STUDY ON DYNAMIC MODAL SPLIT

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INTRODUCTION

Dynamic travel demand analysis has received increasing attention for recent years because of its many advantages comparing with traditional analysis using cross-sectional data.Until now,the most common methods for dynamic travel demand analysis are often based on embedding time-dependent factors to traditional non-dynamic models or using Markov chain.Analysis using these approaches have some critical limits because it offers no explanation but replication.Another specification issue involved in the formulation of dynamic models concerns the structure of lagged variables and the identification of this lag is said to be difficult.

In this paper,a dynamic modal split model which can be used for forecasting travel demand or analyzing transportation policies is formulated.The model belongs to class of structured equations models and there are some good reasons to believe it to be capable of determining the causal relationship among a set of variables for analyzing dynamic modal split.

1-FORMULATION OF MODEL

It is well-known that the number of trips choosing some mode to travel is growing or declining not freely.Suppose that D is a total number of trips which has to be distributed among m modes and $x_{k(t)}$ is number of trips choosing mode k at moment t. Of course,in steady state (equilibrium) all the $x_{k(t)}$'s will be constant .Let D_k is number of trips choosing mode k in steady state we can suppose that $x_{k(t)}$ grows if $(D_k - x_{k(t)})$ is positive and declines if that difference is negative.In other word,behavioral adjustment made is proportional to the difference between the behavior in the previous period and the equilibrium behavior.Using this assumption,for suitable ε_k we can get the following system of differential equations:

$$\frac{dx_{k(t)}}{dt} = \varepsilon_k \left(D_k - x_{k(t)} \right) \qquad k=1,2,3,\ldots,m \qquad (1)$$

where, m is number of available travel modes.

The D_k's are constant only all $x_{k(t)}$'s are not changed in equilibrium or in other words , when $D_k = x_{k(t)}$ .Their values can be determined by following formula:

$$D_k = \frac{A_k}{\sum_{i=1}^{m} A_k} D \qquad (2)$$

$$k = 1, 2, 3, \ldots, m$$

where A_k is a measure of attractiveness of mode k , D is total number of trips by all modes.Typically,the A_k's are each nonlinear functions of $x_{k(t)}$ and in this paper two alternative formulas of A_k are used.

The first formula is:

$$A_{k(t)} = \frac{x_{k(t)}^{\alpha_k}}{\theta_k + \gamma_k x_{k(t)}} e^{\sum_{j=1}^{n} \beta_{jk} z_{jk(t)}} \qquad (3)$$

$$k = 1, 2, 3, \ldots, m$$

where:

n : number of variables used to explain mode choice behavior.

$z_{jk(t)}$: socioeconomic demand and supply variable used to explain mode choice behavior of travelers at time t.

$\alpha_k, \theta_k, \gamma_k, \beta_{jk}$: parameters

The meaning of components of formula (3) can be interpreted as following:

The component $e^{\sum_{j=1}^{n} \beta_{jk} z_{jk(t)}}$ expresses the dependence of attractiveness of travel mode k on socioeconomic demand and supply variables as usually in conventional modal split models.

The component $x_{k(t)}^{\alpha_k}/(\theta_k + \gamma_k x_{k(t)})$describes the dependence of attractiveness A_k on qualitative and attitudinal variables by two opposite ways:

-The attractiveness A_k is directly proportional with number of trips using mode k because of transportation system response and because of psychological factors: the more people who use a mode, the more popular it becomes.

The expression $x_{k(t)}^{\alpha_k}$ of this component is used to describe this assumption.

-At the same time, the attractiveness A_k inversely proportional with number of trips using mode k because of congestion and this assumption described by expression $(\theta_k+\gamma_k x_{k(t)})^{-1}$. Here θ_k can be understood as measurement of unpopularity of travel mode.

