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**Modeling Travel Behavior:**

**The Developing Country Context**

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**Abstract**

The broad goal of this paper is to present a critical appraisal of needs, challenges, and opportunities for advancing urban transportation planning in India in the current-day context of rapid and large-scale changes such as motorization, economic expansion, employment participation, and ICT adoption. Towards this end, the relevant trends and their implications for future mobility needs and travel patterns of people are first discussed and the substantive questions of interest for travel modeling are identified. Issues of measurement of travel demand are presented and the improvements required in analytical techniques are discussed. In the overall, a number of interesting methodological, substantive, and practical issues are articulated in this paper to encourage further investigations on urban transportation in developing countries. It is hoped that addressing these issues and challenges will ultimately enable the prioritization of immediate and long-term needs and the identification of suitable solution strategies.

1. **Introduction**

Rapid and large-scale changes are underway in many developing countries such as India and China. These changes include rapid economic expansion (5-10% growth per annum), growth in motorization levels (10-20% per annum), increased travel needs, significant decline in public transport and non-motorized shares, and changes in land-use and transport relationships (Morichi, 2005; Singh, 2005; ACMA, 2002). Traffic congestion has assumed crisis proportions in many metropolitan cities due to the massive increase in the number of personal vehicles, inadequate road space and lack of public transport (Pucher, *et al*, 2005). The adverse impacts in terms of congestion, energy consumption, air-quality, safety, and efficiency of transport-land-use systems in urban areas is also substantial (Lakshmanan, 2004; Pendakur, 2002; Mitra, *et al*, 2003; Gakenheimer and Zegras, 2004; Agrawal, 2006) and likely to worsen if current trends continue.

Given the continued rapid growth in demand, inadequate capacity of existing infrastructure, as well as the need to address environmental, sustainability, and safety issues, both strategic (long term/ higher cost) and operational (short-term/ lower cost) planning decisions assume significant importance in the context of developing countries. In particular, emphasis should be placed on both a) congestion mitigation and demand management in the near-term, and b) the development of an efficient, integrated, and high capacity multimodal transportation system (roadway, public transport, para-transit, etc.) in the long-term. This is necessary for meeting demand growth in a sustainable manner. Yet, planning attention has largely focused on system capacity expansion and construction (Rakesh Mohan, 1996; PTCS, 2004; Singh, 2005). Relatively less attention is being paid to maintenance, efficient operations and Travel Demand Management (TDM) strategies (World Bank, 2002; Mitric, 2005; NUTP, 2005). Finally, compared to the developed countries, in the developing countries, the paucity of public and governmental resources available for urban transportation system improvements is acute.

The need to develop sustainable solutions to meet the challenges of massive increases in mobility within limited resources pose several important challenges to transportation planning methods in terms of measurement and modeling issues. Currently, planners often rely on over-simplified procedures and “gut feel” (Srinivasan, *et al*, 2007a) in making critical decisions. Clearly such approaches are inadequate, especially when making large scale and long-term investment decisions. Further, transportation systems in developing countries differ in several key respects from their developed counterparts, and hence the solutions and tools developed for the latter conditions may not be directly transferable. Thus, there is a need to understand the context-specific features of developing countries and incorporate these into local travel models and decision-support tools.

In the light of the above discussions, the broad objectives of this paper are to identify the major drivers of passenger transportation demand in India, delineate context-specific and unique problem features, and identify the issues and needs in the context of modeling travel-behavior to support travel forecasting and transportation planning. Thus, this paper aims to contribute to the literature by providing a synthesis of needs, challenges, and opportunities for urban transportation planning in the Indian context.

The rest of this paper is organized as follows. The major factors driving travel behavior changes in India are discussed in Section 2. The resulting changes in activity-travel patterns as a consequence of the driving factors are presented in Section 3. The needs and challenges related to travel-behavior modeling are discussed in Section 4. Section 5 presents an overall summary and identifies the major conclusions.

1. **Factors Driving Travel Behavior Changes**

This section of the paper discusses some of the key factors driving significant travel-behavior changes in India. Wherever appropriate, comparisons are made to corresponding trends in the United States to highlight the differences between the developed- and developing- country contexts.

One of the characterizing features of developing countries is their rapid economic growth. India is one of the ten fastest growing economies in the world (OECD, 2006). In terms of the Gross Domestic Product (GDP), India saw a 220% increase from 1990 to 2007 or, on an average about 13% growth per year. During the same period, the US saw a 139% increase, or equivalently, about 8.1% per year (See Table 1). In terms of the Gross National Income (GNI) per capita (based on the purchasing power parity and converted to equivalent “international dollars”) India grew 218% in comparison to US’ 100% over the seventeen year period from 1990 – 2007.

Aggregate trends presented by Bosworth and Collins (2008) underscore the shift in the economy from the historically agricultural to the modern technological/service sectors. Specifically, in 1978, the services industry represented 16% of employment and 32% of value added whereas in 2004, the corresponding numbers are 25% an 50% respectively. The agricultural sector, on the other hand, declined from 71% of all employment in 1978 to 57% in 2004; the corresponding decline in value added was 44% to 22%. This shift in the employment sectors also contributes to the urbanization. Big cities continue to attract investments, technology and jobs (e.g., Chennai for automotive industry, Bangalore and Hyderabad for software sector). In particular, the last decade has witnessed a ‘boom’ in Information Technology, service sector (e.g., Business process outsourcing, call centers, etc.), and auto-manufacturing industry in India (Ma Foi, 2006).

