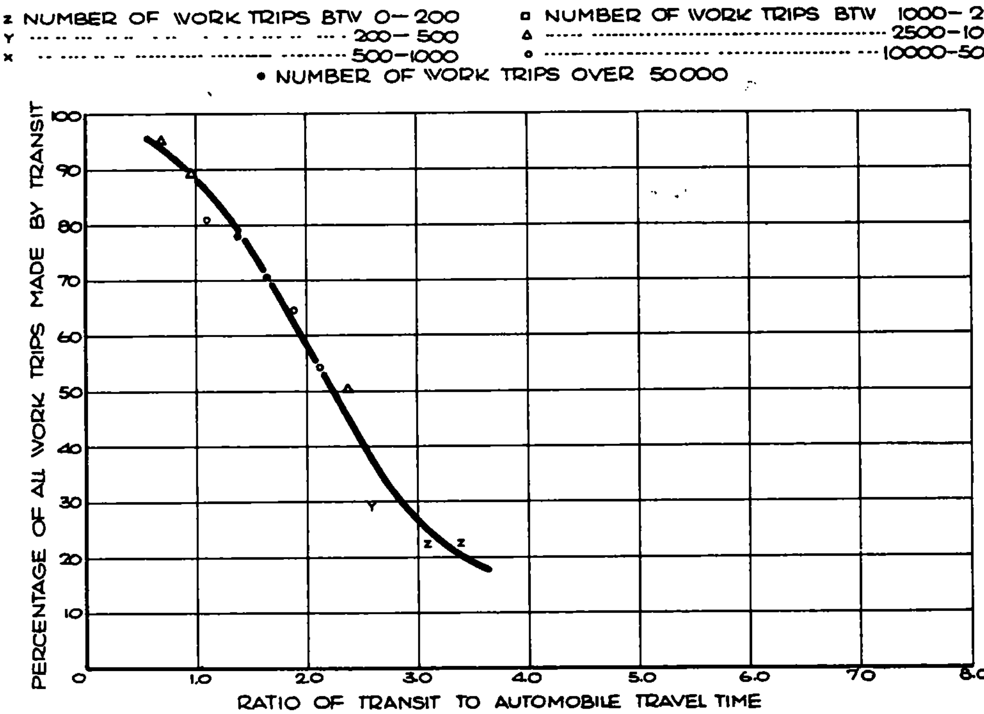

Figure 2. Transit share of work trips related to travel time ratio.

time ratio. A curve was drawn through the plotted observations to show the predominant trend in transit usage.

The observations are coded according to the number of person trips reported for each group observation. Because extraneous influences are more likely submerged in large groups than in small groups, group observations reporting a large number of person trips tend to be more reliable than groups reporting a small number and naturally the curves should agree closely with these reliable observations (Fig. 2).

Economic Motivations

In choosing a mode of travel people consider the relative costs of travel. However, the importance of cost is related to people's economic status, which at this time is considered best measured by family income. One expects that people of low economic status are more conscious of travel costs than people of higher economic status who can afford more expensive modes. For changes in travel costs (such as increases in transit fares) people are likely to choose a new mode of travel, because either they find traveling by their present mode is now too expensive or both modes are equivalent in terms of cost and they are now more conscious of other factors, such as relative travel time and the regularity and convenience of service.

Neither income statistics nor comparative travel costs for each mode of travel were reported with the workers' survey. However, steps were taken to provide this information.

The census report of the Dominion Bureau of Statistics for the year 1951 was reviewed. The review provided information about the median incomes of male and female workers residing in each zone. Although worker's income had increased with rising standard of living between 1951 and 1954, one is justified in assuming that workers during 1954 still received the same income relative to their neighbors' income. The 1951 income scales, uniformly graded up to 1954 standard of living, were considered representative of people's economic status in 1954. Consequently, the worker population of each urban zone was assigned an economic indicator with a range of values from 0 to 35 depending on the median income recorded in each zone.

Figure 3 shows the relationship between the transit share of work trips and the economic indicator for the worker population. The observations are coded according to the number of person trips. Also, the fitted line agrees closely with the heavily weighted observations.

