CPAS

Center Of Planning And Architecture Studies

Lecture Number Four

A NOTE ON TRANSPORTATION PLANNING

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The Process of Transport Planning

Introduction :

In every community, goods and persons have to be moved, using various modes of transport which show considerable technological and operational differences.

Each mode of transport requires a number of facilities (roads, railtrack, rivers, harbours, vehicles, tele communication systems, ...etc.) which together operate as a transportation system. This system has to provide the transport services required by the community concerned.

The transportation system requires investments in capital goods, operational organizations, space for its installations. The building and acquisition of physical facilities and the development of the organizational structure takes time. At the same time the system must be able at any moment to meet the transportation services demand by the community.

The development of the transportation system must be planned so that at any moment there is a coherent system serving the demand of the community in an operational way. This is the aim of transportation planning i.e. transportation planning could be defind as the activities which lead to coherent programme of activities in space and time for the creation of transport facilities.

Transport planning studies have been conducted in a large number of urban areas throughout the world during the past twenty five years. A process for conducting these studies has developed, and is still evolving, which attempts to provide a systematic method for solving urban transport problems.

The fundamental premise which underlines most transport - planning studies is that some future horizon - year equilibrium condition of an urban area is a meaningful state to attempt to predict and evaluate. In the typical study the most probable pattern of land development is predicted for the horizon year (usually twenty years ahead) and the transport demand created by the land use are estimated. A set of alternative transport plans is then generated for the horizon year; these plans incorporate varying amounts of highway, and public transport facilities. The operating characteristics of each alternative in the horizon year are then estimated in the form of flows on each link of the horizon year networks. The usual criterion for choice among the alternatives is that the difference between the collective benefits to users, in the form of reduced travel impendance, and the monetary costs of constructing and maintaining these facilities should be a maximum. The present planning process implies that there will be an orderly and easy identifiable sequence of public investments that will yield the horizon - year plan selected.

Why Is There Traffic In A Community

To participate in traffic or transport is not a social aim in itself. One moves over a road and takes part in road traffic at that moment because a human activity (sleeping, eating, working, shopping ...etc.) has been ended at a certain locality (the point of origin of travel) and one has decided on a next activity to carrded out at a locality (the point of destination of travel) which is geographically seperated from the point of origin of travel.

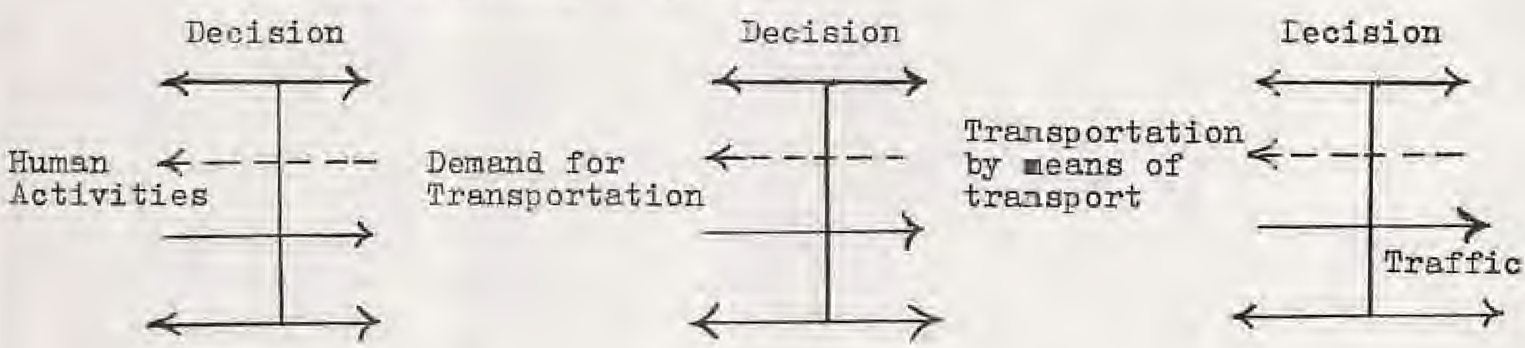
Thus a vehicle, carrying goods or persons moves only between places :

a- When a change in activity (with a good or by a person) is decided upon and the former activity has been ended;

b- When the locality of the following activity is geographically seperated from the locality where the ended activity was performed.

Only if these two conditions are fulfilled, there will be traffic on the road. Traffic volume is thus a reflection on the intensity and diversity of social life and of the geographical structure of the space in which this life takes place (e.g. density populated city versus agricultural area).

The process which leads to traffic appearing in a certain road (or station, or port, or airport,...etc.) can be presented in the following diagram :



If the demand for transportation cannot be met, or not be met sufficiently (e.g. because of traffic congestion or bad road conditions) the desired new activity cannot take place at the desired point of destination. As a result, development of society will take another course than originally expected. The process in the diagram is therefore reciprocal.

Retardation in social-economic development of an area is often caused by the lack of adequate transportation or traffic facilities in and to the area. On the other hand, there is no reason to develop the transport system in an area if there is no potential for socio-economic activities in the area (no population, no natural resources, unsuitable climate...etc.).

The Demand For Transportation

The demand for transportation can be divided in a demand for transportation of persons and a demand for transportation of goods.

Persons want to be transported for various reasons (purposes). This purpose of transport or travel can be described by naming the activity which has been ended at the point of origin and the activity which will be undertaken at the point of destination, e.g.

home - work (V.V.)
home - Shopping (V.V.)
home - School (V.V.)
home - Recreational activity ... etc.

The destination in purpose of travel is important because it influences greatly the type of person to be transported (employee, housewife, child, manager...etc.), the time of day when transportation is required, the destination to be selected, the distance to be travelled...etc., the choice of mode...etc.. The relative number of journeys for a single purpose varies in every city, region and country level of unemployment, level of income and level of car - ownership has a large influence.

The number of actual journeys observed in any area, does not reflect the full optential demand for transport. Actually one has a great choice between subsequent activities, e.g., one could stay in his bed, or go to work, or go to school, or to a football match, or visiting friends...etc. which activity is chosen?

Each possible new activity will give a certain degree of personal satisfaction (not necessary pleasure). Also if one has to move to another point in space one has to make sacrifice for being transported (it costs money, time, discomfort), one will select of destination j where the possible activity in total will give the greatest satisfaction.

i.e. $Uj = \max. \{ Ujbr - Zijtr \}$ where

Uj = net utility

$Ujbr$ = brute utility (profit) of the activity tobe started

$Zijtr$ = Sacrifice for transportation

A journey will take place, if there is at least one point of destination j for which $Uj \geq o$.

An improvement of the transportation system will induce latent demands for transportation to be materialized. New traffic is thus generated and traffic volumes after the improvement will be higher than before. The average number of journeys / inhabitant/ day (= mobility) in a region will therefore be a function of the average level of education and income of the population, and of the quality of the transportation system.

To be able to bring sacrifice (in money, time, and discomfort) there must be a reserve (budget) from which to meet this sacrifice.

Each person has a money budget, a time budget, and a discomfort budget. The scope of the budget depends on his personal income, his social role (employee, housewife,...etc) and mental and physical fitness.

Each of the three budgets has a part which is connected with the primary biologically and socially compulsary activities of life e.g. eating, sleeping, and personal care and providing for those activities (working to earn money to buy food, working to grow food, working in the household, preparing food, maintaining the house...etc.). The remainder of the budgets can be spent on secondary, non, compulsary activities, such as social gatherings, touristic travelling, sport,...etc.