Along with the rapid expansion of their economies, developing countries also face large population growth-rates and urbanization trends. The total population of India grew from about 849.52 million in 1990 to 1124.79 million in 2007 (See Table 2) representing a 32.4% growth. In contrast, the United States grew 20.7% in population during the same period (from 249.62 million in 1990 to 310.29 in 2007). Further, by the year 2001, the urban population of India had exceeded the entire population of the United States. At the same time, the urban population in India represents less than a third of the total population of the country which is in sharp contrast to the United States in which it represents about 80% of the overall population. Urban agglomerations in India are also growing in size and number. For instance, the number of cities with a population of more than a million has nearly doubled to 36 over the last 15 years (Narayan, 2005) and, based on the 2001 Census, there are 6 cities with more than 6 million population (Delhi, Mumbai, Chennai, Calcutta, Hyderabad, Bangalore). Projections estimate that the urban Indian population which is already larger than entire US population would grow to about 473 million in 2021, and 820 million by 2051 (Narayan, 2005).

Along with the overall growth in the economy and population, rapid growth in employment rates and number of workers is occurring in India compared to the stable and maturing labor market in developed countries. The adult population (including workers) is relatively young (age of 21-65 is around 58%, South Asia Co-operative Environment Programme, 2006). The labor force in many cities is predominantly composed of males (about 80%), but female participation in labor force is increasing quickly (doubled over the last five years in Chennai, Srinivasan, *et al*, 2007a). Further, the proportion of women in the labor force is also significantly lesser in India compared to the United States. Among adults, the literacy rate is high (more than 70%), whereas the unemployed fraction is currently substantial (50% in Chennai and around 60% in other cities, Census 2001), which is far larger than those in developed countries.

Consistent with the urbanization trends, there have also been changes in the household structure and composition. There are clear shifts away from the historical “joint family” structures to nuclear families. Table 3 highlights the reduction in average household size over the years in both urban and rural locations. Yet, it is useful to note that the average household size in India is significantly higher than that in developed countries such as the United States.

Rapid urbanization, employment growth and prosperity predictably have led to dramatic growth in the number of motor vehicles on roads (Padam and Singh, 2001; NCAER, 2002). Table 4 indicates the trend in the sale of motor vehicles in India by type. Although two-wheelers constitute a lion’s share of the vehicles, the proportion of passenger cars in relation to total number of vehicles is steadily increasing. Further, the growth in vehicle ownership rates is also quite dramatic in the urban areas. Between1983-1995, growth rates in vehicle ownership in Chennai, Delhi, Calcutta and Mumbai were 533%, 242%, 115%, and 82% respectively (TERI, 2002). In the last decade, the vehicle ownership rates in Chennai have nearly tripled (from 0.77 million to more than 2.1 million in 2006, PTCS, 2004). In addition, vehicle fleet is heterogeneous and varies substantially across cities. Two-wheelers make up 66-72% in Bangalore and New Delhi, whereas, they form only 37 and 35% of fleet in Calcutta and Mumbai, with cars and jeeps forming 37 and 35% in the latter cities (TERI, 2002). The avergae two-wheeler ownership in the sample is 1.11/household and car ownership is 0.23/household in Chennai city and increasing number of households are beginning to own both two-wheelers and cars (15% in Chennai, Srinivasan, *et al*, 2007a). The increase can be attributed to the following factors: high aspiration to own vehicles (as a symbol of economic and social status), inadequacy of public transit, excise reduction, low interest loans, low motor vehicle tax, and tax holidays for automotive industry and inadequacy of public transport system (Narayan, 2005).

Despite these rapid increases, India is only in the initial stages of motorization with vehicle ownership levels of 0.1-0.2/adult (Gakenheimer and Zegras, 2004) in contrast to 0.7/adult observed in developed countries (OECD, 2006). A comparison of number of registered cars/vehicles per 100 persons in India and the US (Table 5) clearly underscores the infancy of motorization in India. Consistent with the auto ownership levels, the proportion of people with drivers’ licenses is also significantly lesser in India. For example, unlike in the developed countries where a majority of workers possess driving knowledge, nearly 86% of male workers and only 27% of female workers in Chennai city possess driving knowledge (Srinivasan, *et al*, 2007a).

In addition to discussing the changes in motorization, it also useful to discuss the trends in the adoption and use of Information and Communication Technologies (ICTs) such as mobile phones and the internet. As shown in Table 6, the broad trends mirror the motorization trends: rapid increases in the recent years and yet in early stages of adoption / market penetration.

In contrast the vast increase in travel demand, there has only been a modest capacity increase in urban roads (186,000 to 232,000 km in terms of urban roads in 1991-1997, TERI, 2002). Existing roadway capacity is less than 15 % (km/ area) in many cities compared to 20-60% in developed countries (with exception of 21% in Delhi, Lakshmanan, 2004; Singh, 2005). At the same time, existence of a fairly large public transport network characterizes many Indian cities. Public transportation modes (both bus and train) carry a significant fraction of urban travel demand (Pucher, *et al*, 2005; Agrawal, 2004; Sarna, *et al*, 1990). For instance, the public transportation ridership on average weekday is substantial in the four largest cities in India ranges from 4 to 10 million riders (comparable to those in largest public transport networks in the world such as London, Tokyo, and New York).

