Transportation Planning Models: A Review

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***Abstract*- The main objective of this paper is to present an overview of the travel demand modelling for transportation planning. Mainly there are four stages model that is trip generation, trip distribution, modal split and trip assignment. The choice of routes in the development of transportation planning depends upon certain parameters like journey time, distance, cost, comfort, and safety. The scope of study includes the literature review and logical arrangement of various models used in Urban Transportation Planning.**

Keywords- transportation planning; trip generation;trip distribution;modal split; traffic assignment; transportation planning parameters (journey time, distance, cost, comfort, and safety); logical arrangement.

I. INTRODUCTION

According to Chattaraj, Ujjal (2003), Transportation is the backbone to the development of urban areas. It enables functioning of urban areas efficiently by providing access and mobility. Passenger transport has an overriding influence on the functioning of the city. Transportation planning and development of infrastructure for the system is one of the most crucial factors particularly for urban areas, where in high level and rapid urbanization is taking place. The demand for transportation in urban area is linked to the residential location choices that people make in relation to places of work, shopping, entertainment, schools and other important activities. As cities grow, they support more people and more dispersed settlement patterns. Increasing demand for transportation is an inevitable outcome of urban growth. As Patel N. A. (2008), a universal trend that has been observed is that as household incomes grow, people prefer personal transportation to public transport. The obvious and compelling reason for this is that personal transport maximizes individual mobility, freedom of choice and versatility that public transport systems cannot match. However, the experience of cities in many developed and developing countries shows that an efficient and economic public transport system can reduce dependence on personal transportation. Transportation planning process involves prediction of most probable pattern of land development for the horizon-year, usually taken as twenty years, and the transport demands created by that land-use are estimated. A set of alternative transport plans is then generated for that horizon-year. 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 as recorded by Pangotra, P. and Sharma, S. (2006), “Modelling Travel Demand in a Metropolitan City”. In the present study, Modelling is an important part of any large scale decision making process in any system. Travel demand modelling aims to establish the spatial distribution of travel explicitly by means of an appropriate system of zones. Modelling of demand thus implies a procedure for predicting what travel decisions people would like to make given the generalized travel cost of each alternatives. This paper presents review of various Transportation Planning Models.

II. TRAVEL DEMAND MODELLING

The process of travel demand forecasting essentially consists of four stage model (see figure 1). The process has been documented by Kadyali L. R. (2007), Mathew T. V. and K. V. K. Rao (2007), Kadyali L. R. and Lal N. B. (2008-09) and others. In the subsequent paragraphs the four stage modelling has been elaborated.

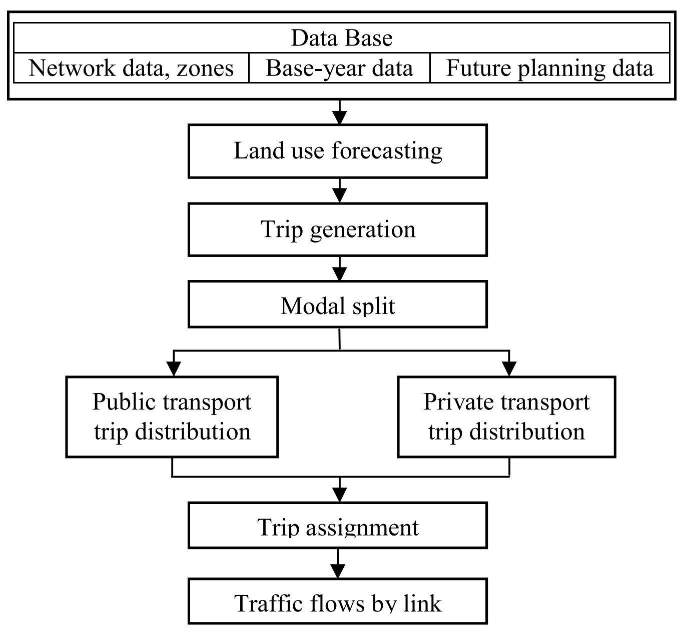

Figure 1. General form of the four stage transportation modeling

A. Trip Generation

Trip generation is the first stage of the classical first generation aggregate demand models. Trip generation is the analysis and model building phase starts with the first step commonly. It is a general term used in the transportation planning process to cover the number of trip ends in given area. Trip generation is classified in production and attraction.

Production (origin) means number of trips end originated in zone-i. Attraction (destination) means number of trips end attracted to zone-j. There are basically two tools for trip generation analysis, multiple linear regressions and category analysis (cross classification), and these methods are explained in the following sections.