The money budget (= expenditure) is determined by one's income in a developing country the average budget available per inhabitant will tend to increase and therefore the "weight" given to the cost of travel to decrease. As a result in a growing economy people travel more frequent, and / or over longer distance, and / or with a more luxurious mode of transport (bus instead of walking, car instead of bicycle, plane instead of boat).

The time budget has a fixed limit of 24 hours. Time spent on primary activities (work, personal care, sleep) taken on a workday from 18 hours in highly industrialized countries, to 24 hours in very poor, underdeveloped countries leaving "free time" in which to do "enjoyable things" and to travel from 6 to 0 hrs. At the same time, the higher developed the individual the higher free times is valued. Time spent on travelling will have a higher weight in higher developed societies than in little developed countries.

Discomfort suffered during travelling can be physical discomfort (walking, standing, noise, vibrations) and mental discomfort (fear, uncertainty, tension because of high frequency of decisions or difficult decisions). Intensive discomfort can be withstood if it has a short duration and can be followed by a period of recuperation. Extensive discomfort can be endured over a long period. The "budget" of physical discomfort depends on sex, age, physical fitness. The "budget" of mental discomfort depends on level of (educational) development, skill, experience, etc.

The above holds in principal also true for the movement of goods. However, goods don't want to be moved themselves. It is a person or organization which wants a goods to be moved. The reason that somebody wants to move a good can be:

a) because at the point of destination the good can be sold at a higher price (= has a higher market value). This is true for finished agricultural and industrial products;
b) because at the point of destination it can be transformed further towards its final form, suitable for consumption (agricultural and industrial half products, raw materials, etc.);
c) because it is a (spare) part for a tool or peice of equipment used for the production of goods, the provision of services or the movement of goods or persons and operating at the point of destination.

In case Ujbr is determined by the market value of the good at the point of destination. In case Ujbr is determined by the value of the loss of production or service suffered at the point of destination.

In goods transport the weight of money and time spend in transport relates to the cost price of the product at the point of destination. Discomfort suffered in passenger transport can be compared with breakage and general decline of quality in goods transport. The "weight" given to breakagedepends much on the type of good (raw material in bulk vs a fine piece of machinery vs flowers and vegetables).

The weight, assigned to each aspect of the transport sacrifice depends much on the purpose of the journey and secondary on sex, age, social position and income of the person involved. This will vary from region to region and from city to city.

For certain purposes of travel also the "reliability" of the journey is important, that is the margin between real time of arrival and the expected (planned) time of arrival at the point of destination. Sometimes it must be small, such as in home-to-work travel and in business travel. The demand for reliability in shopping travel will be much lower. The requirement for reliability in goods traffic is usually rather low.

The sacrifice, resulting from a fourney is for the whole of the journey, from door to door, and should include feeder transport such as walking to a station and driving from an airport. Often the sacrifice in feeder transport is larger than in the trip with the main mode of transport used.

In the case of goods, Ujbr is mainly determined by economic values, which in general can be expected in terms of money value. In the case of persons; Ujbr is, apart from certain economic values, largely determined by social-emotional values, which often hardly can be expected in money values (p.e. satisfaction derived from visiting a relative, or while recreating, etc.).

The Choice of Mode (means) of Transport

Once it is decided upon that a person would want to move or a good is wanted to be moved, a means of transport must be selected from amongst the means of transport that are available at the desired moment to move between the point of origin and the selected point of destination.

Often, a great number of means of transportation are available to the adspirant-traveller or shipper (in the case of goods) such as :

Propulsion by animal force

by foot
by animal (on horseback)
by bicycle
by animal drawn cart

private transport

by moped
by motorbicycle
by car/truck

as driver or as passenger

road transport

individual transport

Fee morning

by rowboat, canoe

by becak

by taxi
by bus

Propulsion natural force

by sailing boat
by motor ship (motor launch)

Propulsion by mechanical force

by airplane

professional transport

by tram
by underground (metro)
by train

colletive transport

by belt
by elevator
by cablecar
by rolling staircase

rail-bound

The named modes of transport are the so-called conventional modes and at present existing in most countries. They can be divided in categories, according to various criteria; p.e. according to

a. the medium in or on which the vehicles move: road, rail, water, air;

b. the number of passenger per vehicle: individual or collective;

c. the mode of exploitation: professional - the owner of the vehicle provides services against pay; private - the owner uses the vehicle to meet exclusively his own needs of transportation;

d. the freedom in lateral movement of the vehicle: free moving or railroad;

e. the source of traction : animal (including human), wind or mechanical.

The conventional modes of transport are listed according to their principal use. Occasional use, falling in another category, is possible and often the destination is not very sharp. e.g. the pleasure sailing boat is a private and individual means of transport. If someone takes a paying passenger in his boat, the vessel is used for professional transport, not for private transport.

The basic technological characteristics (medium, type of propulsion, and freedom of lateral movement) are fundamental with regard to all other, more organizational and operational aspects. This can be made clear by comparing the technological and operational characteristics of a few examples such as pedestrian, motorcar, bike, motorship and tram with regard to manoeuvrality, skill required from the driver, carrying capacity, size, investment cost, moving cost, availability, freedom in movement over the infrastructure, etc.

These different characteristics in practice lead to entire seperated "road systems" and organization of each mode of transport. In some cases the same road space can be used simultaneously be different modes, p.e. road traffic pedestrians, bicycles, becaks, cars, buses. But under circumstances this can lead to unsafe operation.

The transport system in any area therefore actually consists of a number of well seperated sub-systems with their own infrastructure, vehicles and operational organization: In order to work as a coherent system, transfer points are necessary between the sub-systems where people and goods transfer from one sub-system to another (bicycle stand, parking space, railroad station, airport, harbour, etc.).

The listed modes of transport are suitable for the transportation of people. Most of them can also carry goods. This is also true for the pedestrian. A few are principally used only for the movement of passengers, such as bikes, taxis, buses, trams, and a rolling staircase, although the passenger might carry some handluggage with them. Trucks are exclusively used for the movement of goods, although sometimes use by passengers occurs.

How does a person, who wants to move, selects his mode of transport from between the modes available to him at the moment he wants to move?

When somebody wants to move from an origin to a destination he will determine the values, he will allow for the various aspects of the sacrifice of the journey. He will compare these values with the values which he expects each possible available mode of transport to require for each aspects of sacrifice. He will decide on that mode of transport from which he expects the least total weighted sacrifice in comparison to the total of the values set by him before hand.

The selection process (modal choice) is a purely individual decision based on the subjective values which the individual attaches to the aspects of the sacrifice and what he expects to get from the modes of transport available to Him. Often his decision can look very irrational from all points of (others') view.

An analysis of data available on the values which the average person attaches to the services redered by the various modes of transport explains the apparent popularity of a number of modes, mainly those which fall in the category private, individual transport.

Whether a particular mode of transport is avilable to somebody at a certain moment will depend on :

a. the physical availability of the necessary infrastructure. To have a car and no road serves no purpose..This is (generally) determined by the government.

b. the physical availability of the necessary vehicle. To have a road and no car serves no purpose either. This availability is determined sometimes by a government controlled enterprise (railroad, sometimes shipping, air transport, buses), by a privately controlled enterprise (buses, taxi, shipping) or by the private individual himself (walking, bicycle, car, etc.). If he can avail over a private vehicle depends largely on his money income.