1. **Observed and Anticipated Changes in Activity-Travel Patterns**

The substantial changes in the economy, rapid growth in population, changes in the structure of the household and the work force, motorization, and adoption of ICTs can have very significant effects on the activity travel patterns of developing countries.

Clearly, increases in the working population will contribute to substantial growth in travel demand and traffic congestion. For instance, in Chennai city, the number of workers has increased by 25% per household over the last five years, resulting in an addition of nearly 0.5 million work trips annually (Srinivasan, *et al*, 2007a). With greater potential for labor participation and the booming economic conditions, work trips are likely to increase further in the next decade. At the same time, given that a majority of these jobs are in the software / information technology sector often characterized by flexible work schedules or night-shifts (to coordinate with international colleagues), the added work trips may not be in the traditional “peak” periods. Further, public transportation may not be an attractive option for such trips.

With the increase in number of workers and consequently an increase in income levels, one may also expect increased frequencies of discretionary activity and travel of both workers and non workers in households. On the other hand, the increase in workers and working hours in some sectors (information technology, call centers, etc.) may lead to time constraints on activity-travel participation, increased time-pressure (e.g., more eat-out activities), and a greater value of in-vehicle and out-of-vehicle travel time which may inhibit travel to some extent. Similarly, with increasing number female workers and female drivers in the households, modifications in activity and travel patterns such as the need for additional child-care trips may occur (see Nehra, *et al*, 2004). The shift towards nuclear family structures (influenced in part by the increase of two-worker households – Srinivasan, *et al*, 2007a) also contributes towards such travel modifications.

Despite the increases in income, users are found to be relatively quite sensitive to transport cost and transportation costs form a significant component of the income (8-16%). There is also significant variability in sensitivity to costs (Srinivasan, *et al*, 2007b) across different user segments such as two-wheeler versus four-wheeler users, bus and train users.

The non-workers in households play a significant role in household maintenance in developing countries. A significant fraction of activity participation and household travel related to maintenance, shopping, child-care and pick-up or drop-off, etc. may be performed by non-working adults. As the employment rates are still not close to saturation (percentage of unemployed adults is around 50% in the city of Chennai, Census 2001), it is important to understand the travel patterns of these persons as well.

In most households, there are fewer vehicles than workers implying certain activity- and vehicle- allocation patterns. However, the rapid motorization trend, including the ownership of a combination of two wheelers and hour wheelers, has the potential to change activity allocation, vehicle allocation, and mode choice of individuals.

There has also been a dramatic growth in Information and Communication Technologies (ICT) use in developing countries providing for increased social and business connectivity and relaxing time and space constraints for activity participation (e.g., 24x7 banking on internet). Thus, these technologies may offer alternatives for virtual access to some activities and a greater degree of control to individuals over their schedules. Empirical evidence suggests that ICT devices are also being used for unplanned activity-travel modification (uncoordinated ride-share and trip-chaining, Srinivasan and Raghavender, 2006).

With increasing motorization, there is evidence of changes in mode choice decisions in many urban cities in India (Tiwari, 2003; PTCS, 2004; Srinivasan, *et al*, 2007a). In particular, there has been a significant decline of public transport trips (Deb, 2002; Tiwari, 2003; Srinivasan and Bhargavi, 2006). The factors contributing to this decline are overcrowding, poor accessibility, safety, and poor reliability (Singh, 2005). The competition among the different public transport modes, the lack of coordination between buses and train, and inadequate network coverage of public transport in response to rapid urban growth and have also resulted in an imbalanced and inefficient use of public transport systems.

Transit users in developing countries have been less sensitive to extreme overcrowding, comfort, and convenience than in other countries, perhaps due to captivity. For instance, super-dense crush loads (14-16 passengers/m2 of floor space) are encountered in Mumbai city (Pucher, *et al*, 2004), and peak loads of 50% above capacity not being uncommon. However, with increase in affordability of vehicles, the sensitivity to subjective factors may increase and improved Level-of-Service (LOS) may be demanded in the near future.

There is also evidence of growing suburbanization at the city fringes. At the same time, there is also an increase in both activity frequencies as well as the number of activity centers (commercial/retail/official) in urban and suburban areas (auto manufacturing, software export zones, information technology corridor. Mixed land-use and easily accessible activity centers have contributed to a significant mode share of walk and bicycle trips (10-30% in some cities, RITES, 1998; Pendakur, 2002). The trends of increased motorization and suburbanization therefore have clear implications for the use of non-motorized modes of transportation. In fact, declines in walking and bicycling rates have already been reported in developing countries (Srinivasan, *et al*, 2007a).

Traffic congestion and growing motorization are also leading to higher fuel consumption and impose a strain on non-renewable energy resources (12.5% of national energy use, Earth Trends, 2003). Vehicular pollution loads are also substantial (Central Pollution Control Board, 1996). Top 12 cities produce total emissions annually of pm (35.31 tonnes), SO2 (29.84), NOX (423), HC(810), CO (2300). In Delhi, vehicular pollution was estimated to be the leading cause of air pollution problems in the city.

Safety is clearly another major issue of concern. Table 7 compares the crash-rates of India and the US. A systematic increase in crashes, fatalities, and injuries are observed for India (consistent with the increase in motorization and travel demand) in contrast to a fairly “flat” profile of these measures for the United States.

