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An Accessibility-Activity Based Approach to Model Rural Travel Demand in Developing Countries

Mir S. Ali [a], Jennaro B. Odoki [b], Henry R. Kerali [b]

[a] NED University of Engineering and Technology, Karachi, Pakistan.
E-mail address: shabbar_ali@hotmail.com
[b] School of Engineering, The University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK.
Fax: +44 121 4143675, E-mail address: j.b.Odoki@bham.ac.uk

Abstract

This paper describes the development of a method for quantifying rural travel demand suitable for application in developing countries. The methodology provides an approach to analysing household accessibility needs within a framework of a range of activities pursued by people in rural communities to support their livelihoods. The accessibility-activity-based model developed recognises the derived nature of travel, and considers the spatial, temporal, economic, cultural and social constraints faced by individuals.

The model developed has a three-tier structure. The first tier performs village level analysis to determine household needs and the range of activities available. The second tier analyses household access needs and the resulting demand for activity-participation. The third tier analyses the activity-travel pattern of each individual member of the household. Probabilistic behavioural models are used to model activity choice by each individual and the resulting travel characteristics. Household data collected in a field survey of representative rural areas of Pakistan were used to develop the model form and determine the statistical significance of the model parameters. The types of activities analysed were work, education, market, health and leisure. The model developed was validated using a separate set of household data collected from other villages in Pakistan.

A detailed analysis of the household data collected revealed the distinctive nature of the various activities considered and the role-allocation of activity-participation to the individual household members in Pakistan. Evidently, besides income levels and vehicle ownership, gender and household life-cycle-stage are the key determinants in activity choice and travel decision-making. The paper also includes a worked example to describe the application of the accessibility-activity-based model developed.

Keywords: Travel demand model; Household needs; Accessibility; Activity-participation; Rural travel behaviour; Travel opportunities

1. INTRODUCTION

Most rural populations in developing countries are burdened heavily in travelling to access basic needs for sustaining their livelihoods, particularly in terms of excessive usage of their daily time and efforts. The lack of adequate, affordable and reliable rural access infrastructure to promote economic development and social welfare is known to be one of the major factors responsible for problems associated with poverty, high mortality rate, low literacy rate and high sense of isolation. Research on rural travel patterns and demand should therefore consider all constraints faced by rural people in participating in various activities. The understanding of travel pattern in this context and quantification of travel demand in rural areas of developing countries would enhance the existing transportation planning methodologies and provide a sound basis for deriving appropriate and effective development strategies plans and policies.

Over the years, the perspective of rural transportation planning in developing countries has shifted from the conventional approach that relies on infrastructure investment for motorised vehicles to a 'needs-led' approach (Howe, 1996). This change was a result of dissatisfaction with the conventional approach in terms of delivering the expected developmental benefits and welfare improvements. The 'needs-led' approach, still in its evolutionary stage, provides improved insight into the constraints faced by rural individuals, the actual needs for sustaining their livelihoods and their development needs at the local-level. The aim is to ensure that infrastructure investments are directed towards the most urgent needs of rural communities.

Central to the formulation of the 'needs-led' approach is the concept of accessibility. Accessibility is concerned with the opportunity that an individual at a given location possesses to participate in a particular activity or set of activities. Accessibility depends on the transportation, temporal (time), and spatial location constraints which limit the ability of individuals to participate in productive and consumptive activities (Odoki, et al., 2001). The framework for modelling rural travel demand developed in this research integrates the concepts of accessibility of activities and of travel for participation in activities to form an *accessibility-activity approach.* The underlying concept therefore views travel patterns of individuals as a subset of their activity patterns where activities are conditioned on the basis of an individual's accessibility constraints.

2. MODELLING FRAMEWORK

A number of recent studies have opined to base travel demand formulation within the 'needs-led' approach, in which the household is considered as the basic unit of analysis. For example, a study by Turner and Kwakye (1995) in Ghana showed that the roles of individual household members define the overall economic organisation of a household. They found that households with severe monetary and time-budget constraints assign children important roles in carrying out subsistence activities. Their findings also suggest that household activity analysis can provide a flexible framework to study a number of issues like cultural and gender factors that affect transport logistics, the economics of household decision-making, and the accessibility of households to essential services and facilities.