The influence of the relative travel cost is considered connected with the economic indicators. Measurements of the relative cost of travel were made subsequent to a review of the following sources of information:

1. Public transit zone maps and fare tables.
2. "Economic Evaluation of Traffic Networks," by G. Haikalis and H. Joseph. The review provided estimates of the operating costs of an automobile based on speed and distance of travel. The operating cost was set equal to the sum of the running and accident costs. Running costs included gas, oil, and maintenance expenses. High accident costs at low speeds of travel were expected to be representative also of travel discomfort experienced at these low speeds.
3. Annual reports of the Parking Authority of Toronto. The review provided a record of parking charges in zones serviced by off-street parking lots. Relationships established from such data showed that parking costs increased as the demand for parking exceeded a given supply. These relationships were used to determine parking charges in other zones.

Regression analysis was conducted to correlate changes in transit usage with the travel cost difference. Trends were disclosed that were approximately coincident with similar trends in transit usage for changing levels of the economic indicator. Constant increments of costs were shown to cause changes in transit usage that could be

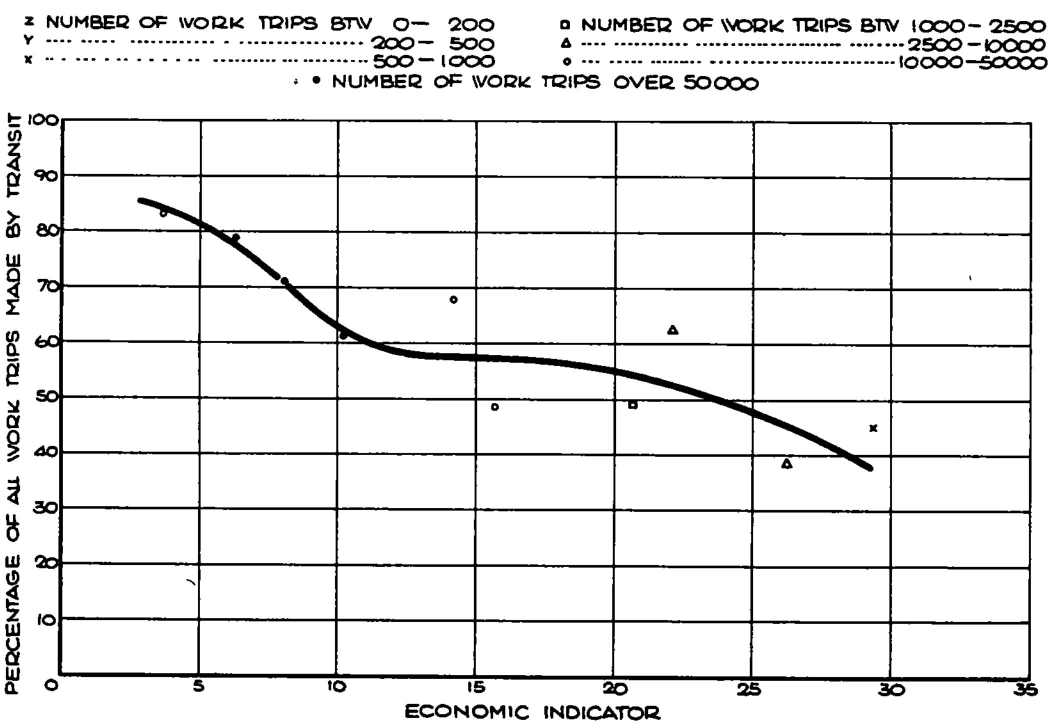

Figure 3. Transit share of work trips related to economic indicator.

explained by a constant increment in the economic indicator. These findings supported the deduction that people of a set economic status alter their travel behavior when changes in costs of travel occur, so that their behavior duplicates that of people of a different economic status. Consequently, it was concluded that the influence of changes in relative cost of travel would be reflected by a linear adjustment in the established economic indicator of the worker population.

Regularity and Convenience of Service

The private vehicle offers a more luxurious and convenient mode of travel than does public transportation, particularly by eliminating lengthy waiting periods and walking times. However, waiting periods and walking times are important considerations when using transit because they reflect the level of service offered on the public transportation facility. People tend to measure the regularity and convenience of public transportation service in terms of the time spent in addition to traveling, such as walking from the trip origin to the station, waiting time at the station, transfer time between route changes, and walking time from the station to the trip destination.