Like in the case of traditional logit model using cross-sectional data,we can formally derive formula (3) by using random utility theory.The basic idea is that each traveler maximizes his utility but that this is subject to some random variation-either to account for unmeasured differences in preferences,lack of information,or whatever.Suppose that the net benefit the traveler get from traveling by mode k is U_k .Then the probability P_k of a traveler choosing mode k is:

$$P_k=Pr\ (U_k \geqq U_i,\ all\ \ i \neq k) \tag{4}$$

with

$$U_k=V_k+e_k \qquad k=1,2,3,\ldots,m$$

where
U_k : utility function for mode k .
V_k : deterministic function of attributes of mode k .
e_k : a stochastic component,a random variable that follows Weibull distribution.

This probability can be calculated as:

$$P_k = \frac{e^{V_k}}{\sum_{i=1}^{m} e^{V_k}} \qquad k=1,2,3,\ldots,m \tag{5}$$

We will use the following form of V_k :

$$V_k= log\ A_{k(t)} \qquad k=1,2,3,\ldots,m \tag{6}$$

and after manipulation:

$$V_k=\alpha_k\, log\, x_{k(t)}-log\ (\theta_k+\gamma_k x_{k(t)}) + \sum_{j=1}^{n} \beta_{jk} z_{jk(t)} \qquad k=1,2,3,\ldots,m \tag{7}$$

The formula (7) means that the probability of choosing mode k is directly proportional to $log\ x_{k(t)}$

and inversely proportional to $log(\theta_k + \gamma_k x_{k(t)})$ while depends on the sum $\sum \beta_{jk} z_{jk(t)}$. This assumption is plausible and corresponding to the above-mentioned assumption to derive formula (3). By substituting (7) to (6) we can get detailed formula for P_k and derive the form of A_k exactly as in formula (3). This analysis shows another way of interpreting the meaning of formula (3).

Another form of attractiveness A_k can be understood as generalization of logit model and simplification of formula (3) is:

$$A_{k(t)} = e^{\sum_{j=0}^{n} \beta_{jk} z_{jk(t)}} \qquad (8)$$

$$k = 1, 2, 3, \ldots m$$

where $z_{jk(t)}$ are the same as in formula (3) with exception for $z_{0k(t)} = x_{k(t)}$ which use to describe the dependence of attractiveness on trip number. Of course, we can formally derive (8) from random utility theory, too.

Substitute (3) or (8) to (2) respectively, then to (1) the system of differential equations of dynamic modal split can be written as following (we call it Model I when using formula (3) and Model II when using formula (8)):

$$\frac{dx_{k(t)}}{dt} = \varepsilon_k \left[\frac{A_{k(t)}}{\sum_{l=1}^{n} A_{k(t)}} \cdot D - x_{k(t)} \right] \qquad (9)$$

$$k = 1, 2, 3, \ldots, m$$

2-CALIBRATION OF MODEL

Since the formulated models are highly nonlinear, the estimation of parameters is much more complex than that of simple demand models which can be linearized. The parameter's estimation based on discrete version of models (with $\Delta_t = 1$):

$$x_{k,t+1} = (1-\varepsilon_k)\,x_{k,t} + \varepsilon_k \frac{A_{k,t}}{\sum_{l=1}^{m} A_{l,t}} D_t \qquad (10)$$

$k = 1, 2, 3, \ldots, m$

The meanings of variables are the same as in (9) but they are discrete.Using least-square technique,the problem of calibrating the models can be written as following constrained nonlinear programming:

$$F = \sum_{t=1}^{T} \sum_{l=1}^{m} (x_{k,t}^{ob} - x_{k,t})^2 \Rightarrow min! \qquad (11)$$

with $x_{k,t}$ calculated from (10) and D_t is the sum of all $x_{k,t}$ at every moment.

The parameters must satisfy suitable trivial constraints depending on their meaning.

Here,

T :number of time periods

F : sum of least-square to minimize

$x_{k,t}^{ob}$:observed number of trip by mode k ,at period t .

This problem can be solved by the methods of nonlinear programming and here we use method SUMT with BFGS or Powell search for derived unconstrained nonlinear programming.The computer program to perform this task is also written in Turbo C.