One of the principal aims of transportation planning is to improve on the infrastructure, on the operational organization of the various transportation subsystems and on the operational coordination between the subsystem through government action. As a result physical availability of transportation facilities to all or particular segments of the population will increase, and/or the sacrifices to move over the system will decrease. As a result the net utility of existing and latent movements of persons and goods will increase and general socio-economic activities will be stimulated.

The availability of non-private vehicles is also usually the responsibility of government, and normally forms part of transportation planning.

The availability of privately-owned vehicles, such as bicycles, mopeds, and private cars depends on private vehicle-ownership, which in turn is a function of the level of private income. Any increase in average income results always in a substantial increase in private vehicle ownership, expressed in number of vehicles per 1.000 inhabitants.

The private vehicle is highly esteemed by his owner, and the sacrifice in making a trip sith such vehicle usually has little weight in the subjective evaluation of the owner. For that reason, a growth in private vehicle ownership, such as bicycle and car, has a subtantial effect on mobility. This means that when a "higher" private vehicle becomes available, not only is there a change in the modal split of the person of household concerned, but there will be also an increase in mobility, that is in the number of journeys made per person per day. The relative increase in, p.e. car traffic volume will therefore always be larger than the relevant growth in car ownership.

The transportation surveys and studies may be carried out to determine the necessity or suitability of a variety of transport systems such as air links, a new motorway or a combination of private and public transport modes such as is found in a large urbanised conurban. The methodology of these surveys will vary in detail - but most transportation surveys that are based on land-use activity tend to be divisible into three major subdivisions:

i) The transportation survey, in which an attempt is made to take an inventory of the trip making pattern as it exists at the present time, together with details of the travel facilities available and the land-use activities, and socio-economic factors that can be considered to influence travel.

ii) The production of mathematical models, which attempt to explain the relationship between the observed travel pattern, and the travel facilities, land-use activities and socio-economic factors obtained by the transportation survey.

iii) The use of these mathematical models to predict future transportation needs and to evaluate alternative transportation plans, (see figure - 1).

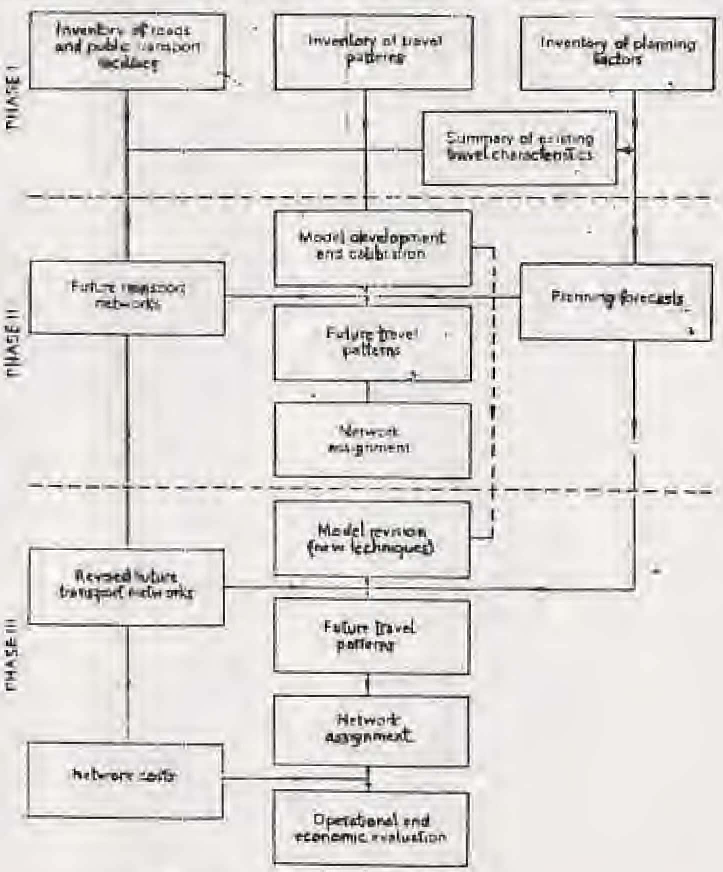


Figure (1)

The Transportation Study Area

The survey area within which travel is tube studied in details is bounded by an extended cordon. The position of the external cordon is fixed so that as far as possible all developed areas which influence travel patterns are included together with areas which are likely to be developed within the forecasting period of the study. Within the external cordon, trip information is collected in considerable detail.

Transport flow patterns are extremely complex and difficult both to describe and to analyse. Origins and destinations are numerous, and their exact locations and numbers differ from day to day. But when reality is schematized so that the"law of big (ger) numbers" are applicable, certain regularities become apparent. The problem is to find the right level of schematization: not so much that details are obscures, making the scheme in consistent with reality; not so little that the numerous --- and, in reality, incidental --- detail present a picture of false accuracy. Clearly, a balanced choice depends to some extent on arbitrary judgment based on professional experience.

Present and future transport flows are described in terms of passengers and tons and related to places or regions of origin and destination called "traffic zones". Each zone has a center in which all traffic - generating social and economic activities are assumed to be concentrated. These traffic zones are connected by the transport network, which is schematized as well as described in terms of "links and nodes".

Usually the survey area is divided into internal traffic zones; the remainder of the country external to the Cordon is also divided into considerably larger external zones.

Zones are selected after consideration of the following factors :-

1 - They should be compatible with past or projected studies of the region or adjacent regions.

2 - They should permit the summarising of land-use and trip making data.

3 - They should allow the convenient assignment of trips, which are assumed to be generated at the centroids of traffic zones, to the transportation network.

4 - While greater accuracy is possible with smaller zones they should not be so numerous as to make subsequent data processing difficult.

5 - The size of the zones will be governed by the size of the survey area and the type of survey. In urban areas where transportation requirements are studied in detail, it is usual to have approximately 1000 households or 3000 people in a zone.

6 - As data is frequently aggragated by zone, the latter should be areas of predominately similar land activity in which similar rates of future growth are anticipated.

The Collection Of Existing Travel Data

Existing trip making or travel data may conveniently be classified into four groups according to the origin and destination of the trip being considered. These four classes of movements are :

a- Trips which have an origin within the external Cordon and a destination outside the external Cordon,

b- Trips which have both an origin and a destination within the external Cordon,

c- Trips which have an origin outside the external Cordon and a destination within it,

d- Trips which have neither origin or destination within the external Cordon but which pass through it.

Details of these trips are obtained in differing ways. Trips of type (a) and (b) are usually recorded by means of a home interview survey while trips of type (c) and (d) are normally recorded by means of an origin and destination survey conducted along the external Cordon.

Other Surveys

Commercial Vehicle Surveys

This survey is designed to measure the trips made by commercial vehicle within the internal area.

Bus Passenger Surveys

Bus trips made by residents are obtained from the home interview survey; trips made by public transport by non-residents are obtained by a bus passenger survey carried out at the external Cordon. Duplication of trips made by residents within the survey area should be checked.

Travel Demand Forcasting Process

Once the transportation survey has collected all the details of the existing trip making pattern, and the socio-economic, land use and transportation - system, characteristics of the survey area, the second stage in the transportation planning process is the development of relationships between the total number of trip origins and destinations in a zone and the zonal characteristics. It is assumed that these relationships will be true in the future and so, if land-use and socio-economic factors can be predicted, future trips can be estimated for any proposed transport system.