The following steps were taken to calculate these measurements:

1. Waiting Times.—The waiting time at a station is set equal to one-half the scheduled headway time of the public transportation facility in a zone as recorded by the Toronto Transit Commission for rush-hour service on October 4, 1955.

2. Transfer Times.—It is reported that approximately 90 percent of subway passengers make at least one transfer, approximately 50 percent of all transit passengers make one transfer, and 10 percent of this number make two or more transfers. Despite the introduction of a small error, each O-D transit movement is recorded with one transfer. This transfer time is set equal to one-half the scheduled headway time of the public transportation facility in the destination zone.

3. Walking Times.—Although walking times were not reported in the surveys, there was sufficient information available, such as the number of miles of transit track, the average spacing between stations, and the number of acres of developed land in a zone, to make possible the computation of average walking times to and from transit stations. A few assumptions concerning first the location of transit lines with respect to the zone boundaries and secondly, people's walking behavior, were necessary for the estimation of these average walking times.

Because transit routes follow the rectangular road layout of the city, it was assumed that approximately one-half of the transit lines servicing a zone run north-south and the other half east-west. Also, one can assume that people tend to walk to the nearest transit station located on a transit route that runs parallel to their desired direction of travel.

If the north-south and east-west transit lines are evenly distributed throughout the same developed area, then the following formulas may be used to compute representative walking distances, and walking times, which people may experience in each zone.

The average distance walked in miles,

$$D = \frac{1}{3}\sqrt{d^2 + w^2} + \frac{d^2}{6w} \cdot \ln\left(\frac{\sqrt{d^2 + w^2} + w}{d}\right) + \frac{w^2}{6d} \cdot \ln\left(\frac{\sqrt{d^2 + w^2} + d}{w}\right)$$

in which

$d = \frac{1}{2} \times$ stop spacing, miles,

$w = \frac{A_D}{L_T} \times \frac{1}{640}$, miles,

A_D = number of acres of developed land,

= total land—vacant land—open space,

L_T = number of miles of transit track.

The average walking time in minutes,

$$T = \frac{60}{3} \times D \quad \text{(walking speed of 3 mph)}$$

The level of O-D transit service is measured by the sum of the walking plus waiting time in the origin zone, a transfer time, and the walking time in the destination zone.

Observations were grouped and plotted on graph paper. A curve was drawn through the grouped observations to show the relationship between transit usage and the changing levels of O-D transit service (see Fig. 4).

DEVELOPMENT OF TRAVEL MODE SPLIT MODEL

Knowledge of the order of magnitude of the factors that influence people's choice of travel mode is especially important if the mechanism at work in the travel mode split is to be adequately explained. The trends in transit usage now established indicate the relative order of magnitude of the influence of the three factors:

1. Relative travel time.
2. Economic indicator as recorded for the population (based on average travel costs).
3. Level of transit service between origin and destination.

To formulate a mathematical model for the purpose of projection of transit usage the relationships between these factors and the transit share of person trips are united into a single model. The expected trends in travel behavior are shown in Figure 5.

The following condition is satisfied by this model of travel mode split: Population groups indexed by a high economic indicator, place more emphasis on time and comfort than cost considerations. Other population groups with a low economic indicator possibly ignore time and comfort considerations to choose a mode of travel they can afford to use. This mechanism is duplicated in the model where transit usage by persons of high economic status is more elastic with changes in the travel time ratio than transit usage by persons of low economic status.

The transit usage of person movements reported in the workers' survey was strati-