Ali (2001) carried out a field survey of rural household in Pakistan. An analysis of the household level data collected revealed that the activity-travel pattern of each individual household member is a result of the individual's role within the household. Household needs are transformed into activities performed by each individual household member. The activity-travel pattern of an individual is therefore a function of the individual characteristics, the availability and type of activity, and accessibility indicators (e.g. time constraints, distance to activities, connection to engineered roads). Cultural and gender issues are important factors in determining role-allocation to household members of participation in 'home-based' and 'non-home-based' activities.

The framework for modelling rural travel demand is based on the premise that the desire of individuals to access services and facilities required to fulfil their household needs is an indicator of travel demand in developing countries (Ali et al., 1999). Thus the framework developed integrates household needs and individual activity decision-making into a three-tier modelling structure as follows:

1. Needs allocation
2. Accessibility criteria
3. Activity participation

Figure 1 illustrates the relationship between these stages. A description of these stages is given in the proceeding paragraphs.

Needs allocation

This is the first tier of the modelling framework in which analyses are performed at the village level to determine household needs and the range of activities available. The household level needs are fulfilled by activities performed by household individuals. Activities required to fulfil these needs are allocated to each individual according to their role within the household. Cultural and gender considerations are also addressed at this stage of the modelling framework. Thus, the needs allocation stage provides an activity agenda to each member of the household.

Accessibility criteria

The second tier analyses the individual activity agenda, and applies a set of accessibility criteria in order to determine the resulting demand for activity-participation. The accessibility criteria include consideration of location of the individual, and the transportation, temporal, spatial, economic and social constraints facing the individual. An activity that falls within the bounds of these accessibility constraints is considered to be an opportunity for the individual. The analysis at this stage delineates the set of opportunities available to each individual household member, and this defines their activity choice set. Each activity performed by an individual has an associated accessibility benefit, the magnitude of which depends upon the attributes of the individual and the activity.