1. **Travel-Behavior Modeling: Needs and Challenges**

Travel-demand models are mathematical representations of travel behavior and are fundamental to the quantitative assessments and prioritization of alternate transportation-planning strategies. These models should (1) facilitate the evaluation of a variety of policies and planning strategies as discussed in Section 1 (2) be sensitive to the trends driving the travel-behavior changes as described in Section 2, and (3) be able to capture the behavioral responses and context-sensitive phenomenon as described in Section 3.

There are three major components in any travel-demand model: (1) measures of travel behavior, (2) representation of exogenous factors, and (3) analytical methods that relate the exogenous factors to the travel behavior descriptors. The needs for each of these three components and the challenges associated with meeting these needs are discussed in the content of developing countries.

**4.1 Measures of Travel Behavior**

There are four broad levels of representation of disaggregate travel demand (measures of travel behavior). These are (in an increasing order of completeness and consistency of description and closeness to real choices made by people) trips, tours, out-of-home activity pattern, and daily time use (in-home and out-of-home activity pattern). Each representation typically quantifies the volume of travel demand along the dimensions of activity purpose, mode-of-travel, time-of-day, and route of travel.

The state of the practice (in both developed and developing countries) approach is to use trips as the unit of demand. This approach generally ignores the spatial, temporal, and modal linkages among the various trips made by a traveler during a day, and the inter-dependencies among the travel choices of the different household members. The need to consider such linkages/interdependencies is of importance in the context of developing countries for at least two reasons. First, there are substantial inter-dependencies in the modes chosen for the different segments of travel by the same person especially if public transit is involved. This is further compounded by the availability of a large number of para-transit modes leading to correlations among the access, line haul and egress modes. The number of possible mode combinations range from 10-22 (Hyodo, *et al*, 2005). Second, one may expect greater intra-household inter-dependencies (such as activity allocations, joint travel, and escort trips) given the larger average household sizes, the need to share automobiles, and cultural factors. Therefore, the use of tours and/or activity-patterns to describe travel demand might be more appropriate as the intra-personal- and inter-personal- dependencies can be explicitly accommodated. Such approaches (i.e., “tour-based” and “activity-based” models) are being increasingly adopted by large Metropolitan Planning Organizations (MPOs) in developed nations. Detailed representations of in-home activity participation behavior within the context of measuring individuals’ time use would be of critical value in assessing the impacts of ICTs; however, these have not been well incorporated within the scope of practical travel demand modeling.

All the discussions thus far have focused on the short-term or daily travel attributes. These choices are conditional upon certain longer term mobility choices. The most important ones in the context of developing country contexts are: (1) vehicle ownership (measured in terms of both two- and four- wheeler ownership and bicycles), (2) employment choices (measured in terms of attributes such as work location, schedule and flexibility), and (3) ownership of ICT devices (measures in terms of cell phones and internet access at home).

A critical challenge in this context relates to obtaining data. Cost considerations, low response to self-filled questionnaires, and possible biases with other methods (such as the effect of literacy), face-to-face interviews are used for travel data collection in developing countries (Rastogi and Rao, 2002). However, the potential for obtaining richer time-use activity data is limited in face-to-face interviews. Consequently suitable data collection methods need to be developed to elicit travel-behavior data in developing countries.

**4.2 Representation of Exogenous Factors**

The exogenous factors used in travel modeling falls under one of two broad categories: (1) traveler characteristics and the (2) travel environment (i.e., transportation system) characteristics.

Given the substantial heterogeneity in the population of developing countries, it is important to characterize the travelers in terms of a variety of demographic and economic factors. These factors should describe taste variations, captivity to specific modes, differences in sensitivity to system characteristics (for example, differences in value of travel time), knowledge, and attitudes/preferences. This is necessary for accurately predicting the travel demand patterns (accounting for preference heterogeneity), to capture differences in the responses to policy actions (accounting for response heterogeneity), and to facilitate comparative assessments of impacts on various population segments (equity or “environmental justice” analysis). Further, it is important to recognize that with growing affluence, choices such as vehicle ownership are not driven only by the need to satisfy latent mobility needs; rather, vehicle ownership is seen as a symbol of economic well being and social status. The expansion in production capacity of the automotive industry (ACMA, 2002) and the increasing availability of convenient and easy financing options is also contributing to significant growth in vehicle ownership. Thus, any model for auto-ownership should be sensitive to the supply of vehicles (reflecting costs and wait times to acquire the vehicle) and the financing options available to the household.

Factors such as inter-zonal travel times, speeds, and costs are most commonly used measures to describe the roadway system in the travel-demand models of developed countries. In the case of transit, fares, access times, egress times, and headways (schedule) are used as system descriptors. Generally, the representation of non-motorized transportation system (walking and bicycling) is very limited. In the context of developing countries, these are largely inadequate. In the case of the roadway system, factors such as the roadway-surface characteristics (potholes, unevenness, etc.) and the mix of traffic on any facility are important. Further, the availability and type of parking is also a relevant factor. This is primarily because the two-wheelers and four-wheelers (the two largest classes of vehicles) using the same facility might perceive the system to be very different given the differences in the maneuverability between the two classes of vehicles and space needed for parking. In the case of transit, factors such as crowding and (un)reliability are important. Further, the fact that a wide variety of para-transit modes are available as access- and egress- modes requires good representation of the inter-modal connectivity as a descriptor of any transit route (Sarna, *et al*, 1990; TERI, 2002). Finally, given the continued large shares of people walking and bicycling, attention must be paid to the descriptors of the system from the stand point of non-motorized modes.