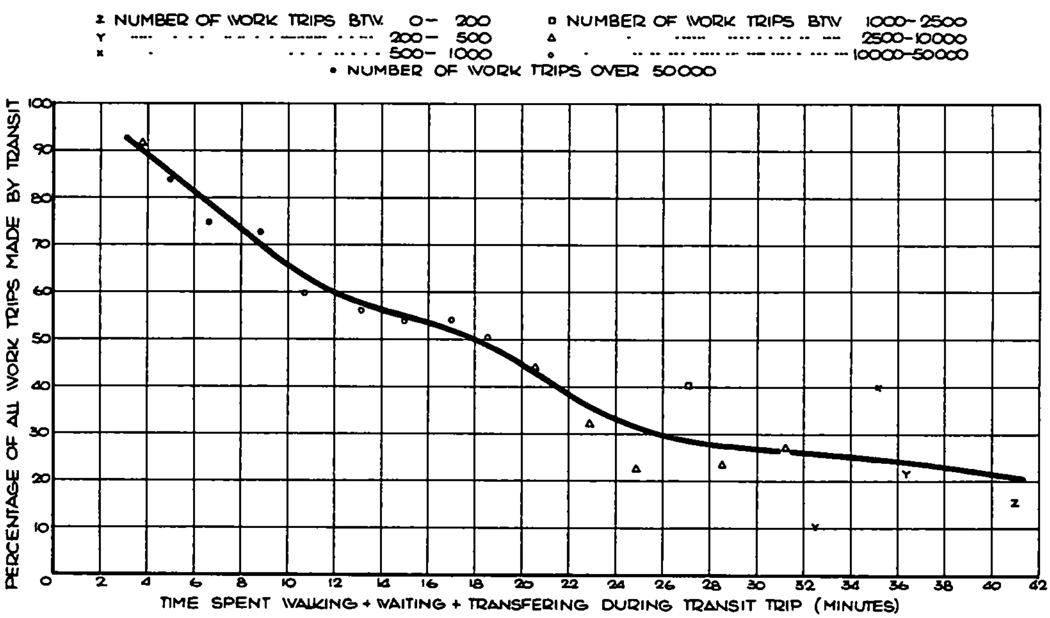

Figure 4. Transit share of work trips related to total walking and waiting times.

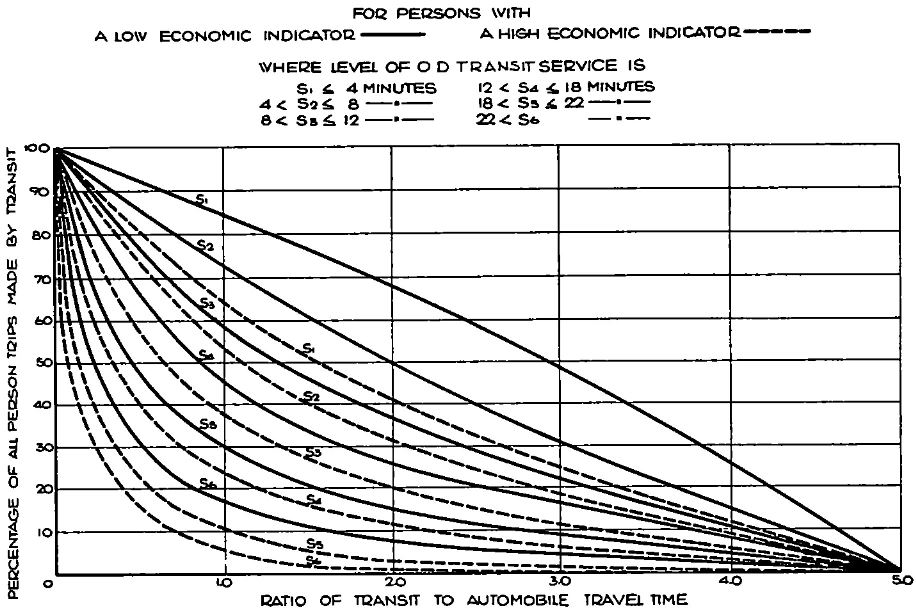

Figure 5. Model for forecast of transit share of person trips.