The conventional travel-demand forcasting process has four sub-models :

a- Trip generation models
b- Trip distribution on model
c- Modal split model
d- Traffic assignment model

The usual flow of activities involved in this analysis is presented in Figure (2).

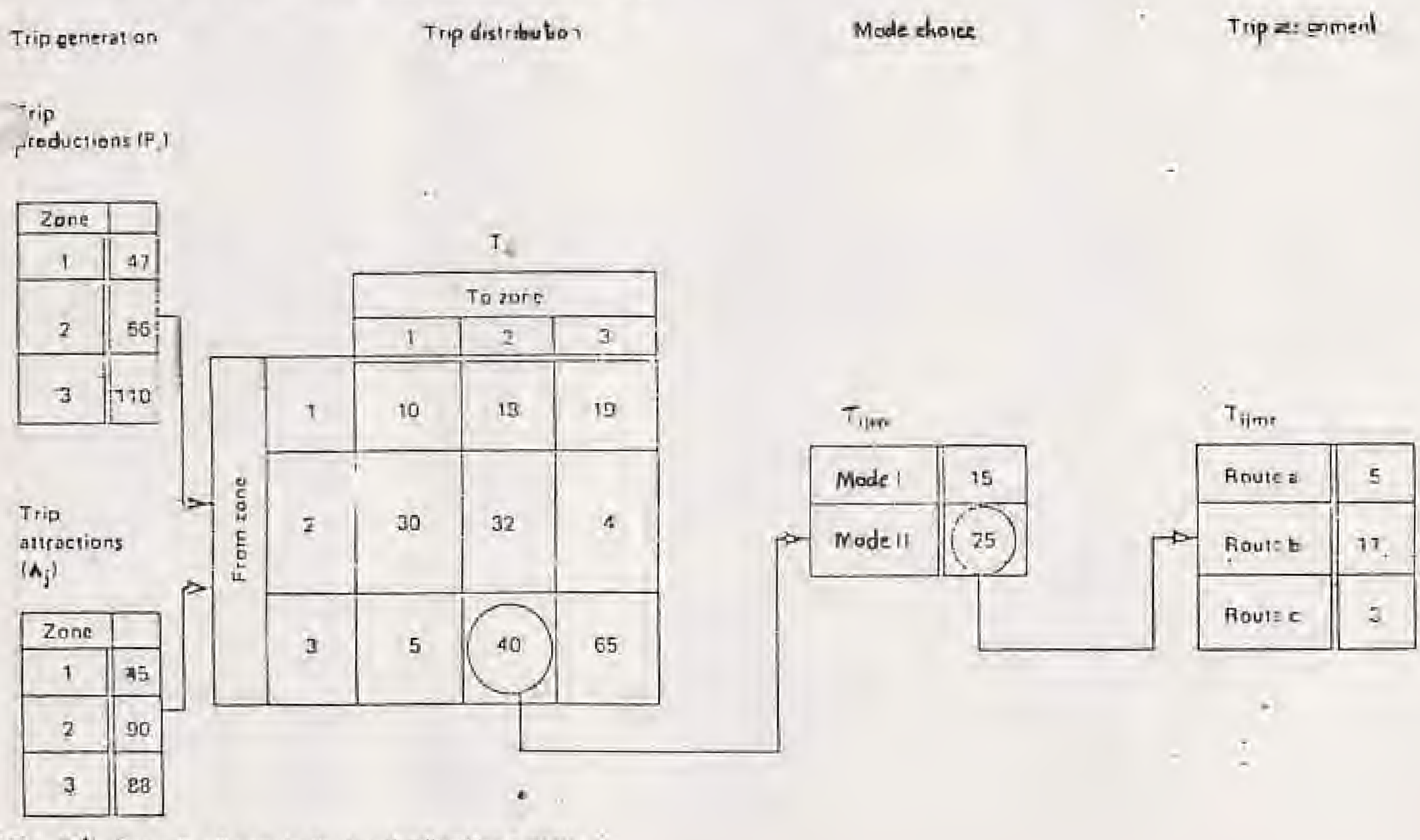


Fig. (2) Example of steps in the travel estimation process.

Trip Generation Model

The purpose of the trip generation analysis phase is to develop equations that allow the trip ends of a particular trip type generated by a traffic analysis zone to be estimated from a knowledge of the land use properties of those zones. The technique most commonly for the development of these prediction equations is multiple-regression analysis.

The equation obtained is of the general form,

$$Y = a_0 + a_1 x_1 + a_2 x_2 + \dots\dots\dots + a_n x_n$$

where a_0 is the intersept or constant

b_1 , b_2 , ... , b_n are (regression coefficients) obtained by regression analysis.

x_1 , x_2 , ... , x_n are the independent variables.

Typical example of the trip generation developed are :-

work - trips produced = 9.3 + 0.32 (population in zone)

work - trips attracted = 43.7 + 0.63 (employment in zone)

Most of the regression equations have been developed using a step wise regression analysis computer program.

Trip Distribution Model

The purpose of the trip distribution analysis phase is to develop a procedure that sythesizes the trip linkages of interchanges between traffic zones for both transit captive and non-captive trip makers. The technique used most commonly to sunthesize these trip linkages is the gravity model.

The equation is of the general form :

$T_{ij} = KP_iA_jf(Z_{ij})$ where

K = Constant

Pj = Total trip production of zone i

Aj = Total trip attraction of zone j

f (Zij) is some function of deterrence to travel expressed in terms of the cost of travel, travel time or travel distance between zones i and j.

Modal Split Model

<u>The purpose of the captive modal -split analysis phase</u> is to develop relationships that allow the trip ends estimated in the trip-generation phase to be partitioned into two groups of trip ends : trips by persons captive to public transport and trips by persons who have a choice between using public transport and a private car. Captive trip-makers are defined as those persons without access to a car for a particular trip. Captive trip-makers are normally identified by certain socioeconomic characteristics such as age and income.

<u>The purpose of the choice modal-split analysis phase</u> is to develop a procedure that simulates the manner in which choice tripmakers travelling between an origin and destination pair will choose between the use of a car and public transport for the trip. Typically, the proportion of public-transport tripmakers is related to some function of the costs of traveling by the competing modes.

This two-stage-type modal-split analysis is required because of the existence in urban areas of essentially two seperate submarkets for public-transport services. These two submarkets have been labeled <u>captive transit riders</u>.

The aim of the captive modal-split analysis phase is to establish relationships that allow the trip ends estimated in the trip-generation phase to be partitioned into "captive"transit riders and "choice" transit riders. The origin and destination patterns of the two groups of tripmakers are then synthesized seperately.

The purpose of the choice modal-split analysis phase is to estimate the probable split of choice transit riders between public transport and car travel given measures of the generalzed cost of travel by the two modes.

The many studies of modal transport choice have demonstrated that the major determinants of public transport patronage are :

- the socio economic characteristics of the trip-makers; and
- the relative cost and service properties of the trip by car and the trip by public transport.