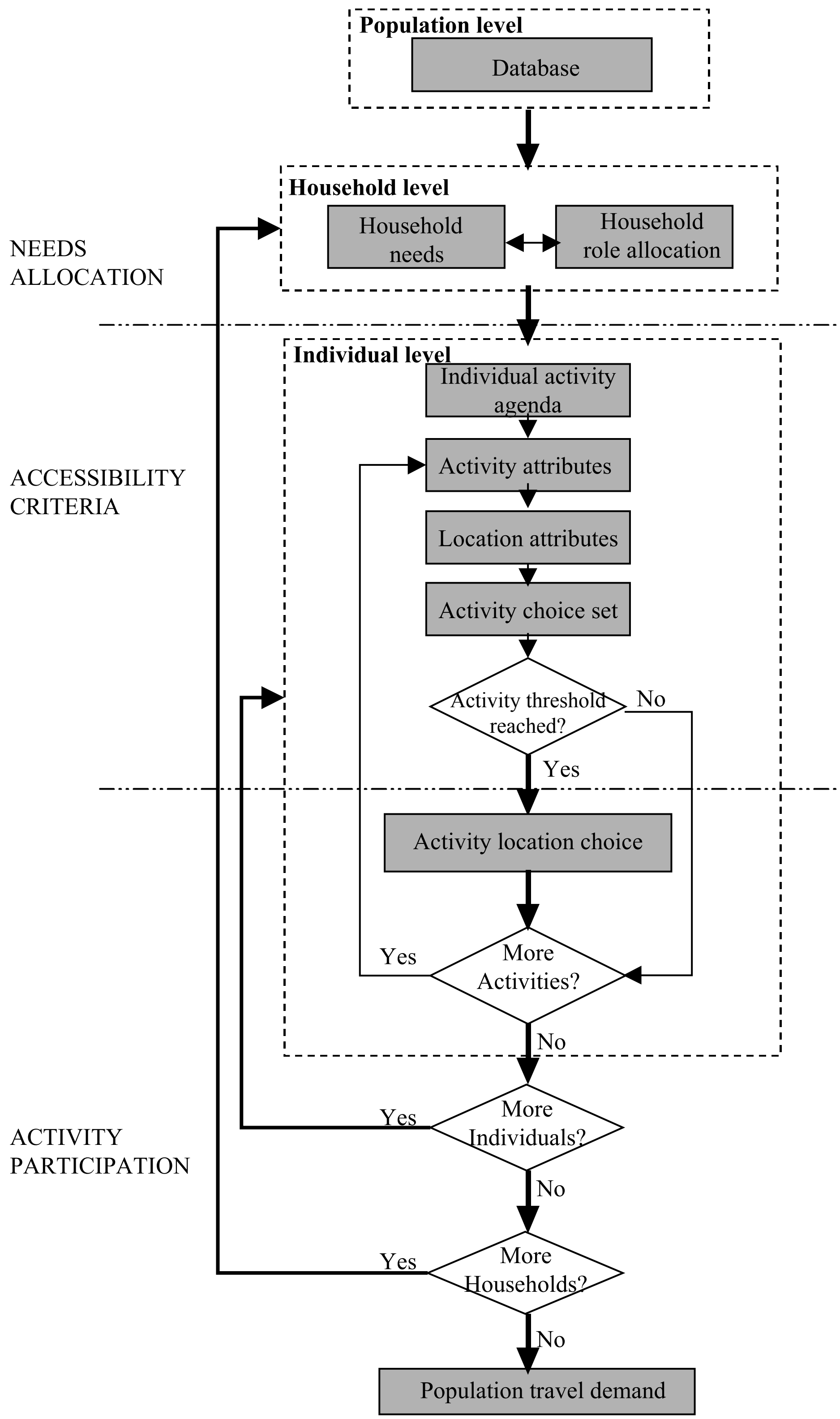

Figure 1 Rural travel demand modelling framework

Activity participation

The third tier analyses the activity-travel pattern of each individual member of the household and quantifies the aggregate travel demand. It is assumed that an individual weights all opportunities available within their activity choice set, on a daily basis, in order to determine whether or not they require to travel to participate in a particular activity or set of activities. The framework considers this as a discrete choice problem in which the utility function is based on the accessibility benefits estimated for each opportunity.

It is assumed that each activity in the choice set is characterised by a threshold level that defines the level of accumulated need beyond which the desire for travel to participate in the particular activity should be realised. Each opportunity is tested against its threshold level and if the threshold level were reached, the individual would decide to participate in the activity, thus giving rise to their travel demand. In this way, it is possible to determine for each activity in which the individual decides to participate their individual travel demand. The outcome of this stage is the quantity of an individual's travel demand derived for different types of activities, at different locations, and using different modes; which is analogous to the first three steps in the conventional four-stage transportation planning method, namely trip end estimation, trip distribution, and modal split, respectively.

Analysis loops

As illustrated in Figure 1, stages 2 and 3 of the modelling framework are repeated for all the individuals of the household and then for all households within the study area. The total travel demand for the population sample is estimated by the aggregation of all the individuals' travel demand.

3. MODEL FORM

The travel demand modelling framework discussed in Section 2 incorporates a decision-making process to be undertaken by an individual regarding their choices of activity type and location. To model this decision-making process, it is assumed that the desire to participate in an activity is related to the amount of accessibility benefits that can be derived by the individual. This assumption is used to develop a mathematical form of the travel demand model based on the principles of discrete choice theory and utility maximisation. The accessibility benefits index is used as a proxy to the utility of the activity for the individuals.

Accessibility benefits model

The utility of an opportunity is defined on the basis of accessibility benefit of an activity that may accrue to an individual. The accessibility benefit model (BM) developed by Odoki (1992, 2001) was used to define the utility function as follows:

$$BM_j^k = \exp\left[-\left(\frac{m}{\alpha I} + \frac{1}{v}\right)2x_k\right] \cdot [c\rho\omega] \cdot h^\gamma [\tau - \frac{2x_k}{v}]^\gamma \tag{1}$$

where BM_j^k is the index measure of accessibility benefit to an individual for an participating in an activity type *j* located at k a distance x km from the origin; *m* is the monetary travel cost per km; αI is value of travel time per hour to an individual with income '*I*' (or who expects an average earning of '*I*' as a result of making a journey); *v* is the average speed of travel using a particular mode in km/hr; ρ defines the level of activity; ω represents the attraction characteristics of the activity in the form of weight attached to the activity; *c* is the model calibration parameter (c>0); *h* is a measure of utility per unit time; γ is a parameter that defines the marginal utility of time available to the individual for the activity participation; and τ is total time budget available to the individual. This utility function combines the three components of accessibility, namely: the transportation component, accounting for (dis)utility of travel; the spatial component, considering utility of location-activity; and the temporal component, incorporating the utility of time.