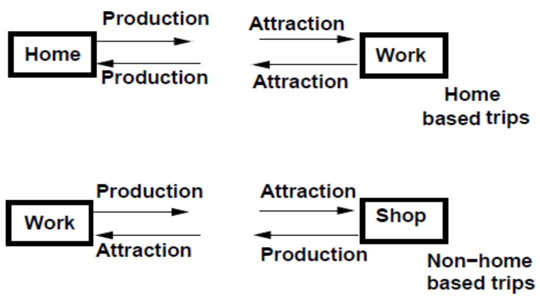

Figure 2. Types of trips

1) Regression Methods: The trip generation models are generally developed using regression analysis approach and a zonal trips prediction equation is developed. Typically the functional form will be a multiple linear regression model is:

$$y = a_0 + (a_1\, x_1) + (a_2\, x_2) + (a_3\, x_3) + \ldots\ldots\ldots + (a_n\, x_n) + e \qquad (1)$$

A simple one variable model is represented as:

$$y = a_0 + (a_1\, x_1) + e \qquad (2)$$

Where, y = dependent variable
x_i = independent variable (i = 1, 2, 3……n)
a_0 = constant term
a_i = coefficient of independent variables (i = 1, 2, 3……n)
e = error term
n = number of independent variables

2) Category Analysis: The category analysis is also called cross classification analysis, which developed by Wottom and Pick. This technique is widely used for to determine the number of trips generated. The approach is based on a control of total trips at the home end. The amount of home-end travel generated is a function of number of households, the characteristics of households, the income level, and car ownership. The density of households could also be considered. At the non-home end, a distribution index is developed based on land use characteristics, such as the number of employees by employment category, land use type, and school enrollment.

B. *Trip Distribution*

The decision to travel for a given purpose is called trip generation. The decision to choose destination from origin is directional distribution of trips forms the second stage of travel demand modeling. Trip distribution is determined by the number of trips end originated in zone-i to number of trips end attracted to zone-j, which can be understood by the matrix between zones. The matrix is called origin - destination (O-D) matrix. Table I represents typical O-D matrix.

TABLE I. *NOTATION OF A TRIP DISTRIBUTION MATRIX*

Zones	1	2	3	…	j	…	n	O_i
1	T_{11}	T_{12}	T_{13}	…	T_{1j}	…	T_{1n}	O_1
2	T_{21}	T_{22}	T_{23}	…	T_{2j}	…	T_{2n}	O_2
3	T_{31}	T_{32}	T_{33}	…	T_{3j}	…	T_{3n}	O_3
:	…	…	…	…	…	…	…	:
	T_{i1}	T_{i2}	T_{i3}	…	T_{ij}	…	T_{in}	O_i
:	…	…	…	…	…	…	…	:
n	T_{ni}	T_{n2}	T_{n3}	…	T_{nj}	…	T_{nn}	O_n
D_j	D_1	D_2	D_3	…	D_j	…	D_n	T

Where, $D_j = \sum_i T_{ij}$ $O_j = \sum_j T_{ij}$ $T = \sum_{ij} T_{ij}$

a. Mathew, T. V., Krishna Rao, K. V. (2007), "Trip Distribution".

1) *Trip Distribution Models:* The various trip generation models are listed below classified as a Growth factor models, Synthetic models, and opportunity models.

a) Growth factor models
i) Uniform factor model
ii) Average factor model
iii) Fratar model
iv) Detroit model
v) Doubly constrained growth factor model (Furness model)
b) Synthetic models / Interaction models
i) Gravity model
c) Opportunity models
i) Intervening opportunity model
ii) Competing opportunity model

a) Growth Factor Models: The growth factors are based on the assumption that the present travel pattern can be projected to the design year in the future by using certain expansion factor. The growth factor methods are used in the urban planning for approximation.

i) *Uniform Growth Factor Model:* The uniform growth factor method is only a crude method, because there is differential growth in different zones. If the only information available is about a general growth rate for the whole of the study area, then we can only assume that it will apply to each cell in the matrix, which is called uniform growth rate.

$$T_{ij} = F * t_{ij} \qquad (3)$$

Where, T_{ij} = future number of trips from zone-i to zone-j (the expanded total number of trips)
t_{ij} = present number of trips from zone-I to zone-j (the previous total number of trips)
F = the uniform growth factor

$$Growth\ \ Factor\ \ (F) = \frac{All\ \ the\ \ future\ \ trip\ \ in\ the\ study\ \ area}{All\ \ the\ \ present\ \ trip\ \ in\ the\ study\ \ area}$$

$$F = \frac{\sum_{i}^{n} \sum_{j}^{n} Tij}{\sum_{i}^{n} \sum_{j}^{n} tij} \quad (4)$$

Advantages

- They are simple to understand.
- They are useful for short-term planning.