While the complex, heterogeneous conditions warrant significantly larger volumes and types of data to model behavior and forecast demands, there are also unique challenges to acquiring such information. The issues with collecting traveler characteristics via surveys have already been mentioned. With the substantial variability in education and skill levels, mixed-mode surveys might be needed to collect data from diverse socio-demographic segments. The transportation agencies may not have good quality data on system descriptors. However, the improvements in technology such as Global Positioning System (GPS) devices and Geographic Information Systems (GIS)-based mapping capabilities coupled with the high technical expertise locally available will clearly facilitate the assembly of such data. Overall, it would be of substantial value for developing countries to invest in the collection of critical data to enable the development of models and decision-support systems.

**4.3 Analytical Methods**

Currently available analytical methods for modeling travel choices are broadly divided into three major categories (in general, in increasing order of mathematical sophistication): 1. statistical aggregation methods, 2. econometric methods, and 3. behavioral / decision theoretic models.

Aggregated statistical approaches include descriptive statistics such as averages, mode shares, and frequency distributions to represent trends in dependent variables of interest. Statistical methods are commonly used in determining the volume of travel demand (e.g., cross classification tables for number of trips) and the apportioning of trips to various destinations (e.g.,, growth factor and gravity models for trip distribution). Aggregate approaches have been criticized in terms of offering limited behavioral insight and decision-support capabilities. In contrast, econometric models tend to combine disaggregate measurement with statistical theories and include multivariate approaches such as regression models. As a result, these methods facilitate hypothesis testing and allow the quantitative assessment of the marginal effects (or relative strengths) of the influencing factors. Econometric methods enable more decision support (via elasticity, marginal effects); however, behavioral insight in practice may be limited by the error structure assumptions. Behaviorally-based models seek to integrate the rigor of economic theory with a richer representation of choice, decision-maker preferences and decision rules (e.g., utility maximization) in order to yield more causal and policy sensitive models. The most common class of travel-demand models in this category is the class of logit-based models (Ben-Akiva and Lerman, 1985).

Travel-demand modeling systems in developed countries most commonly involve components from each of the three classes of analytic methods (for example, behavioral models for mode choice versus statistical/aggregate methods for trip generation). It is quite possible that such approach be adopted for developing countries as well.

However, practically, all travel-demand models in developed countries are “static” or cross-sectional, i.e., built using data collected at any one point in time. This seriously limits the transferability the modeling approaches from developed countries to developing countries. In periods of rapid economic and mobility transitions, as observed in developing countries such as India, assumptions made in cross sectional models such as stationarity in coefficients over time and absence of dynamic effects can lead to erroneous forecasts and policy evaluations (Goodwin, 1977; Clarke, *et al*, 1982; Kitamura, 1990; Meurs, 1993). This is also partially evident from the substantial inaccuracies in several demand forecasts in developing countries (Nashikkar, *et al*, 2000; PTCS, 2004; Harris, 2005).

Therefore, travel models for developing countries should explicitly accommodate dynamics in behavior; i.e., model changes in choices due to changes in explanatory factors, often using panel data. Such approaches imply that behavioral and travel pattern changes may not be instantaneous (as assumed in cross-sectional models) but occur over time. Some of the aspects of behavioral dynamics of relevance to modeling travel behavior in developing countries include period effects, state dependence, and habit persistence.

‘Period’ refers to instants or time-points when behavior is recorded or observed. The variation in choice behavior (e.g., mode choice) of the same individuals across different time periods is known as the “Period Effect”. Period effects may arise in mode choice from various sources including: a) changes in exogenous variables at the disaggregate level (effect of increase in income, increase in vehicle ownership, number of workers, number of drivers, etc., on change in mode choice), b) exogenous shocks and perturbations at the system level (e.g., increase in fuel price, more fuel efficient vehicles, low-price car, increase in automotive manufacturing capacity, new flyovers/overpasses, new modes – Delhi Metro, etc.) c) sensitivity dynamics: the change in sensitivity or responsiveness over time to exogenous attributes (such as cost and time) that affect choice behavior is referred to as ‘sensitivity dynamics’, and d) cohort-dynamics: the change in the behavior of individuals belonging to a given cohort group over time. A recent study points out that inclusion of period effects can explain mode choice dynamics in Chennai city substantially better than a cross-sectional model (Ramadurai and Srinivasan, 2006).

State dependence refers to temporal effects that arise when the consequence of a previous decision substantially or causally alters the decision-makers’ preferences and/or choice set structure relevant to current (and future) decision(s). Possible reasons for such state-dependence include retention of choices over time due to inertia, satisfaction with choice, and search/opportunity costs involved in switching decisions. Recent studies in the city of Chennai show evidence of state-dependence at three levels: inertia, interaction with LOS variables, and differences across socio-demographic segments (Ramadurai and Srinivasan, 2006) and may lead to declining public transport and non-motorized shares.

Habit persistence on the other hand refers to the influence of delayed or lagged impacts of previously experienced exogenous variables on current choice decisions. For instance, a user may continue to choose a given mode because of habit or unobserved factors (e.g., sensitivity to comfort or convenience) which may persist over time. For instance, a user may have perceived scheduled modes to be inaccessible in the past, and may continue to avoid that mode based on perception and past experience even after changes to improve accessibility. Similarly, adverse consequences and experience with regard to safety, and reliability experienced in the past may also result in a lagged and intrinsic aversion to certain modes.