The characteristics of the tripmakers that influence their modal transport choice decisions are those which determine car availability to the tripmakers, and therefore captive or choice status. Variables which have been used to identify this status at the household level are :

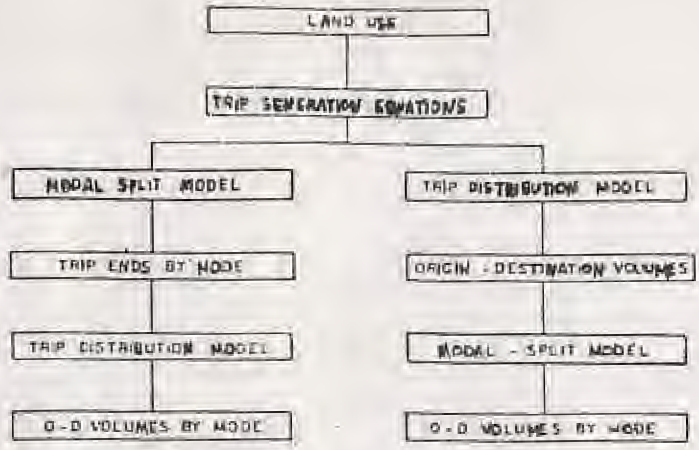
1- Household income, or car ownership directly;
2- The number of persons per household;
3- The age and sex of household members;
4- The purpose of the trip (trip classification)

This section describes typical examples of the modal-split models, developed in earlier transport studies. These models accomplished modal-split estimation in one stage and contained socio-economic characteristics variables.

Earlier modal-split models.

The earlier modal-split models were used either before or after the trip-distribution analysis phase of the travel-demand forecasting phase.

Modal-split models which have been used before the trip-distribution are usually referred to as <u>trip-end modal-split models</u>. Modal-split models that have followed the trip-distribution phase are normally termed <u>trip-interchange modal-split models</u>. Figure (3) illustrates the differences in the roles of these two types of modal-split models.



Sequnce of Activities for Trip-End-Type Model Split Models

Sequnce of Activities for Trip-Interchange-Type Model Split Models

Fig. 3

In transport planning studies in developed countries performed to data in medium and smaller-sized cities, trip-end modal-split models have normally been used. Figure (3) demonstrates that with this type of model the potential patronage of each transport mode is determined following the trip-generation phase. The basic assumption of the trip-end-type models is that transport patronage is relatively insensitive to the service characteristics of the transport modes.

Modal patronages are determined principally by the socio-economic characteristics of the trip-makers. Transport studies performed in larger urban areas, where the public-transport system is well developed, or where significant improvements in the public-transport system are contemplated, have usually employed trip- interchange modal-split models that have been developed, incorporate measures of the relative service characteristics of competing modes, as well as measures of the socio-economic characteristics of the trip-makers.

Perhaps the principal limitation of these earlier modal-split models is that captive and choice transit riders have not been identified and represented seperately in the models. For this reason the models do not reflect adequately the matter in which choice transit riders react to changes in transport system characteristics.

Tranport service-sensitive modal-split relations can only be developed if trip-makers are first segregated into various socio-economic categories, i.e. captive and choice trip-makers.

Southern Wisconsin Model

The modal split model developed in this study consisted of seven estimating surfaces that related the percentage of trip ends that will use transit services from a particular traffic analysis zone to the following variables : trip type, characteristics of trip maker, and characteristics of the transport system.

Four trip purposes were used to stratify the trips made on public-transport services and these were home-based work trips, home-based shopping trips, home-based "other" trips, and non-home-based trips. Only the surface developed for home-based work trips is discussed in this book.

The socio-economic characteristics of trip-makers were defined on a zonal basis in terms of the average number of cars per household in a zone. Figure (4) shows the relationship that was observed between the zonal percent transit usage and the zonal average number of cars per household for the journey to work in the Milwaukee region.

The characteristics of the transport system relative to a given zone were defined by an accessibility index calculated from the following equation :

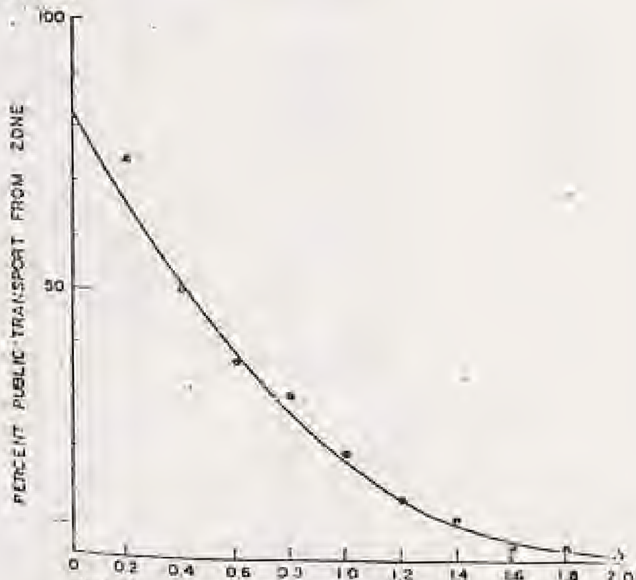
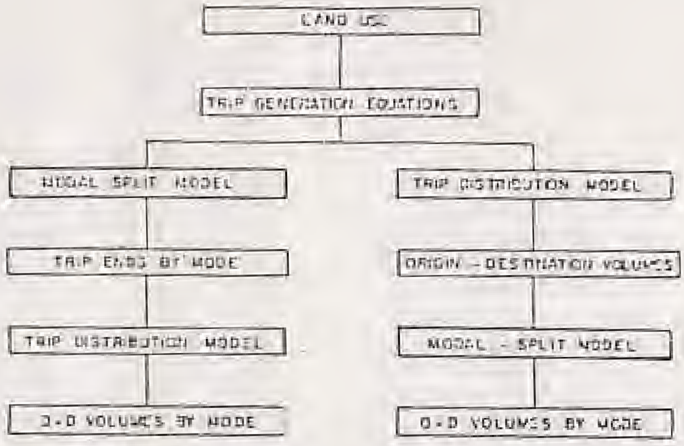


FIG. (4) Percent transit usage vs. zonal average number of cars per household



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The socio-economic characteristics of trip-makers were defined on a zonal basis in terms of the average number of cars per household in a zone. Figure (4) shows the relationship that was observed between the zonal percent transit usage and the zonal average number of cars per household for the journey to work in the Milwaukee region.

The characteristics of the transport system relative to a given zone were defined by an accessibility index calculated from the following equation :

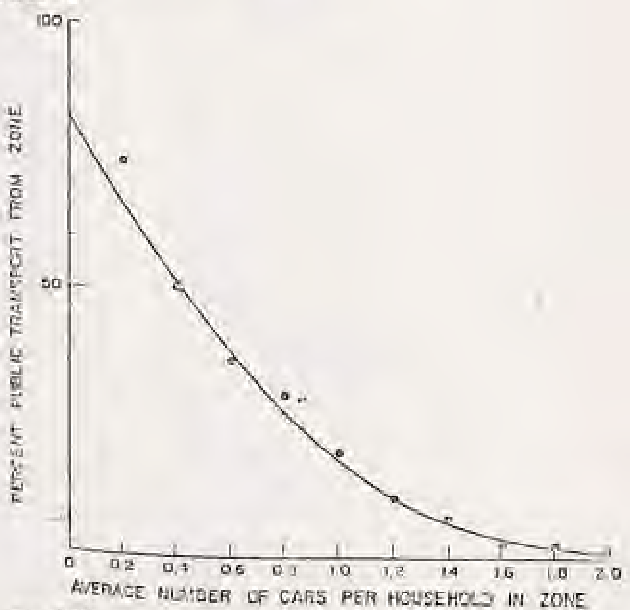


FIG. (4) Percent transit usage vs. zonal average number of cars per household.

$$acc_i = \sum_{j=1}^{n} a_j f_{ij}$$

where acc_i = accessibility index for zone i

a_j = number of attrqctions in zone j

f_{ij} = travel time factor for travel from zone i to zone j for the particular mode being considered.