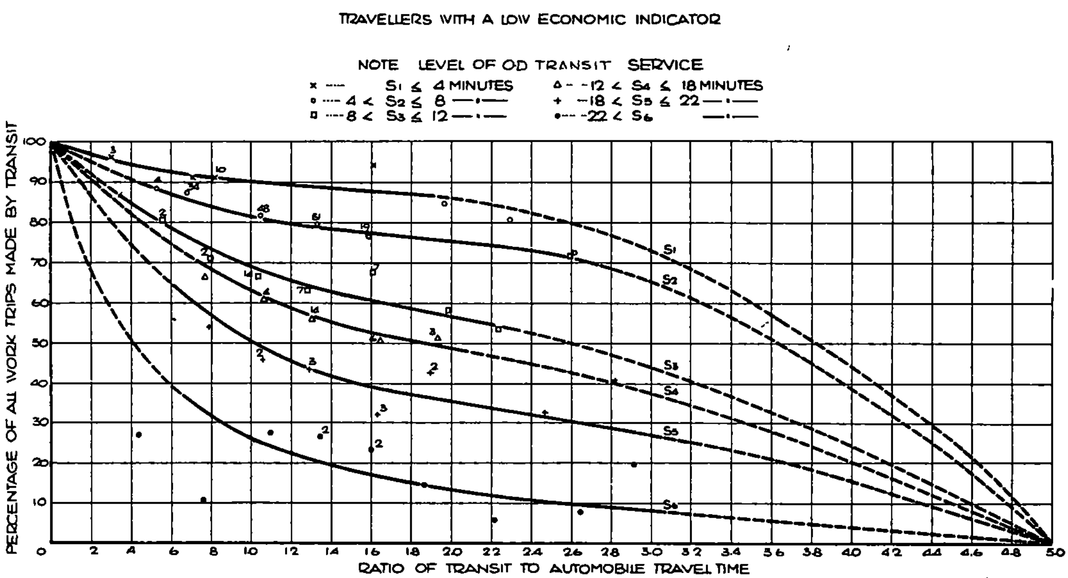

Figure 6. Transit share of work trips related to ratio of transit to automobile travel time.

fied by the economic status of the population and by levels of O-D transit service. Once the observations were stratified, transit usage was next correlated with the transit to automobile travel time ratio. The observations were assigned weights according to the number of person trips (unit = 1,000) grouped together for each interval of time ratio. Curves were drawn through the plotted observations to demonstrate the trends in transit usage (Figs. 6 and 7). Dotted lines are extrapolated beyond the range of observations to indicate the postulated trends.

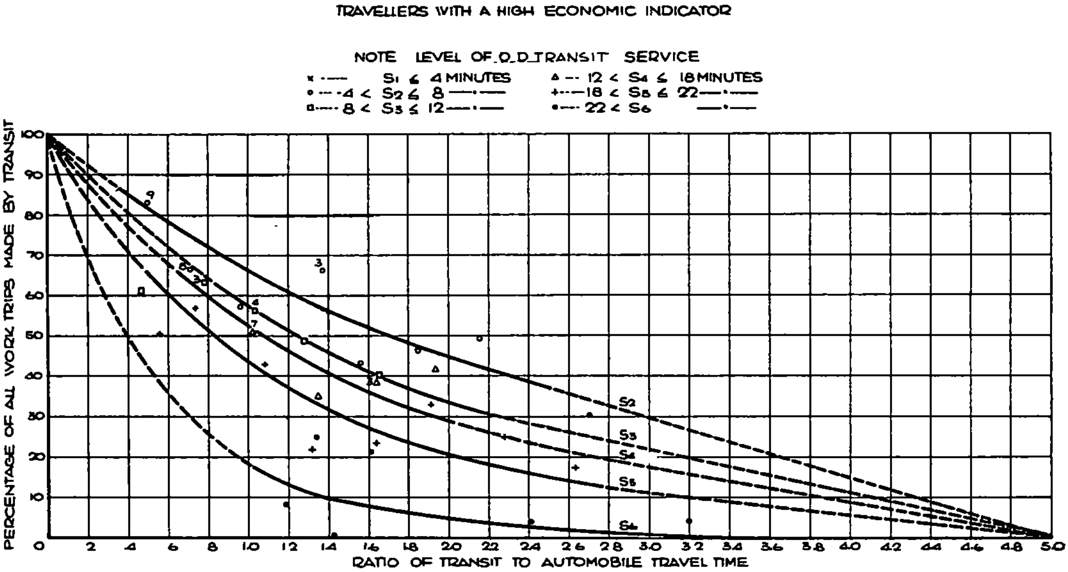

Figure 7. Transit share of work trips related to ratio of transit to automobile travel time.

Although these established trends are characteristic of work trips, further studies indicated that they approximately duplicate the behavior of people who make business, commercial, or school trips in autos or on transit during the rush hour.

The behavior of people making social trips appeared to differ from the behavior of people who make other types of trips.

In the analysis of the data of the home interview survey, social trips were less than 1 percent of total trips made during the morning rush hour and 3 percent of total trips made during the evening rush hour. If the model is used to determine the transit usage during the morning rush hour, the resulting discrepancy of calculating the transit share of social trips is negligible.