Limitations

- The same growth factor is assumed for all zones as well as attractions.

ii) *Average Growth Factor Model:* The average growth factor model is calculated for the both ends of the trip (O-D zones).

$$T_{ij} = t_{ij} * \left(\frac{F_i + F_j}{2} \right) \quad (5)$$

Where, T_{ij} = future number of trips from zone-i to zone-j (the expanded total number of trips)
t_{ij} = present based year number of trips from zone-i to zone-j (the previous total number of trips)
F_i = producted growth factor for zone-i

$$F_i = P_i / p_i \quad (6)$$

Where, P_i = future producted number of trips for zone-i
p_i = present producted number of trips for zone-j
F_j = attracted growth factor for zone-j

$$F_j = A_j / a_j \quad (7)$$

Where, A_j = future attracted number of trips for zone-i
a_j = present attracted number of trips for zone-j

iii) *Fratar Model:* The Fratar model is introduced by T. J. Fratar (1954) and Fratar model of successive approximation is widely used for to distribute trips in a study area. This model has been used extensively in several metropolitan study areas, particularly for estimating external trips coming from outside the study areas to zones located within the study area.

$$T_{ij} = t_{ij} * F_i * F_j * \left(\frac{L_i + L_j}{2} \right) \quad (8)$$

Where, L_i = location factor for zone-i

$$L_i = \frac{\sum_j t_{ij}}{\sum_j t_{ij} * F_j} \quad (9)$$

L_j = location factor for zone-j

$$L_j = \frac{\sum_i t_{ij}}{\sum_i t_{ij} * F_i} \quad (10)$$

Assumptions

- The distribution of future trips from a given origin is proportional to the present trip distribution.
- This future distribution is modified by the growth factor of the zone to which these trips are attached.

iv) *Detroit Model:* The Detroit model is used for trip distribution in Detroit area of USA future trips between zone-I and zone-j.

$$T_{ij} = t_{ij} * \left(\frac{F_i * F_j}{F} \right) \quad (11)$$

Where, F = growth factor of entire area

v) *Doubly Constrained Growth Factor Model:* When information is available on the growth in the number of trips originating and terminating in each zone, we know that there will be different growth rates for trips in and out of each zone and consequently having two sets of growth factors for each zone. This implies that there are two constraints for that model and such a model is called doubly constrained growth factor model. This model is also called Furness model. In this model, the production from zones is balanced and then the attraction to the zones is balanced. One of the methods of solving such a model is given by Furness who introduced balancing factors r_i and s_j as follows:

$$T_{ij} = t_{ij} * r_i * s_j \quad (12)$$

Where, r_i = row balancing factor
s_j = column balancing factor

Limitations

- No consideration of spatial separation only growth is given.
- Travel behavior is not incorporated.

b) *Synthetic Models / Interaction Models:* The gravity model is included in this category.

i) *Gravity Model:* This model originally generated from an analogy with Newton's gravitational law, which states that the attractive force between any two bodies is directly related to their masses and inversely related to the distance between them. Similarly, in the gravity model, the number of trips between two zones is directly related to activities in the two zones, and inversely related to the separation between the zones as a function of the travel time.

$$T_{ij} = K_{ij} * O_i * D_j * F(d_{ij}) \quad (13)$$

Where, T_{ij} = Future number of trips from zone-i to zone-j (the expanded total number of trips)
K_{ij} = constant value (initial value = 1)

$$K_{ij} = r_i * s_j \quad (14)$$

Where, r_i = row balancing factor

$$r_i = \frac{O_i}{\sum_j t_{ij}} = \frac{O_i}{R_i} \quad (15)$$

Where, O_i = total number of trips end originated in zone-i
s_j = column balancing factor

$$s_j = \frac{D_j}{\sum_i t_{ij}} = \frac{D_j}{C_j} \quad (16)$$

Where, D_j = total number of trips end destinated to zone-j
t_{ij} = Present based year number of trips from zone-i to zone-j (the previous total number of trips)

$$s_j = t_{ij} = r_i * R_j \quad (17)$$

Where, $F(d_{ij})$ = the generalized function of the travel cost, which is called deterrence function because it represents the disincentive to travel as distance (time) or cost increases.

$$F(d_{ij}) = d_{ij}^{-b} \quad (18)$$

Where, b value depends on the trip purpose.