The transport service provided to a particular zone by the two modes was characterized by the following accessibility ratio :

$$\text{Accessibility ratio} = \frac{\text{highway accessibility index}}{\text{transit accessibility index}}$$

The modal split surface developed for work trips in the Milwaukee region is shown in Fig. (5) in which the percent transit usage from a zone is plotted against the accessibility ratio and the zonal average number of cars per household. This modal split surface demonstrates quite clearly the rapid decline in transit use with decreasing level of transit service for the higher income groups. In contrast, the zones with lower per household car ownership were relatively insensitive to changes in transit levels of service.

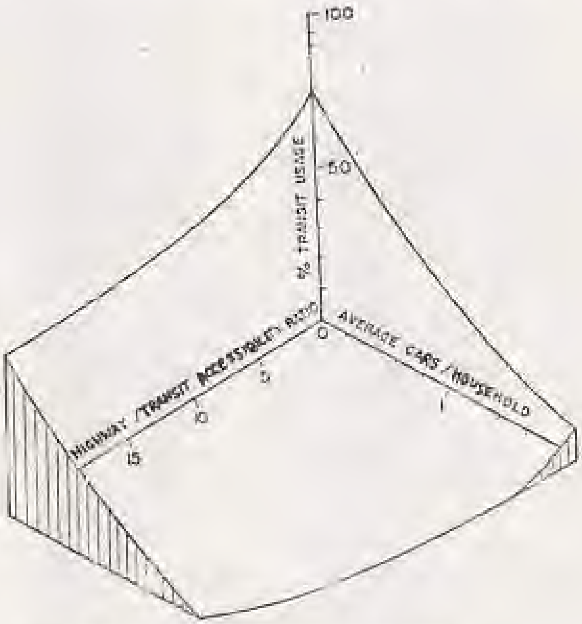


FIG. (5) Modal split surface for work trips.

Toronto modal split model

The basic hypothesis underlying the modal split model developed for Metropolitan Toronto has been stated as follows (3) :

The total number of pepole moving between an origin-destination pair constitutes a travel market and the various modes compete for this market and secure a portion of it in relation to their relative competitive positions which are expressed in terms of: relative travel time, relative travel cost, relative travel service, and the economic status of the tripmaker.

The relative travel time by competing modes was expressed by ratio of door-to-door travel time by public transit and car as follows:

$$TTR = \frac{a + b + c + d + e}{f + g + h}$$

where
a = time spent in the transit vehicle
b = transfer time between transit vehicles
c = time spent waiting for transit vehicle
d = walking time to transit vehicle
e = walking time from transit vehicle
f = car driving time
g = parking delay at destination
h = walking time from parking place to destination

The relative travel cost was defined by the ratio of out-of-pocket travel costs by public transit and car as follows:

$$CR = \frac{i}{(j + k + 0.5l)\ /m}$$

where
i = transit fare
j = cost of gasoline
k = cost of oil changes and lubrications
l = parking cost at destination
m = average car occupancy

The relative travel service was characterized by the ratio of the excess travel times by car and transit. The excess travel time was defined as the amount of time spent outside the vehicle during a trip. The service ratio was defined as follows :

$$SR = \frac{b + c + d + e}{g + h}$$

Figure (6) shows part of the model split curves developed for the journey to work in Metropolitan Toronto. The economic status of trip-makers was characterized by four salary classifications and the boundaries of each of these salary classes are shown in the diagram.

The Toronto modal split model was used as follows. Total person trips by all modes were forecast and distributed using the gravity model for the highway network. The travel time, cost and service ratios, and the income levels were then used to estimate percent transit usage from the diversion curves. The total person trips between the origin-destination pair were then multiplied by this percentage to obtain the transit trips. The car-person trips were then factored by the car occupancy rate to determine the number of car trips between the origin-destination pair. Each group of trips was then assigned to the appropriate network.

While the two models described above have been assigned to different categories, their underlying model structures exhibit many similarities. Both contain a measure of the socio-economic characteristics of trip-makers as well as a measure of the relative service provided by the different transport modes. The essential difference is in the extent to which the two types of variables dominate the model. In the southern Wisconsin model the service characteristics of the transport system are introduced in a macroscopic way through the ratio of the accessibility indices. In the Toronto model the service characteristics are introduced very directly in the form of such factors as the travel-time ratio, and so on.

Some limitations of earlier modal split models

Perhaps the principal limitation of these models is that captive and choice transit riders have not been identified and represented seperately in the models. For this reason the models do not reflect adequately the manner in which choice transit riders react to changes in transport system characteristics. The transit patronage data used to calibrate the models have contained both captive and choice riders. In addition, the patronage data have been of a zonally aggregated nature. Some evidence was introduced in Chap. 2 which demonstrated that in the typical traffic-analysis zone there is a great deal of within-zone variability in trip-making which tends to submerge important differences in trip-making behavior..

Transport service-sensitive modal split relations can only be developed if tripmakers are first segregated into various socio-economic categories, and diversion curve-type relationships are then constructed for each of these categories.

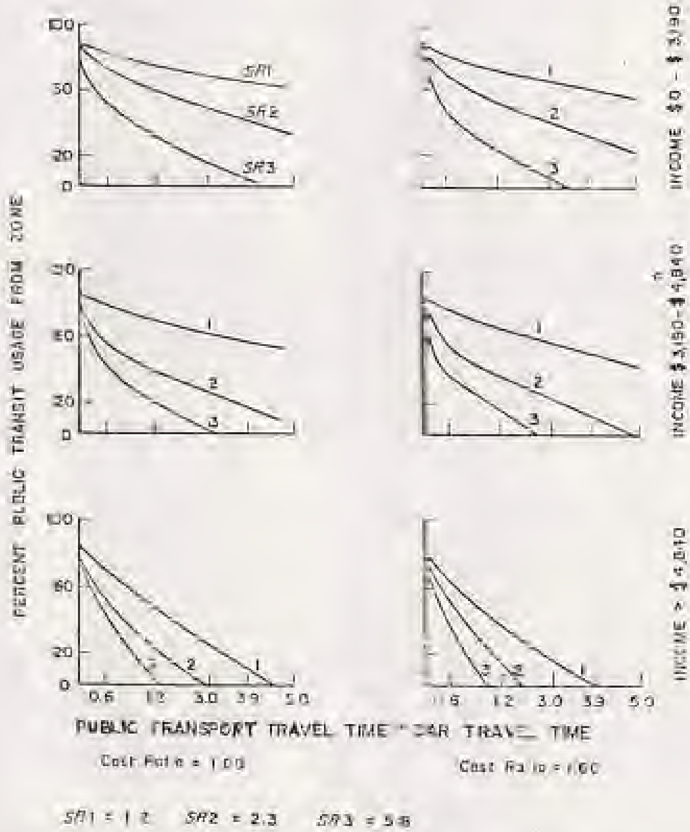


FIG (6) Modal split curves developed for Toronto, Ontario.

Traffic Assignment Model

The purpose of the route-assignment analysis phase is to develop a technique that simulates the way in which the car and the transit trips between each origin and destination pair distribute over the links of their respective networks.