3-NUMERICAL EXAMPLE

Here,the case of modal split between railway and airway from Osaka to Tokyo(Japan) is shown as a simple numerical example.In Japan,these two modes are very competitive between the biggest cities.The attributes of each mode to be considered are total travel expense,total travel time,frequency and trip number itself.The result of estimated parameters are:

ε_1=1.09777, ε_2=0.77995, α_1=1.46889, α_2=1.51608

θ_1=1.10862, θ_2=1.05367, γ_1=1.09064, γ_2=0.9516

β_{11}=-0.99843, β_{12}=-0.93694, β_{13}=0.74076, β_{21}=-1.0339

β_{22}=-0.9476, β_{23}=1.0259

for Model I and:

ε_1=0.93088, ε_2=0.88468, α_1=0.36956, α_2=0.79047

β_{11}=-0.95116, β_{12}=-0.9692, β_{13}=0.76775, β_{21}=-1.01524

β_{22}=-1.01031, β_{23}=-1.14891 for Model II.

Table 1 and Table 2 shows observed and estimated trip number rate by each mode.The graphic comparison of observed and estimated trip number are given on the Figure 1 and Figure 2.

Table 1:Observed and estimated trip number rate by railway.

Year	Japanese railway (JR)		
	Observed	Model I	Model II
1975	0.8173	0.8173	0.8173
1976	0.7988	0.8000	0.8114
1977	0.7512	0.7779	0.8114
1978	0.7510	0.7675	0.7529
1979	0.7507	0.7705	0.7529
1980	0.7820	0.7808	0.7804
1981	0.7798	0.7816	0.7796
1982	0.7883	0.7782	0.7794
1983	0.7821	0.7805	0.7849
1984	0.7526	0.7587	0.7491
1985	0.7794	0.7734	0.7818
1986	0.7636	0.7644	0.7666
1987	0.7651	0.7644	0.7532
Average error	—	0.0952	0.0704
Average error (%)	—	1.7400	1.2900
Theil coefficient	—	0.0021	0.0014

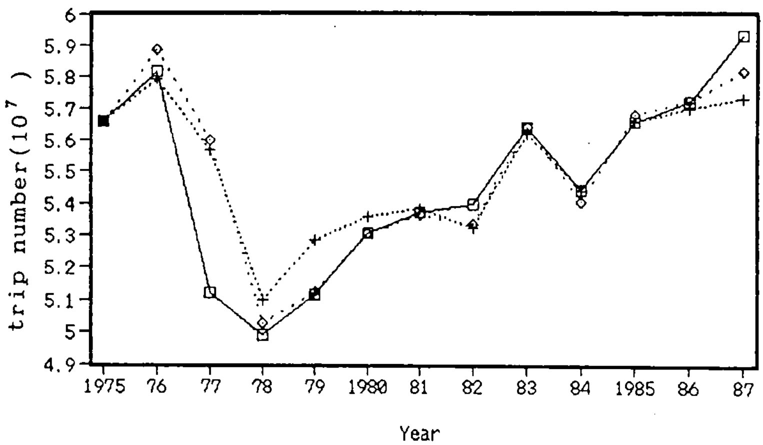

Figure 1 ; □ Observed + Model I ◇ Model II

Table 2: Observed and estimated trip number rate by airway.

Year	Airway		
	Observed	Model I	Model II
1975	0.1827	0.1827	0.1827
1976	0.2012	0.2000	0.1886
1977	0.2488	0.2221	0.2227
1978	0.2490	0.2325	0.2471
1979	0.2493	0.2295	0.2471
1980	0.2180	0.2192	0.2196
1981	0.2202	0.2184	0.2204
1982	0.2117	0.2218	0.2206
1983	0.2179	0.2195	0.2151
1984	0.2474	0.2413	0.2509
1985	0.2206	0.2266	0.2182
1986	0.2364	0.2356	0.2334
1987	0.2349	0.2554	0.2468
Average error	—	0.0618	0.0390
Average error (%)	—	3.8000	2.3600
Theil coefficient	—	0.0035	0.0027