TABLE II. VALUE OF 'B' AS PER TRIP PURPOSE

Trip Purpose	'b' Value
Work	0.5 - 2.0
Shopping	1.5 - 2.0
Recreational	2.0 - 2.5
Other Purpose	2.0 - 2.5

a. Kadyali, L. R. and Lal, N. B. (2007), "Traffic Engineering and Transport Planning", Khanna Publishers, Delhi-6.

c) *Opportunity Models:* The intervening opportunity model and competing opportunity model are included in this category.

i) *Intervening Opportunity Model:* According to Stouffer (1943), number of trips from one origination in zone-i to a destination to zone-j is directly proportional to the number of opportunities at the destination zone and inversely proportional to number of intervening opportunities.

$$t_{ij} = K \frac{a_j}{v_j} \quad (19)$$

Where, a_j = total number of opportunities in zone - j
v_j = the number of intervening destination opportunities between zone-i and zone-j
K = constant of proportionality

According to Schneider (1963),

T_{ij} = O_i [P_r(acceptance in volume including zone-j) – p_r(acceptance in volume immediately prior to zone-j)]

$$T_{ij} = O_i [e^{-LV_{j-1}} - e^{-LV_j}] \quad (20)$$

ii) Competing Opportunity Model:

$$t_{ij} = O_i \left[\frac{A_j / A_x}{\sum_i A_j / A_x} \right] \quad (21)$$

Where, A_j = number of destination opportunities in zone-j.
A_x = total number of destination from origin zone-i within the time bond containing the zone of destination.

C. Modal Split

The third stage in travel demand modeling is modal split. Modal split is determined by number of trips of people process by the different mode of travel. In other words, modal split sub model of travel demand modelling is used to distribute the total travel demand in two or more mode categories. These categories are public transport riders and personal / private vehicle riders. The demand can further be split into different modes. According to Tom V. Mathew (2007), N. A. Patel (2008), the socio-economic demand variables used to explain mode choice behavior are income, vehicle ownership, household size, residence location etc. The supply variables are in vehicle time, waiting time, travel time, travel cost, transfer time etc.

1) *Modal Split Methods:* The probit method and logit method are included in this category.

a) *Probit Method:* The determination of the co-efficient of the supply and demand is done by calibration procedures, which are lengthy and time consuming.
The probit equation can be written as:

$$y = a_0 + (a_1 x_1) + (a_2 x_2) + (a_3 x_3) + \ldots\ldots\ldots + (a_n x_n) \quad (22)$$

Where, y = probit value for the probability of transit mode choice
x_n = supply and demand vector
a_n = associated parameters

b) *Logit Methods:*

$$P_1 = \frac{1}{1 + e^{G(x)}} \quad (23)$$

Where, P_1 = probability of an individual choosing mode-1
$1-P_1$ = probability of an individual choosing mode-2

$$G(x) = \alpha_1 (c_1 - c_2) + \alpha_2 (t_1 - t_2) + \ldots.. \quad (24)$$

Where, c_1 and c_2 = travel cost by mode 1 and mode 2
t_1 and t_2 = travel time by mode 1 and mode 2
$\alpha_1, \alpha_2 \ldots. \alpha_n$ = model parameters

The binary logit method and multinomial method are included in this category.

i) *Binary Logit Method:* Binary logit model is the simplest form of mode choice, where the travel choice between two modes is made. The traveler will associate some value for the utility of each mode. If the utility of one mode is higher than the other, then that mode is chosen. But in transportation, we have disutility also. The disutility here is the travel cost.

ii) *Multinomial Method:* Multinomial logit model is a function of the system characteristics and user characteristics.

The binary model can easily be extended to multiple modes. The equation for such a model is:

$$P_1 = \frac{e^{\Delta u}}{1 + e^{\Delta u}}$$

$$P_{(i)} = \frac{e^{u_i}}{\sum e^{u_i}} \qquad (25)$$

Where, $P_{(i)}$ = probability that mode-i is chosen
u_i = utility associated with the choice of alternative-i

D. Trip Assignment

Trip assignment is the fourth and the final phase of the four stage modelling. Travelers will choose the route which will take minimum travel time, minimum travel distance dependent on the traffic volume on the road. The following are commonly used traffic assignment models.

1) All-or-nothing assignment model
2) Multiple route assignment model
3) Capacity restraint assignment model
4) Capacity restraint multipath route assignment model
5) Diversion curves technique model

Transportation planning involves so many iterative models, and large road networks, which is not possible to solve manually. Trip assignment is the last phase of four stage transportation planning. Multipath route assignment model seems to be the most realistic among all those models.