Discrete choice model

Individual discrete choice behaviour has been modelled using three approaches; namely, multinomial logit model, binary logit model and grouped regression model. The binary logit model was found to be most suitable for modelling decision-making of individuals based on the theory of utility maximisation. The binary logit model used is expressed as follows:

$$P_j^i = \frac{\exp(\beta \cdot BM_j^i)}{1 + \exp(\beta \cdot BM_j^i)} \tag{2}$$

where P_j^i is the probability of selection of activity *j* by the individual *i*; and β is the model parameter. In a binary logit (BNL) model one variable (e.g., an activity) is considered at a time. This is a binary choice of the activity being selected or otherwise. The model parameter β may be estimated using the maximum likelihood procedure.

Ali (2001) carried out a field study on household travel characteristics in 4 representative rural areas of Pakistan: Hala, Khudzar, Sindh, and Balochistan provinces. The types of activities analysed were work, education, market, health and leisure. Households were divided into 4 'life cycle stages' for analysis. The individual household members were considered in four types as: the household head (HEAD), the partner (PARTNER), a child over 15 years (CHILD>15), and a child under 15 years of age (CHILD<15). Based on the data collected during this study, a set of binary logit models was formulated for each relevant combination of activity and individual type. These models together with their statistical significance are presented in Table 1. The index measure of accessibility benefits BM is the explanatory variable in each model.

In the model for activity Work, for Household Head, the probability of choosing Work is directly proportional to accessibility benefit of Work and Market. The model for work for Partner, for example, showed a joint effect of the utility of participation in Health and Leisure activities to be the cause for reported work trips. The negative value of constant in the model implies a decrease in the overall likelihood of participation in the activity Work for the Partner, whereas in the case of Child for school activity the positive constant implies an increase in the likelihood of travel for School.

Estimation of model parameters

The form of the binary logit model used in parameter estimation stage is:

$$P_j^i = \frac{\exp(A)}{1+\exp(A)} \tag{3}$$

such that $A = \left(\beta_o\right)^j + \sum_{m \in C} \left(\beta_m\right)^j BM_m^i$ (4)

where j is the activity for which model parameters are being estimated, m the activities comprising the choice set of individual $i, \{\beta\}^j$ is the vector of model parameters for j^{th} activity, BM_m^i is the utility index (i.e., an index measure of accessibility benefits) for individual i for each activity m in their choice set C.

The estimation of probabilities for each activity requires a set of model parameters (β) specific for the activity j and applicable for the whole sample. The input data for model development include the calculated BM_j^i values and the observed trip data for each activity j and individual type i. The following model was derived for Market activity using a statistical analysis package:

$$(\Pr_i)_{Market}^k = \frac{\exp(-1.102 + 2.343 \cdot BMMARKET)}{1+\exp(-1.102 + 2.343 \cdot BMMARKET)} \tag{5}$$

where $(\Pr_i)_{Market}^k$ is the probability that individual i will choose activity j at location k, BMMARKET is the accessibility benefit for individual i for participating in Market activity at location k.