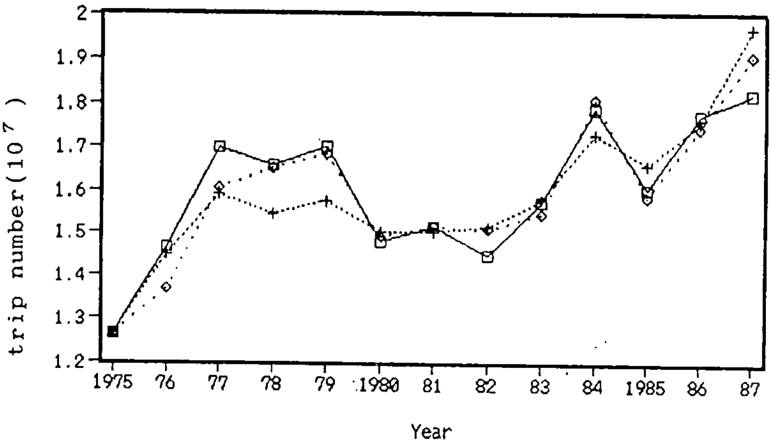

Figure 2: □ Observed + Model I ◇ Model II

As we can see, the result of both models are quite good, especially the dynamic of whole process. The calibrated model can be used for various purposes: conditional forecasting for policy making, analysis elasticities of trip number to attributes, determining the causes of demand fluctuation, studying the effects of bifurcation and even more, using as basic model to find optimal policy for controlling dynamic modal split process.

Model II seems to be more precise and the number of parameters is less than Model I. This fact can be an advantage when the number of samples is not large enough. In other side, Model II gives us more information about the behavior of traveler by analyzing the values of parameters with their corresponding meanings. That's why using which model depends on the available data and purpose of analysis.

4-CONCLUSION

The dynamic modal split models in this paper although developed for aggregate level but can be easily modified for individual level, too. The main advantage of them is the capability of describing clearly fluctuation of travel demand, analyzing the causes of that phenomenon. Because of high nonlinearity, the models can be used for studying some effects which can not be seen by linear models. It is obvious that the explicit form of solution of system of differential equation describing the models is very difficult to obtain. However, the dynamic simulation technique can be used instead of that. Simulation technique is also a powerful tool for studying the equilibrium behavior of the system. It seems that the technique used in this paper can also apply to other problems of dynamic travel analysis.

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AN APPRAISAL OF MODE CHOICE ANALYSIS AND RESEARCH IN INDIA

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INTRODUCTION

Eventhough major transportation studies began in early seventies in India still there has been less importance in travel behaviour forecasting in these studies. Due to constraints of income, infrastructure availability usually the commuters were captive. Growth of technology, economic development and the growing consumerism has generated a choice environment in the urban transportation scenario. Attempts have been made in the academic institutions and research institutions to study the various aspects of mode choice. An attempt has been made in this paper to compile most of the research work done in this field. This compilation of research work would help to know the research direction and to assess the future research need in this country. The work reviewed here is mainly those work based on the principle of utility maximisation.

1. APPROACHES TO MODE CHOICE ANALYSIS

Eventhough in the developed nations a variety of approaches has been made to mode choice analysis, in the Indian case most of the approaches are oriented in the economic psychological theory. Chari(1), Sinha(3), Rao(7) have developed mode choice models for some of the Indian cities based on the principle of utility maximisation of economics. According to Chari(1), "A traveller derives utility from the activity that is to be carried out at the end of the trip. Since travel is necessary to derive that utility it is considered as a good yielding indirect utility. "Sinha has derived the conceptual framework from the economic hypothesis that the individual maximises his utility. An individual will choose that alternate which has maximum utility.

Since some of the utilities are not measurable it is necessary to assign a probability to an individual decision. Rao(7) has slightly deviated in utilising this concept and has used the notion of disutility minimisation which is just the negative of utility maximisation.