There have been several recent advances within the class of behavioral / decision-theoretic models (Bhat, 2003) enabling more realistic and explicit treatments of uncertainty, dynamics, and heterogeneity in choice. Future developments to deal with behavioral aspects such as knowledge, learning, perception, attitudes, and non compensatory decision rules will facilitate increased applicability of these methods to travel modeling.

Other methods such as neural networks, fuzzy logic, and agent-based simulation methods may also be considered for analysis of elemental decisions (Goulias and Kitamura, 1992). The primary advantage of such methods is their flexibility in representing interactions and specification of fuzzy and ill-formed decision behavior. While they have been proposed in sociology to capture interactions between multiple decision makers with multiple objectives, their applicability and usefulness in the context of urban travel demand is unclear (due to limited applications in transportation and intensive data needs).

Of course, models that capture behavioral dynamics do need more data (panel data) than cross sectional methods. Given the rapid changes taking place in developing countries such as India, it would be worthwhile to invest in a panel survey of travel patterns.

1. **Summary and Conclusions**

Rapid and large-scale changes relating to motorization, economic expansion, employment participation, and resulting changes in activity-travel patterns and land-use are currently occurring in many urban areas in India. Given that motorization and labor markets are not near saturation, these changes are likely to continue over the next decade, leading to more changes and transitions in economic activity, mobility requirements and decisions and system impacts. Meeting the mobility needs in such periods of rapid change and uncertainty presents many challenges and opportunities for improved urban transportation planning and modeling methods.

Urban transportation planners face the challenges of explicitly recognizing, understanding and modeling substantial spatial and temporal changes in transportation system, land-use, activity and travel patterns in the planning process (e.g dynamics in vehicle ownership, activity-travel patterns, network, socio-economics, information and communication technologies, ITS, etc.). To understand and capture the rapid changes in travel patterns and conditions that are currently underway, richer data and improved modeling frameworks are essential. In particular, data are needed at sufficient temporal and spatial resolution and at a disaggregate level and should be collected at frequent intervals (in contrast to once every 10-20 years).

Insights and tools to support planning are essential that accommodate: a) realistic behavior and constraints on individuals, b) spatial and dynamic characteristics, c) multimodal network representation, and d) complex and non-linear interactions at various levels (user behavior, network level, and transportation-landuse interactions). To meet these challenges, there is a need to develop, implement and validate a set of methodologies and models for activity-based urban transportation systems planning that:

1. Capture dynamics (short-term to long-term), spatial, behavioral and interpersonal characteristics in activity-travel behavior corresponding to urban areas with rapid changes in economy, technology and motorization levels.
2. Develop a set of computationally efficient modeling tools and techniques for large-dimensional spatial, dynamic and activity based models for planning
3. Incorporates the role of advanced information and communication technologies and Intelligent Transportation Systems in the context of urban transportation planning
4. Account for multimodal traveler behavior and develop associated network algorithms
5. Identification and development of pro-active demand management strategies and coordination with supply side measures with multiple planning objectives of demand growth, congestion management, and meeting mobility needs.
6. Develop a GIS-based decision-support platform integrated with dynamic modeling tools for evaluating short-term and long-term planning and transportation demand management strategies

From a planning perspective comprehensive and contingency planning methods based on least cost principles may prove to be valuable in developing countries particularly during transition periods. While it is tempting to try quick-fixes such as local capacity additions which may provide symptomatic relief in the short run, the importance of concerted efforts in the long-run on data collection, improved analysis techniques and better decision support tools cannot be emphasized enough. In particular, substantial investments in research and development are needed in the next decade towards better data and understanding, and the development of improved analysis methods and planning practice in developing countries.

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**Appendix**

*Table 1. Economic growth rates of India and United States of America*

|  |  |  |
| --- | --- | --- |
| **Year** | **GDP (Billion US $)** | **GNI per Capita (International $)** |
| **India** | **US** | **India** | **US** |
| **1990** | 317.46 | 5750 | 859.99 | 22930 |
| **1991** | 267.52 | 5940 | 879.98 | 23330 |
| **1992** | 245.61 | 6280 | 929.92 | 24210 |
| **1993** | 275.95 | 6600 | 979.97 | 24990 |
| **1994** | 323.39 | 7010 | 1040 | 26220 |
| **1995** | 356.22 | 7340 | 1130 | 27320 |
| **1996** | 388.27 | 7760 | 1220 | 28590 |
| **1997** | 410.87 | 8250 | 1270 | 30110 |
| **1998** | 416.24 | 8690 | 1340 | 31640 |
| **1999** | 450.42 | 9210 | 1430 | 33270 |
| **2000** | 460.16 | 9760 | 1490 | 35180 |
| **2001** | 477.82 | 10070 | 1590 | 35800 |
| **2002** | 507.16 | 10410 | 1650 | 36360 |
| **2003** | 599.39 | 10900 | 1800 | 37570 |
| **2004** | 700.86 | 11630 | 1980 | 39850 |
| **2005** | 810.1 | 12370 | 2210 | 42030 |
| **2006** | 914.87 | 13130 | 2460 | 44200 |
| **2007** | 1017 | 13750 | 2740 | 45840 |
| Source: World Bank Data Visualizer, http://devdata.worldbank.org/DataVisualizer/<<Sources should be given in the references section. Please provide the appropriate in text citation here and reference information in the reference section for ALL of the table sources.>> |