Table 1 Binary logit models (all individual types)

ACTIVITY CHOICE	INDIVIDUAL TYPE	PARAMETER ESTIMATES[1]						MODEL STATISTICS[2]		
		Indicator[1a]	Constant	BMWS	BMMAR	BMHLT	BMLEI	*LR*	*df*	*p-value*
WORK/ SCHOOL	HEAD			0.225	0.135			40	4	0.000
	PARTNER	-3.319				0.178	0.088	192	6	0.000
	CHILD>15	1.285				0.178	0.088			
	CHILD<15					0.178	0.088			
MARKET	HEAD				0.150	0.091		49	4	0.000
	PARTNER	-9.189		-0.069		-0.198	-0.164	162	7	0.000
	CHILD>15	1.435		-0.069		-0.198	-0.164			
	CHILD<15			-0.069		-0.198	-0.164	56	4	0.000
HEALTH	HEAD	3.486	-3.431		-1.388			105	7	0.000
	PARTNER	0.875	-3.431		-1.388					
	CHILD>15	1.674	-3.431		-1.388					
	CHILD<15		-3.431		-1.388					
LEISURE	HEAD	0.513	-1.878	-0.180				125	7	0.000
	PARTNER	-0.327	-1.878	-0.180						
	CHILD>15	0.961	-1.878	-0.180						
	CHILD<15					-0.672		31	4	0.000

Notes:

1 Parameter estimates are reported for the parameter coefficients found to be at or above 90% significance level.

1a Indicator variable adjusts the base model (shaded) to account for the effect of the individual type.

2 Model statistics refer to the overall model providing the parameter estimates, the degree of freedom (df) refers to this overall model. The p-value is the significance level of the Chi- Square test statistic, given as a probability value; a zero indicates very low value

4. APPLICATION OF THE MODEL

The main tasks involved in modelling travel demand can be summarised by the following tasks:

1. Preparation of the model inputs
2. Estimation of the model parameters
3. Prediction of the aggregate travel demand

Figure 2 illustrates the overall logical framework that describes how the model works.

The database and models developed in this research have been used in the worked example for the Market activity presented in Table 2. It may be seen in the table that the column $(\Pr_i)^k_{Market}$ contains a range of values between 0 and 1. These probability values are converted to individual travel demand $(T_i)^k_{Market}$ using the 0.5 as the threshold value.

All probability values above 0.5 give the modelled travel demand as 1, probability values ≤ 0.5 would render no travel demand ($(T_i)^k_{Market}$ =0). The aggregate travel demand is the summation of all 1's in this column. For details of this worked example refer to (Ali, 2001).

Table 2 Example calculations for model application

MODEL FORM	$(\Pr_i)^k_{Market} = \frac{\exp(-1.102 + 2.343 \cdot BMMARKET)}{1+\exp(-1.102 + 2.343 \cdot BMMARKET)}$			
ID NUMBER	BM MARKET	$(\Pr_i)^k_{Market}$	$(T_i)^k_{Market}$	OBSERVED MARKET
262	0.00194	0.250219	0	1
268	0.00002	0.249373	0	1
279	4.37301	0.999893	1	1
288	0.00062	0.249639	0	0
295	6.31739	0.999999	1	1
302	0.00000	0.249365	0	0
307	3.62301	0.999381	1	1
312	0.00003	0.249378	0	0
319	0.03545	0.265232	0	0
325	0.00000	0.249365	0	1
AGGREGATE DEMAND:			3	6
GOODNESS OF FIT:			(3-6)/6=-50%	

The main test of the goodness of fit for the model is to compare the predicted frequencies with the observed frequencies. In the worked example, the observed frequency was 6 and the modelled frequency is equal to 3 trips per day (Table 2). The model therefore was capable of predicting travel demand for Market with an accuracy of 50% against the observed travel demand.