The approaches of Reddy(4), Deb(6) are entirely different from the conventional approach with total deviation from the utility maximisation principle. Reddy(4) has developed a non compensatory model of mode choice based on the attribute by attribute comparison of various alternatives. Based on the concepts of decision theory maximin, maximax and predominant attribute models are formulated. The results obtained from the maximin and maximax models compare well with the observed data but the predominant attribute model need further investigation.

Deb(6) has adopted the fuzzy set approach which believes that well defined systems are easily analysed by the modern system theory but the real world systems which are imprecise, vague and complex may not be easily analysed by the conventional methods. Management and planning processes are very much influenced by subjective judgement, perception and human error. This is mainly due to lack of detailed structural knowledge in the process, its parameters and variables. He has shown that fuzzy approach can be effectively used to solve the mode choice analysis process.

Sarna(2,5,9) has probed in great detail about the various causal variables influencing mode choice decision in Indian situation. He has studied the temporal changes in modal split structure of the cities.

All ofthe above studies are mainly confined in the academic and research institutions. Except for the HATS(8) no transportation study has developed a mode choice model for any of the Indian city. Still now most of the mode choice models developed in the western countries are based on the principle of utility maximisation. A review of Indian work in this field would help to evolve our research needs in this field.

2. DETERMINANTS OF MODE CHOICE

A number of socio-economic and transport system variables have been found to be strongly influencing the mode choice decision of individual commuter. Sarna(5) has classified these determinants of mode choice into the following categories.

a) Demographic Factors -

i) Age, sex, race and education of individual
ii) Auto-ownership, income and size of household
iii) Purpose and auto availability of trips
iv) Travel time, frequency and speed of transportation system
v) Landuse and population distribution
vi) Environmental factors such as weather and land topography

b) Psychological and Social Factors -

i) Needs, attitudes, awareness and roles of the individual
ii) Needs, resources, activities, hierarchy and life style of household
iii) Comfort, convenience and prestige of the system

c) System Factors -

i) Capacity, delay and route choice

However, Chari(1) has dealt these influencing variables in a more systematic manner. He has categorised these influencing variables into

a) User variables,
b) Modal characteristics,
c) Level of service factors,
d) Environmental conditions.

The study result indicates that income is the most important user variable, vehicle ownership the major modal characteristics and travel time, travel cost are the important level of service factors which decide the mode choice in the metropolitan areas in India. Sinha(3) has classified the causal variables in the following manner.

a) Socio-Economic Variables -

i) Income
ii) Number of residents in household
iii) Number of school going children
iv) Vehicle ownership
v) Occupation of head of household
vi) Occupation status of trip maker

b) Transport Variables -

i) Door to door travel time for both mode used and alternative modes available
ii) Transfer and waiting time
iii) Any other measurable factor

c) Locational Characteristics -

i) Distance of work place
ii) Distance to school

d) Attitude Characteristics -

i) Comfort, convenience and reliability
ii) Waiting, walking, actual travel time
iii) Costs which commuter can afford actually

Rao(7) has used the causal variables developed by his predecessors and besides them he has used these variables in a much more disaggregated way. While door to door travel time was used earlier he broke down this travel time into the walking time, waiting time and invehicle time. This division of travel time helped to understand the relative harshness of individual components of travel time.

3. PROBABILISTIC MODELS OF MODE CHOICE

Chari(1), Sinha(3) and Rao(7) have developed logit models to estimate the probabilistic models of mode choice. Due to limited choice situation Chari has developed a mode choice model for a binary situation. Sinha(3) has developed both a multinomial logit model (MNL) and equivalent binary hierarchy (EBH) model. Rao(7) has developed a sequential binary mode choice model (SBM). All these models assume that the response to the stimulus of the various causal variables is in the form of a logit distribution.