Figure (7) illustrates that a knowledge of the properties of the alternative horizon-year transport systems is required for the trip-distribution, choice modal-split and route-assignment phases. The principal outputs of this travel-demand forecasting process for each alternative network are :

1) the travel demand between any pair of zones
2) the proporties of the travel between any pair of zones such as travel between time, and therefore average speed;
3) the volume of travel on any link; and
4) the proporties of travel on any link.

Figure (7) illustrates in detail the interrelationship between each of the activities for the horizon-year analysis. This diagram shows more specifically the way in which mode-specifically origin and destination matrices are developed for each alternative horizon-year transport network tested.

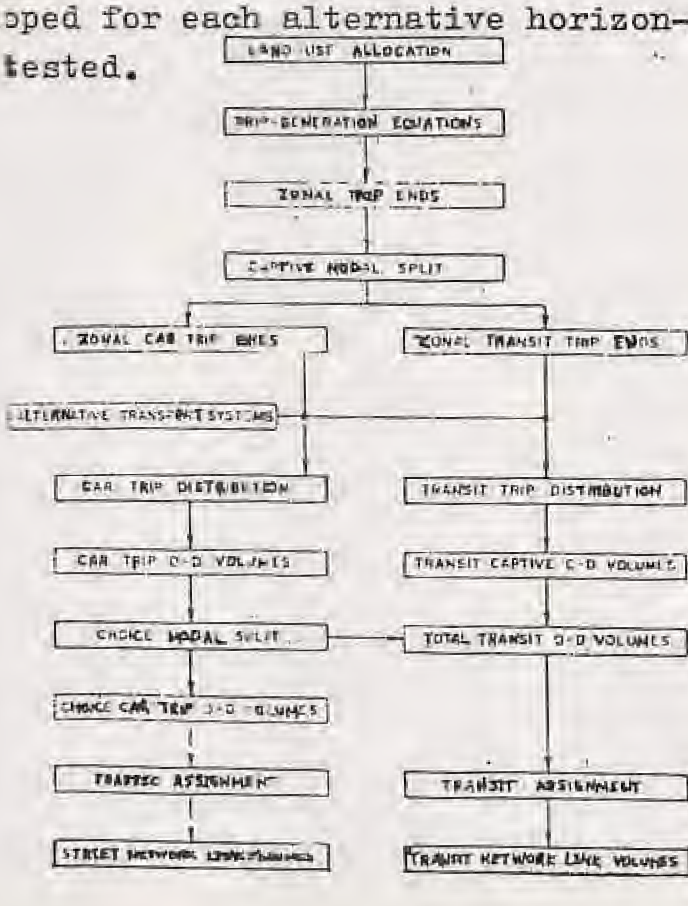


Fig. (7)

Route- assignment analysis

The final phase of the travel-demand forecasting process described before has been identified as route-assignment analysis phase is to develop a technique that simulates the way in which the car and transit trips between each origin and destination pair distribute over the links of their respective networks. The principal concern of this paragraph is with traffic-assignment methods, as route-assignment for the public-transport network is not normally a problem, except in very large cities with complex public-transport systems.

Network- assignment methods

Network-assignment methods allocate car travel demands between each origin and destination pair to the entire systems of streets exclusive of the local street system. A number of network assignment procedures have been developed and all of these techniques contain the following three components :

1) a driver route-selection criterion;
2) a tree-building technique which selects vehicle routes through a network of streets; and
3) a methods of allocating vehicle trip interchanges between these routes.

The most fundamental elements of any traffic-assignment technique is to select a criterion which explains the choice by a driver of one route between an origin-destination pair from among the number of potential paths available. The first is that motorists act selfishly and attempt to minimize their individual travel times through a network. The second criterion suggests that motorists act so as to minimize the total travel time spent by all motorists on the network. This implies that individual motorists are aware of the way in which their choice of route influences the change in the total travel time experienced by all motorists. Some limited empirical testing of these two criteria has been performed and the evidence available would suggest that motorists behave according to some intermediate criterian. However, most of the traffic-assignment techniques used on a routine basis in urban transport studies assume that Wardrop's first criterion governs the route choice of motorists.

The second requirement of a network-type traffic-assignment technique is for an algorithm which searches out routes from a street network according to the driver route selection criterion. In some of the assignment methods described below the analyst is concerned only with the minimum travel time paths between origin-destination pairs. In other methods the analyst is concerned with the " n - best " paths, between origin -destination pairs.

The final requirement of network-type assignment techniques is for a rational to assign trip-interchange volumes between centroid pairs to a route or routes between the centroid pair. The various methods may be classified into one of the following groups : all-or-nothing assignment, capacity-restrained assignment and multipath assignment.

With the all-or-nothing assignment method the trip-interchanges volumes are assigned to the minimum path tree independently of the traffic capacities of the links that make up the minimum path tree. Several network-assignment procedures have been developed that attempt to recognize that as a traffic system is loaded with vehicles, the travel-time characteristics of the system change. The capacity-restrained assignment techniques attempt to achieve compatibility between the volume of vehicles using a road link and the travel time on that link. The multipath assignment incorporate the fact that there are normally a number of potential routes between a centroid pair and they assign the trip interchanges among these potential routes.

Route-building algorithms

Figure (8) shows portions of an urban transport network coded in terms of links, nodes, and centroids. All links are read into the computer in a one-way form. For example, link 315-316 is also entered as link 316-315 since it is a two-way street. On the other hand, link 315-318 only is entered since it is a one-way street.

A number of algorithms have been developed for searching out minimum path trees for centroids. The classical work on the shortest path through a network is that by More. Most of the available algorithms are similar in principle and differ only in the way in which they keep track of the calculations. For each origin centroid, the aim of this algorithm is to assign a label to each node in the network of the following form: node j label $= \{i, d(j)\}$

where i = the node nearest to zone j which is on the minimum travel-time path back to the origin

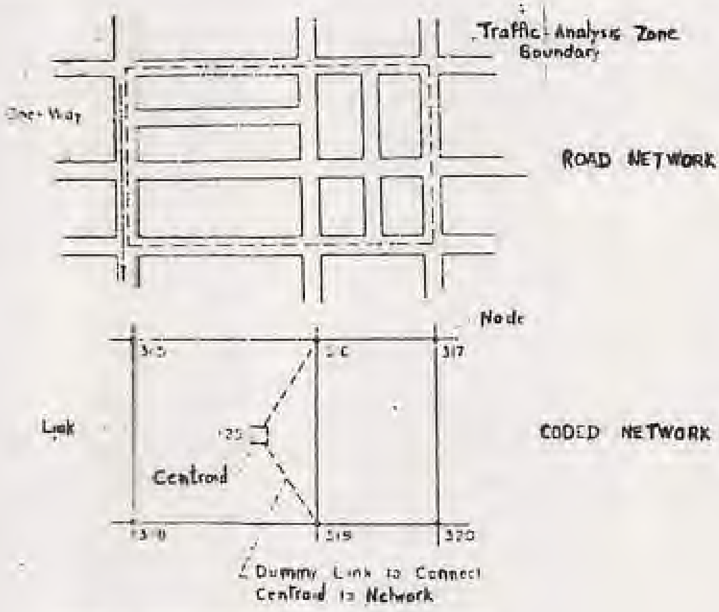
$d(j)$ = the minimum travel-time from node j back to the origin centroid.