It is a well-known fact that estimates of traffic for the morning rush hour are more reliable than the traffic estimates for the afternoon rush hour, because of the predominance of work trips and the absence of other types of trips. It was concluded that curves for the estimation of the transit share of work trips (such as those shown in Figs. 4 and 5) will give accurate forecasts.

TRAVEL MODE SPLIT IN A TRAFFIC PREDICTION PROGRAM

The travel mode split model determines a realistic split of the O-D traffic between privately-owned vehicles and public transportation. Other components of the program calculate route assignment factors by travel mode to be used for assigning the O-D transit traffic to surface transit routes, subway routes, rail and bus commuter routes, likewise O-D vehicular traffic to local streets, arterial roads, and expressways.

The travel mode split is a component of the time factor block, one of the following six program blocks of the model:

Block 1	Tree generation
Block 2	Time factor
Block 3	Trip distribution
Block 4	Proportional split
Block 5	Assignment
Block 6	Link updating

Auxiliary blocks such as grid reduction block and the trip generation block are necessary to summarize land-use data and data characteristic of the transportation facili-

TRAVEL MODE SPLIT IN TIME FACTOR BLOCK

Thirty curves that describe the relationship between the transit share of traffic and the travel time ratio are expressed in table form for input to the time factor block. Each curve describes the transit usage of a specific population group for a specific level of transit O-D service. The population is divided into five groups where the first group are people of low economic status, and the fifth group are people of high economic status. There are six levels of transit O-D service, the first representative of very regular and convenient service, the sixth representative of irregular and inconvenient service.

To calculate the transit and/or vehicular share of O-D traffic for the AM rush hour the order of steps is as follows:

1. The economic indicator that is representative of the population residing in a home zone is linearly adjusted by a multiple of the travel cost difference for each O-D movement. The travel cost difference equals the sum of operating costs, accident costs, and parking charges minus the transit fare.
2. The regularity and convenience of service is measured by the sum of waiting, transfer, and walking times likely to be experienced in each O-D movement. The waiting time is set equal to one-half the average headway time of the transit facility in the origin zone. Walking times are calculated for both the origin and the destination zones, then added together. One transfer time is included, this is set equal to one-half the average headway time of the transit facility in the destination zone of the traffic.
3. Average O-D travel times are calculated for the vehicle mode and the transit mode. Transit O-D travel time is divided by the vehicular O-D travel time to form the travel time ratio.
4. The adjusted economic indicator and the level of O-D transit service specify the travel mode split table to be used. The travel time ratio then indexes the transit share of each O-D movement.

RESULTS OF A TRAFFIC ASSIGNMENT

The traffic prediction program was used to forecast total traffic via alternate modes for the historical period 1956 when traffic counts were made at various cordons, on major roads, and on surface transit and subway facilities. The results of this forecast are shown in some of the figures.

At the completion of eleven iterations (one initial, ten complete), stable traffic flow patterns resulted. During the first five complete iteration (2 to 6) new routes were generated, traffic was resplit, redistributed, reassigned, and travel times on links re-evaluated. In the final five iterations, (7 to 11) the program iterative cycle was complete with the exception that no further routes were generated. The first iteration provided an unrestricted assignment and an estimate of the ideal system cost; i.e., total time of persons, subject to ideal travel conditions (off rush hour), on roads in autos, in trucks, or on transit. The final iteration provided the traffic flows and system cost that would exist under peak-hour, congested conditions.

An analysis of results shows close agreement between total estimated and observed traffic crossing cordons, transit traffic crossing cordons via transit corridors, and transit traffic on the Yonge Street Subway. Most deviations between the observed and estimated counts are within day-to-day traffic fluctuations (10 to 20 percent).

CONCLUSIONS

The travel mode split with its ability to assess and reassess the division of traffic between alternative transportation systems is an essential component of any traffic prediction program. Consequently, the traffic prediction program simulates human behavior on roads. The sufficient accuracy of the results in the traffic assignment for a historical period warrants the model's application to transportation planning.

The scope of the model's application will widen as future research and experience is gained in the use of the model. Also, this research will undoubtedly result in further refinements of the program.

ties. The summarized data are then used as basic input data for the model. The sequence of information flow between each of the six blocks and between the six blocks and the auxiliary blocks is shown in Figure 1. A brief explanation is given here to explain the function of each block; a more detailed description can be found elsewhere (1).