a) Chari's model -

$$p_m(m_1 | m_1, m_2) = \frac{\exp [V_1 (x)]}{\sum_{i=1}^{2} \exp [V_i (x)]}$$

$$V_i(x) = a_1(t_c - t_{Nc}) + a_2 (c_c - c_{Nc})$$

$p_m(m_1 | m_1, m_2)$ = probability of chosing mode m_1 out of m_1 & m_2

m_1, m_2 are two modes available to the commuter
a_1, a_2 are parameters to be estimated
t_c, c_c are time and cost of travel of chosen mode c
t_{Nc}, c_{Nc} are time and cost of travel by nonchosen mode Nc

b) Sinha's model -

$$P_j^i = \frac{\exp U[X_j^i, S_i]}{\sum_{k=1}^{m} \exp U[X_k^i, S_i]}$$

P_j^i = probability of chosing mode j by i
X_k^i = transportation system variable of mode k for individual i,
S_i = socio economic variable for individual i

$$U[X_j^i, S_i] = a_{\theta j} + \sum_s a_s X_{sj} + \sum_t tj S_i$$

$U[X_j^i, S_i]$ = measurable utility for alternative j to individual i
$a_{\theta j}$ = alternative specific dummy variable
s = number of attributes related to transport j for the traveller i
t = number of attributes related to the socio economic aspect of raveller i

c) Rao's model -

The basic premise behind the sequential binary choice model of Dr. S.B.S. Rao is that, "the human beings possess a tendency to pair and sequence before making selection". He has developed a number of binary choice models to cover the various categories of commuters. A sample binary choice model developed by him is given below.

$$\text{Prob}(i-j/m1) = \frac{\text{Exp}[U(Xm1)]}{\text{Exp}[U(Xm1)] + \text{Exp}[U(Xm2)]}$$

where

$$U(Xm1) = a\theta + a1(WKKT)m1 + a2(WTT)m1 + a3(INVT)m1 + a4(OPC)m1$$

$$U(Xm2) = a\theta + a1(WKKT)m2 + a2(WTT)m2 + a3(INVT)m2 + a4(OPC)m2$$

WKKT = Walking time to access mode (m1/m2)
WTT = Waiting time to board mode (m1/m2)
INVT = Time spent in travelling by mode (m1/m2)
OPC = Cost of journey by mode (m1/m2)

aθ,a1,a2,a3,a4 are to be estimated.

4. ESTIMATION OF MODEL PARAMETERS

To arrive at final values of the parameters Dr. Chari had investigated 48 models with the various combinations of (i) mode specific constant, (ii) time difference, (iii) cost difference, (iv) age, (v) income, (vi) distance of trip. The model parameters were scrutinised in the light of various statistics such as -2log, pseudo R^2 value etc. He has developed 8 sets of parameters for 8 different types of commuter groups. Dr. Sinha presented for the first time a clear explanation and detailed methodology of the maximum likelihood technique for estimating the logit models under Indian conditions. He has tested the significance of model parameters using 't' test and likelihood ratio test. Rao(7) has examined the statistical reliability of models by studying R^2 values, 't' ratios of each of the coefficients.

Due to different model structures and variables it is not possible to compare these models in a relative scale. While Chari(1) has classified the commuters into 8 homogeneous groups namely (i) car employed, (ii) scooter employed, (iii) bicycle employed, (iv) walk employed, (v) car self employed, (vi) scooter self employed, (vii) bicycle self employed, (viii) walk self employed; Rao(7) has classified the commuters into 3 homogeneous groups i.e., (i) public transport user, (ii) car available group, (iii) two wheeler available group.

5. INFORMATION NEED FOR MODEL DEVELOPMENT

Various studies which have been quoted above have used different amount of information both qualitatively and quantitatively for the model development. Chari(1) has utilised 2221 household samples from Ahmedabad to develop mode choice model. After inserting a number of restrictions to scan the choosers his final model has been developed over 1342 individual trip journeys. Sinha(3) collected the information for Patna city by interviewingh the commuters in various employment locations. He has developed the final model on a sample size of 400 commuters. Rao(7) has developed mode choice model based on the household survey of 1979-80 collected by CRRI for the Bombay metropolitan area, the final sample used by him consists of 150 car owned, 50 two wheeler owned and 50 no vehicle owned household.