*Table 2. Population growth rates of India and United States of America*

|  |  |  |
| --- | --- | --- |
| **Year** | **India** | **US** |
| **Total (million)** | **Urban (million)** | **Urban** **(% of total)** | **Total (million)** | **Urban (million)** | **Urban** **(% of total)** |
| **1990** | 849.52 | 216.54 | 25.49 | 249.62 | 187.94 | 75.29 |
| **1991** | 866.53 | 222.61 | 25.69 | 252.98 | 191.48 | 75.69 |
| **1992** | 882.82 | 228.56 | 25.89 | 256.51 | 195.18 | 76.09 |
| **1993** | 899.33 | 235.53 | 26.19 | 259.92 | 198.81 | 76.49 |
| **1994** | 915.7 | 241.65 | 26.39 | 263.13 | 202.32 | 76.89 |
| **1995** | 932.18 | 247.87 | 26.59 | 266.28 | 205.81 | 77.29 |
| **1996** | 948.76 | 254.17 | 26.79 | 269.39 | 209.29 | 77.69 |
| **1997** | 965.43 | 260.57 | 26.99 | 272.66 | 212.65 | 77.99 |
| **1998** | 982.18 | 268.04 | 27.29 | 275.85 | 216.24 | 78.39 |
| **1999** | 999.02 | 274.63 | 27.49 | 279.04 | 219.58 | 78.69 |
| **2000** | 1015.92 | 281.31 | 27.69 | 282.17 | 223.17 | 79.09 |
| **2001** | 1032.47 | 287.97 | 27.89 | 285.04 | 226.29 | 79.39 |
| **2002** | 1048.64 | 294.56 | 28.09 | 287.73 | 229.58 | 79.79 |
| **2003** | 1064.4 | 301.12 | 28.29 | 290.21 | 232.43 | 80.09 |
| **2004** | 1079.72 | 307.61 | 28.49 | 292.89 | 235.75 | 80.49 |
| **2005** | 1094.58 | 314.04 | 28.69 | 295.56 | 238.78 | 80.79 |
| **2006** | 1109.81 | 321.73 | 28.99 | 298.36 | 241.94 | 81.09 |
| **2007** | 1124.79 | 329.56 | 29.3 | 301.29 | 245.25 | 81.4 |
| Source: World Bank Data Visualizer, http://devdata.worldbank.org/DataVisualizer/ |

*Table 3. Changes in the structure of the Indian households*

|  |  |  |
| --- | --- | --- |
|  | **Urban** | **Rural** |
| **1992** | **1998** | **2005** | **1992** | **1998** | **2005** |
| **<<HH Head in Man>>** | 90.4 | 88.9 | 86.8 | 90.9 | 90 | 85.1 |
| **Mean HH Size** | 5.4 | 5.2 | 4.6 | 5.7 | 5.5 | 4.9 |
| **HH Structure (Nuclear)** | - | 59.3 | 63 | - | 55.6 | 59.3 |
| **Number of Members** |  |  |  |  |  |  |
| **1** | 3.3 | 3.2 | 5.6 | 2.6 | 3.1 | 5.0 |
| **2** | 7.1 | 7.6 | 10.6 | 7.3 | 7.8 | 11.0 |
| **3** | 11.3 | 13.1 | 16.1 | 10.3 | 11.5 | 13.1 |
| **4+** | 78.3 | 76.1 | 67.6 | 79.8 | 77.6 | 70.9 |
| Source: National Family Health Survey (NFHS 1, 2 and 3) |

*Table 4. Number of vehicles registered by type in India*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year (As on 31 March)** | **Jeeps** | **Cars** | **Commercial Vehicles** | **Two Wheelers** | **Three Wheelers** | **Tractors** | **Total** |
| **1990-91** | 35898 | 177439 | 141782 | 1808272 | 89448 | 139419 | 2392258 |
| **1991-92** | 34871 | 166233 | 138776 | 1608747 | 76551 | 146799 | 2171977 |
| **1992-93** | 38348 | 164845 | 120633 | 1503352 | 64321 | - | 1891499 |
| **1993-94** | 49478 | 210672 | 150779 | 1763558 | 90704 | - | 2265191 |
| **1994-95** | 51078 | 264803 | 198580 | 2209270 | 133288 | - | 2857013 |
| **1995-96** | 65780 | 345340 | 257092 | 2658288 | 174057 | - | 3500557 |
| **1996-97** | 77770 | 411305 | 296955 | 2963497 | 215578 | - | 3965105 |
| **1997-98** | 133302 | 417720 | 157898 | 3042855 | 233733 | - | 3985508 |
| **1998-99** | 111710 | 409966 | 139565 | 3403427 | 210220 | - | 4274888 |
| **1999-00** | 123422 | 638815 | 171319 | 3776778 | 205238 | - | 4915572 |
| **2000-01** | 126954 | 590718 | 150355 | 3745516 | 198162 | - | 4811705 |
| **2001-02** | 169920 | 558361 | 158541 | 4307908 | 215738 | - | 5410468 |
| **2002-03** | 167449 | 611754 | 202937 | 4991808 | 274895 | - | 6248843 |
| **2003-04** | 209914 | 821473 | 277546 | 5629301 | 352222 | - | 7290456 |
| **2004-05** | 247108 | 980595 | 348387 | 6575584 | 374688 | - | 8526362 |
| **2005-06** | 266450 | 1052198 | 391641 | 7565560 | 436801 | - | 9712650 |
| **2006-07** | 309126 | 1269305 | 517302 | 8491978 | 547806 | - | 11135517 |
| **2007-08** | 351762 | 1414641 | 545816 | 8068436 | 505938 | - | 10886593 |
| Source: Motor Transport Statistics of India, 1995; Road Transport Year Books 4004-05 and 2006-07 |