Auxiliary Blocks

Grid Reduction. —The area to be studied is manually divided into zones. Land-use data of each zone such as population, the number of dwelling units, and car registration are attached to each node centroid.

Road and transit networks are represented by a detailed grid of links and nodes, where a link is the travel path between two adjacent nodes.

Trip Generation. —Relationships established from survey data are used by this block to estimate how many trips by purpose are made by the urban population during the AM rush hour. The output of the block provides an estimate of the traffic generated in each zone, and also of the traffic to be attracted to each zone.

Main Program Blocks

Tree Generation. —The tree generation block determines routes of travel and consequently travel times from each node centroid to all other node centroids. Up to nine routes for each origin destination pair may be generated.

Time Factor. —The time factor block determines the propensity to travel for various trip purposes from one zone to another zone (time factors). The transit share, and consequently the private vehicular share of traffic is simultaneously calculated for each O-D movement (travel mode split factors). Lastly, the proportion of private vehicular and/or transit traffic to be assigned to alternate routes of travel is calculated (route assignment factors). At this time, both the time factors and route assignment factors are functions solely of the travel time. The travel mode split factors are alone functions of several factors, one of which is time.

Trip Distribution. —The trip distribution block takes into account the time factors and also the opportunities offered for beginning and ending trips in each zone. Consequently, the block estimates by trip purpose how many people in total will travel from one zone to another zone.

The Proportional Split. —The proportional split block uses total O-D trip volumes of the trip distribution block, travel mode split factors, and route assignment factors to evaluate how many people will travel via each mode and on each alternative travel route from zone to zone.

Assignment Block. —The assignment block assigns the O-D split trips to each link of each route. This calculation provides estimates of traffic flows via each mode, on each link of the transportation network.

Link Update Block.—The link updating block uses the assigned link loads to evaluate the current travel time on each link of the grid. This evaluation is based on empirical formulas derived from speed vs traffic flow studies.

During successive iterations (6 complete blocks) of the program new travel routes are found, the traffic is resplit, redistributed, and reassigned. The information flow continues until stable traffic flow patterns are attained. The forecast in iterative steps is completed when the following observations are made:

1. There is little change in the system cost (total time spent traveling in autos or on transit).
2. There is little change in the distribution of the traffic (trip frequency remains stable).
3. There is little change in the traffic flows on all links of the transportation network.

Consequently, a series of program iterations duplicates human behavior as people will be influenced by changing travel conditions until they are content that their choice of route, travel mode, and trip destination is best among all possible choices.

REFERENCES

1. Irwin, N., and von Cube, H. G., "Capacity Restraints in Multi-Travel Mode Assignment Program." HRB Bull. 347, 258-289, (1962).
2. Adams, W. T., "Relationship of Use of Transit and Automobile in Urban Areas to Principal Factors Influencing That Use." U. S. Bureau of Public Roads (1959).
3. Trueblood, D. L., "Effect of Travel Time and Distance on Freeway Usage." HRB Bull. 61, 18-37 (1952).
4. von Cube, H. G., Desjardines, R. J., and Dodd, N., "Assignment of Passengers to Transit Systems." Traffic Engineering, 28:No. 11 (Aug. 1958).
5. Griffith, B. A., and von Cube, H. G., "Evaluation of Alternative Subway Routes." Jour. City Planning Division, Proc., ASCE, Vol. 86 (May 1960).
6. Quinby, H. D., "Traffic Distribution Forecasts Highway and Transit." Traffic Engineering, 31:No. 5 (Feb. 1961).
7. Schwartz, A., "Forecasting Transit Usage." HRB Bull. 297, 18-35 (1961).
8. Sutcliffe, E. D., "The Transit Planning Study Including Rapid Transit." A Study on Highway Planning Part II for Metropolitan Vancouver, British Columbia.
9. Irwin, N. A., Dodd, N., and von Cube, H. G., "Capacity Restraint in Assignment Programs." HRB Bull. 297, 109-127 (1961).
10. Mortimer, W. J., "Transportation Usage Study." Cook County Highway Department (Dec. 1957).
11. Haikalis, G., and Joseph H., "Economic Evaluation of Traffic Networks." HRB Bull. 306, 39-64 (1961).