1) *All-Or-Nothing Assignment Model:* All-or-nothing assignment model is the simplest model and is based on the premise that the route followed by traffic is one having the least travel resistance. This model is also called shortest path model. The resistance itself can be measured in terms of travel time, distance, cost or a suitable combination of these parameters. This model assumes that either all drivers prefer a particular route or nobody will take that route. This method is based on Moore's algorithm.

2) *Multiple Route Assignment Model:* All road users may not be able to judge the minimum path for themselves. It may also happen that all road users may not have the same criteria for judging the shortest route. These limitations of the all-or-nothing approach are recognized in the multiple route assignment models. The method consists of assigning the inter zonal flow to a series of routes, the proportion of total flow assigned to each being a function of the length of that route in relation to the shortest route.

This model recognizes that several paths between two nodes might have nearly equal impedance, and therefore, equal use. So, there is some probability that even longer route will be taken by some travelers.

3) Capacity Restraint Assignment Model: This is the process in which the travel resistance of a link is increased according to a relation between the practical capacity of the link and the volume assigned to the link. This model has been developed to overcome the inherent weakness of all-or-nothing assignment model which takes no account of the capacity of the system between a pair of zones. This model assumed that if the traffic on a road is increased its resistance to flow is also increased. This model is also known as the Wyne state arterial assignment.

a) Bureau Of Public Roads (BPR) Model

$$T_N = T_0\left[1 + 0.15\left(\frac{Assigned \quad Volume}{\Pr actical \quad capacity}\right)^4\right]$$

$$T_N = T_0\left[1 + 0.15\left(\frac{V}{C}\right)^4\right] \qquad (26)$$

Where, T_0 = free flow time or base travel time at zero volume
T_0 = 0.87 * travel time at practical capacity
V = assigned volume
C = practical capacity

b) *Smock Model:* Smock model is used to compute link travel time as:

$$T_A = T_0 e^{\left(\frac{V}{C} - 1\right)} \qquad (27)$$

Where, $T_A \leq 5T_0$
T_A = adjusted travel time which is used to determine the minimum paths or routes.
T_0 = Original travel time
e = exponential base
V = assigned volume
C = computed link capacity

4) *Capacity Restraint Multipath Route Assignment Model:* This model is almost same as multipath route assignment model but in this model we also consider the capacity of each link instead of only distance. This model can be considered as combination of capacity restraint and multipath model.

5) *Diversion Curves Model:* Diversion curves represent empirically derived relationship showing the proportion of traffic that is likely to be diverted on a new facility (bypass, new expressway, new arterial street, etc.) once such a facility is constructed. The curve is constructed by the data collected from the pattern of road usage in the past. It is a one of the frequently used assignment model. This model is based on the travel time saved, distance saved, travel time ratio, travel distance ratio, distance and speed ratio, travel cost ratio, etc.

a) *California Curves Model:* In the California curves model, travel time saved and distance saved for two routes can be assigned the traffic.

$$\% \ traffic \quad diverted \quad (P) = 50 + \frac{50 * (d + 0.5t)}{\left[(d - 0.5t)^2 + 4.5\right]^{0.5}} \qquad (28)$$

Where, d = distance saved on the new route (miles)
T = travel time saved (minutes)

b) *Detroit Model:* In the Detroit model, speed ration and distance ratio for two routes can be assigned the traffic.

$$Speed \quad Ratio \quad (S.R.) = \frac{Speed \quad on \quad new \quad route}{Speed \quad on \quad old \quad route}$$

$$Dis\tan ceRatio \quad (D.R.) = \frac{Dis\tan ce \quad on \quad new \quad route}{Dis\tan ce \quad on \quad old \quad route}$$

Limitations

- Only two routes are considered.
- Capacity is not considered.
- Driver behavior is not considered.

III. CONCLUSION

Trip generation gives an idea about the total number of trips generated to and attracted from different zones in the study area. In trip distribution, growth factor modeling and in trip generation, regression methods can be used to predict the trips. Trip matrix can be used to represent the trip pattern of a study area. Growth factor methods and gravity model are used for computing the trip matrix. Transportation planning involves so many iterative techniques, and large road networks, which is not possible to solve manually. But the computer programmers are created readymade softwares available for solved the transportation planning problems. Trip assignment is the last phase of four stage transportation planning. Multipath route assignment technique seems to be the most realistic among all those techniques. The basic steps in Transportation Planning Models are:

- Assessment of the existing road network, traffic and travel characteristics of the study area.
- Forecast travel demand up to the horizon year 2021 and identify transport system requirements.
- Digitization of road network.
- Conducting sample surveys for trip rates, mode choice and O-D.
- Preparing trip generation models and O-D matrices.
- Traffic assignment on selected network and assessment of vehicle/capacity ratio.
- Creating transportation scenario for future.

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