*Table 5. Growth in per-capita vehicle ownership: India and the United States*

|  |  |  |
| --- | --- | --- |
| **Year** | **India** | **US** |
| **Cars/100 persons** | **Vehicles/100 persons** | **Cars/100 persons** | **Vehicles/100 persons** |
| **1991** | 0.3409 | 2.4777 | 50.72 | 76.02 |
| **1992** | 0.3630 | 2.6627 | 49.35 | 75.80 |
| **1993** | 0.3737 | 2.8360 | 49.99 | 76.19 |
| **1994** | 0.3898 | 3.0206 | 48.60 | 76.69 |
| **1995** | 0.4120 | 3.2499 | 48.21 | 77.15 |
| **1996** | 0.4431 | 3.5611 | 48.16 | 78.12 |
| **1997** | 0.4839 | 3.8669 | 47.59 | 77.60 |
| **1998** | 0.5231 | 4.2119 | 47.79 | 78.12 |
| **1999** | 0.5561 | 4.4919 | 47.46 | 79.01 |
| **2000** | 0.6047 | 4.8091 | 47.35 | 80.03 |
| **2001** | 0.6836 | 5.3262 | 48.29 | 82.56 |
| **2002** | 0.7260 | 5.6191 | 47.24 | 81.54 |
| **2003** | 0.8079 | 6.2953 | 46.75 | 81.58 |
| **2004** | 0.8753 | 6.7349 | 46.58 | 82.97 |
| **2005** | 0.9428 | 7.4459 | 46.21 | 83.71 |
| **2006** | 1.0386 | 8.0751 | 45.38 | 84.07 |
| Source: Car ownership data for India from Table 4; Car ownership data for US from http://www.bts.gov/publications/national\_transportation\_statistics/; Population data from Table 2 |

*Table 6. Growth in ICT adoption: India and the United States*

|  |  |  |
| --- | --- | --- |
| **Year** | **Internet Users/100 persons** | **Mobile Phone Subscriptions/100 persons** |
| **India** | **US** | **India** | **US** |
| **1996** | 0.04 | 16.7 | 0.03 | 16.34 |
| **1997** | 0.07 | 22 | 0.09 | 20.28 |
| **1998** | 0.24 | 30.65 | 0.12 | 25.08 |
| **1999** | 0.28 | 36.55 | 0.18 | 30.83 |
| **2000** | 0.54 | 43.94 | 0.35 | 38.78 |
| **2001** | 0.67 | 50.08 | 0.63 | 45.06 |
| **2002** | 1.58 | 60.03 | 1.23 | 49.24 |
| **2003** | 1.73 | 63.07 | 3.16 | 55.3 |
| **2004** | 3.24 | 66.21 | 4.83 | 63.02 |
| **2005** | 3.83 | 69.53 | 8.23 | 71.98 |
| **2006** | 6.84 | 70.53 | 14.95 | 80.92 |
| **2007** | 7.20 | 73.51 | 20.77 | 84.67 |
| Source: World Bank Data Visualizer, http://devdata.worldbank.org/DataVisualizer/ |

*Table 7. Crash statistics: India and the United States*

|  |  |  |
| --- | --- | --- |
| **Year** | **India** | **US** |
| **Crashes (1000s)** | **Fatalities (1000s)** | **Injuries (1000s)** | **Crashes (1000s)** | **Fatalities (1000s)** | **Injuries (1000s)** |
| **1990** | 283 | 54 | 244 | 6471 | 45 | 3231 |
| **1991** | 295 | 56 | 255 | 6117 | 42 | 3097 |
| **1992** | 276 | 60 | 267 | 6000 | 39 | 3070 |
| **1993** | 285 | 60 | 288 | 6106 | 40 | 3149 |
| **1994** | 326 | 64 | 312 | 6496 | 41 | 3266 |
| **1995** | 352 | 71 | 323 | 6699 | 42 | 3465 |
| **1996** | 371 | 75 | 370 | 6770 | 42 | 3483 |
| **1997** | 374 | 77 | 378 | 6624 | 42 | 3348 |
| **1998** | 385 | 80 | 391 | 6335 | 42 | 3192 |
| **1999** | 386 | 82 | 375 | 6279 | 42 | 3236 |
| **2000** | 391 | 79 | 399 | 6394 | 42 | 3189 |
| **2001** | 406 | 81 | 405 | 6323 | 42 | 3033 |
| **2002** | 407 | 85 | 409 | 6316 | 43 | 2926 |
| **2003** | 407 | 86 | 435 | 6328 | 43 | 2889 |
| **2004** | 430 | 93 | 465 | 6181 | 43 | 2788 |
| **2005** | 439 | 95 | 465 | 6159 | 44 | 2699 |
| **2006** | 461 | 106 | 496 | 5973 | 43 | 2575 |
| **2007** | 479 | 114 | 513 | 6024 | 41 | 2491 |
| Source: Road Transport Year Book, 2006-07 (India); Motor Transport Statistics of India, 1995 (India); http://www.bts.gov/publications/national\_transportation\_statistics/ (US) |