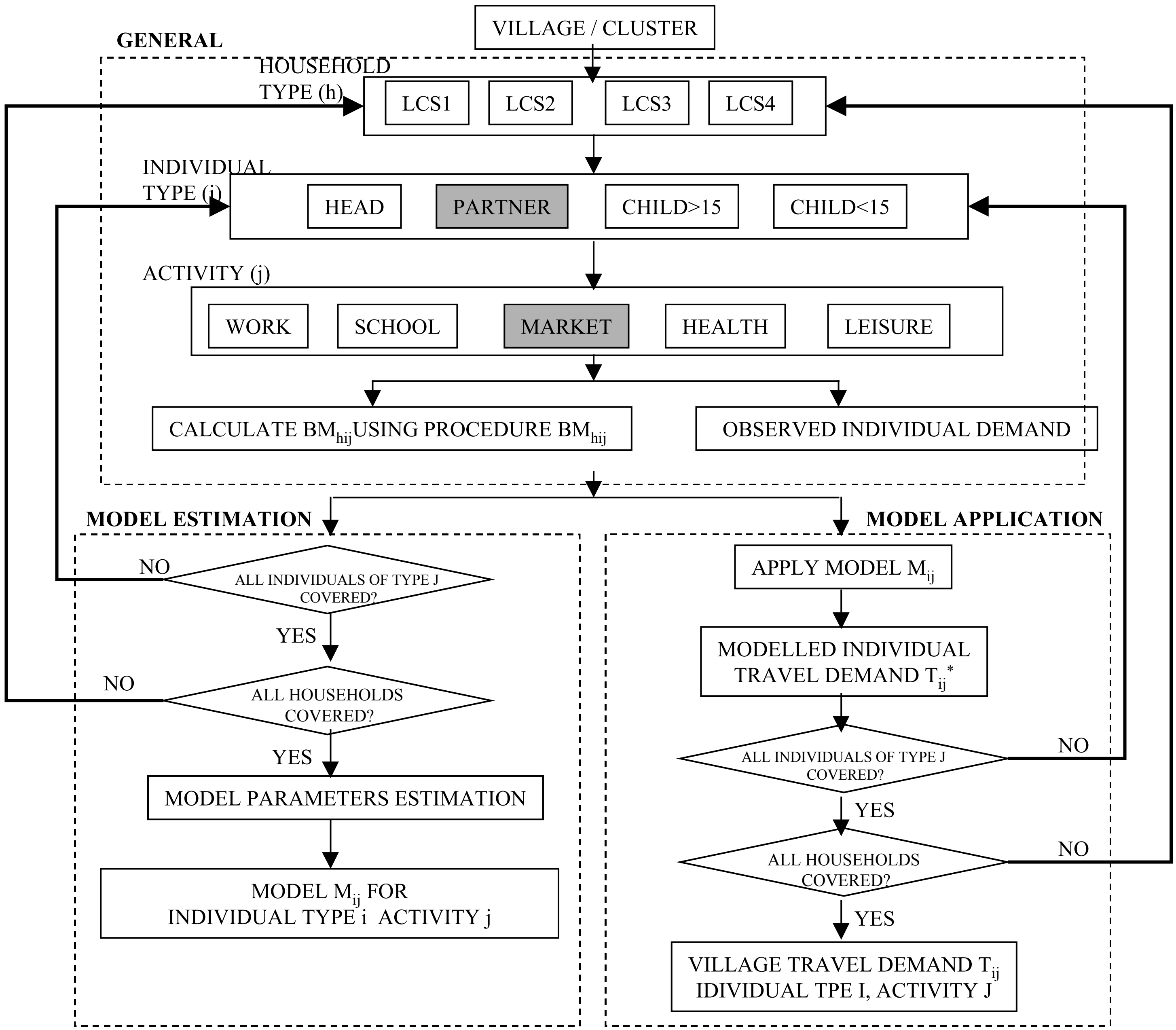

Figure 2 Overall modelling logic

5. CONCLUSIONS

The development of a rural travel demand model suitable for application in developing countries has been discussed. The underlying theme considers travel to participate in different activities as a requirement for fulfilling household needs. The components of the model developed include the modelling framework, the utility function for perceived benefits that can be derived by individuals, and the probabilistic behavioural models for activity and location choices. Individual discrete choice behaviour has been modelled using three modelling approaches; namely, multinomial logit model, binary logit model, and grouped regression model.

The analysis of rural activity-travel behaviour using household data collected from Hala, and Khuzdar provinces in Pakistan showed that the individual travel decisions were attributed to the household socio-economics. The household head carries out most household activities. Older children share this responsibility with the household head. Housewives and female children above 15 years of age do not take part in out-of-home activities. Data collected from household surveys were used to develop and validate the accessibility benefits model for various activities and individual types. The observed choice for an activity was defined as travel for the out-of-home activity, while the actual activity duration provided the data for utility function of the activity. A worked example demonstrated the procedures involved at the model development and application stages.

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