This review of sample sizes reveals that in Indian context there has been no work on the optimum sample size. Individual researchers have chosen sample according to their own constraints, conveniences and there has been little study to study the sensitivities of the model to sample size.

6. APPLICATION OF MODE CHOICE ANALYSIS

Mode choice analysis have been used to demonstrate its application for policy analysis. Chari(1) used mode choice models for the first time in India to determine the value of travel time, elasticities of travel demand, mode split and mode choice probabilities of innovative modes. In determining the value of travel time he had adopted the approach that human beings trade off money for travel time. He used the following formula for calculating the value of travel time.

$$\frac{\partial \Delta c}{\partial \Delta t} = \frac{a_1}{a_2}$$

where,

Δc = differential change in cost
Δt = differential change in time
a_1 = model coefficient of travel time
a_2 = model coefficient of travel cost

The find out elasticities of mode choice he has calculated percentage change in mode choice probability with respect to changes in the attributes that influence the choice decision. One of the strength of disaggregate behavioural model is its capacity to determine the mode split of any new type of mode without reestimation of the modes once they are calibrated. Since the calibrated models contain mode abstract attributes the name of the mode is no concern for analysis.

Rao(7) has done significant work regarding the application of mode choice model to determine the relative harshness of various attributes of transportation system. He has found that waiting time has been the most important from the modelling point of view and is most frustrating from the commuters point followed by walking time. Again walking time has been more frustrating to the car available group than the public transport group.

Sarna(2) has used the models to determine essentially the empirical socio economic factors that affect mode choice.

7. RESEARCH NEEDS

The work reviewed here covers almost the major mode choice research on India. The comparison of this work with the recent state of art at global level highlights the research needs in this field in this country.

1) Model specification : Its still a myth that what are the socio economic variables to be included as input parameters in the model. The role of different variables relative to each other is not clearly known.

2) Model structure : Eventhough a number of model structures have been tried in the other parts of the world still in India only the logit model has been applied in the name of simplicity. The advanced forms of the logit model like the NL model, dogit model, GEV model which take care of the some of the basic drawbacks of the logit model have the potential for the future application.

3) Data collection : Very often a practical planner may face the problem in determining the information need for development of mode choice models since we have very little knowledge as far as this aspect is concerned. Different researchers in India have collected different amount of data based upon their own constraints or their resources. There has been no attempt to study the optimum sample size and the qualitative characteristics of the information collected.

4) Stratification : Different researchers have adopted different methods of strtifying the population. Mainly these stratification is based on the economic and vehicle ownership criteria. Recent researchs in the European

countries have revealed that segmentation of population based on the principles of activity analysis yields better results. An activity based approach may be a more meaningful tool for the study of travel characteristics in the urban areas.

5) Stated preference : The mode choice models developed in our country are based on the revealed preference approach where the future behaviour is predicted based on the study of existing behaviour. Use of stated preference approach would be helpful to understand the choice behaviour in a hypothetical condition in a better way.

6) Transferability : Time and again many researchers have repeated the statement that the disaggregate models are transferable over geographical and time dimension. But the achievements in this field has been very poor even at the global level. Till now a model developed for a particular area can not be transferred to another area as it is and need some amount of moderation. In Indian case this has to be explored in a detailed manner since there has been no research at all.

8. CONCLUSION

Mode choice research in India had a remarkable beginning in the mid seventies with the work on binary choice models. But this model is handicapped due to its restricted choice set which is unrealistic in a present day situation. The work of early eighties helped in the evolution of a simplified methodology for multiple choice situation. After this there had been some research in the application of non conventional technique like noncompensatory approach and fuzzy set theoretic approach. The work of late eighties is very useful in studying the relative characteristics of the different variables that influence the mode choice decision process. Besides the HATS there has been no other case where mode choice analysis has been used for the preparation of transportation plan of a city. This reflects that more research is needed in this area to address the diversified problems associated with the mode choice analysis to make it a feasible tool for the transportation planners.

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