Initially, each node is assigned a d (j) magnitude which is very large, say 999, with the exception of the origin node where it is set to 0. As the tree is built out from the origin, the following sum is fromed for each node, node j sum $= \{d(i) + l\ (i,j)\}$

where $d(i)$ = the travel-time from the origin to node i which has just been connected to the origin

$l(i,j)$ = the travel-time along the link which connects node j to node i

If the sum just formed is greater than the d(j) already recorded for node j, then the node is bypassed.



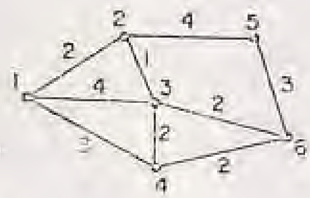
Node From	Node To	Distance (miles)	Speed (mph)
315	316	0.7	20
315	318	0.6	25
316	315	0.7	20
[illegible]	317	0.5	20
[illegible]	316	0.5	15
317	320	0.6	20
[illegible]	319	0.7	20
[illegible]	318	0.7	20

COMPUTER DESCRIPTION

Fig.(8) Computer coding of road network.

If the sum is less than the existing d(j), then the d(j) is replaced by the newly formed sum and the i is changed in the table to reflect the new connecting link for node j back to the origin.

New sums are formed for all of the nodes adjacent to the nodes just connected to the origin and these sums are tested against the d(j) magnitudes recorded for the nodes. This process is continued until all nodes have been reached. The label numbers for each node show the minimum travel-time back to the origin as well as the node which is the next nearest on the minimum travel-time path back to the origin. This tree building process must be carried out for each origin centroid in turn. Figure (9) illustrates this algorithm with a simple example.



Origin node 1
node 1 label = [–,0]

node 2 sum = 0 + 2 = 2 2 < 999 node 2 label = [1,2]	node 2 connected to 1
node 3 sum = 0 + 4 4 < 999 node 3 label = [1,4]	node 3 connected to 1
node 4 sum = 0 + 3 = 3 3 < 999 node 4 label = [1,3]	node 4 connected to 1
node 3 sum = 2 + 1 = 3 3 < 4 node 3 label = [2,3]	node 3 connected to 2
node 5 sum = 2 + 4 = 6 6 < 999 node 5 label = [2,6]	node 5 connected to 2
node 4 sum = 4 + 2 = 6 6 > 3 node 4 label = [1,3]	node 4 connection remains
node 6 sum = 4 + 2 = 6 6 < 999 node 6 label = [3,6]	node 6 connected to 3
node 6 sum = 3 + 2 = 5 5 < 6 node 6 label = [4,5]	node 6 connected to 4
node 6 sum = 6 + 3 = 9 9 > 5 node 6 label = [4,5]	node 6 connection remains.

Fig.(9) Example of minimum path tree building algorithm.

The algorithm is best explained through the use of a simple example network. Figure (10) shows a simple street network and the following example will show how the algorithm can be used to build the minimum path tree for centroid 15.

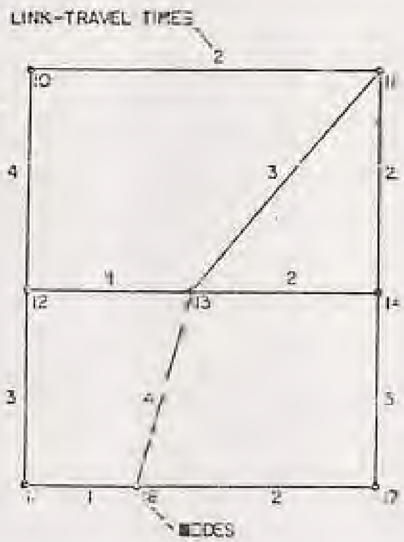


FIG. (10) Simple street network.

Table (1) Link table for simple network

Node From	Node To	Travel time
10	11	2
10	12	4
11	10	2
11	13	3
11	14	2
12	10	4
12	13	1
12	15	3
13	12	1
13	11	3
13	14	2
14	13	2
14	11	2
14	17	5
15	12	3
15	16	1
16	15	1
16	13	4
16	17	2
17	16	2
17	15	5

Table (2) Initialized tree table

Node To	Total time	Node From
10	999	0
11	999	0
12	999	0
13	999	0
14	999	0
15	0.0	0
16	999	0
17	999	0

Table (3) Revised tree table

Node To	Total time	Node From
10	999	0
11	999	0
12	3	15
13	999	0
14	999	0
15	0.0	
16	1	15
17	999	0

The link table for the network of Fig. (10) is shown in Table (1). The minimum path tree is constructed by the following sequence of operations:

1) Initialize the tree table with all the total times equal to 999 with the exception of the origin node which is set equal to 0.0 and this activity is shown in Table (2).
2) Add to the list all nodes connected to the nodes just added to the tree table.
3) Test all entries in the list to determine if "Node To" + "Total Time from Origin" travel time is less than the "Total Travel Time" in the tree table and if so enter it in the tree table.
4) Return to step 2 and repeat the process until the list is empty.

The sequence of steps for the simple network of Figure (10) is given below.

		Node From	Node To	Time
Step 2 :	LIST			
		15	12	3
		15	16	1

Step 3 : TEST Is Node To + Total Time from Origin $<$ Tree Table Total Travel time?

$0.0 + 3 < 999$ Add 12 to Tree Table

$0.0 + 1 < 999$ Add 16 to Tree Table

The revised tree table is shown in Table (3)

		Node From	Node To	Time
Step 2 :	LIST			
		12	10	4
		12	13	1
		16	13	4
		16	17	2

Step 3 : TEST

$3 + 4 < 999$ Add 10 to Tree Table

$3 + 1 < 999$ Add 13 to Tree Table

$1 + 4 \nless 4$ Do not add to Tree Table

$1 + 2 < 999$ Add 17 to Tree Table

The revised tree table after this second iteration is shown in Table (4).

The process may be repeated until the list is empty and the tree table in Table (5) would result. The minimum path tree for centroid 15 can easily be read from the tree table and this minimum path tree is shown in Fig. (11) if the row from the origin-destination matrix for centroid 15 is that shown in the lower part of Fig. (11) then the volumes on the links due to trips from centroid 15 would be as shown in Fig. (11).

Table (4) Revised tree table

Node To	Total time	Node From
10	7	12
11	999	0
12	3	15
13	4	12
14	999	0
15	0.0	
16	1	15
17	3	16

Table (5) Final tree table

Node To	Total time	Node From
10	7	12
11	7	13
12	3	15
13	4	12
14	6	13
15	0.0	
16	1	15
17	3	16

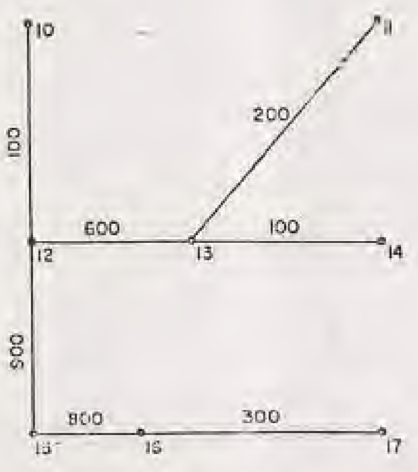


FIG (11) Minimum path tree for node 15.

ORIGIN NODE	DESTINATION NODE						
	10	11	12	13	14	15	17
15	100	200	200	300	100	500	300