Developing a Geo-Spatial Urban Form - Travel Behaviour Model for the City of Ahmedabad, India

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ABSTRACT:

(English) Urban land use and transport planning and management are constant mutative interrelated processes. Even though, there is a growing body of research concerned with the relationship between urban and travel behaviour, studies. Since these studies originate from a diversity of sources and encompass a variety of geographic scales and locations and their contextual application need to be reviewed. This paper reviews urban form and travel behaviour relation in context of Ahmedabad city. A geo-spatial urban form and travel behaviour model is constructed using urban form data derived from conventional data sources like census and remote sensing and travel behaviour data from household survey for Ahmedabad city. The developed model would be able to position and relate urban form and travel behaviour indicator on strategic (planning, economic, social), spatial (block, ward, zone) and integration (individual or combined indicators) dimensions. The model developed would be able explain the inter-related urban and transport mutative process so as to monitor the effect of urban and transport interventions and policy implications.

(French) L’utilisation du sol en milieu urbain et la planification et gestion du transport sont des processus constamment en corrélation. Bien qu’il y ait des recherches croissantes concernant les rapports entre l’utilisation du sol en milieu urbain et les comportements de voyage, ces études proviennent d’une diversité des sources, et englobent une variété d’échelles et de localisations géographiques et par conséquent leur application contextuelle doit être révisée. Ce document passe en revue la relation entre la forme urbaine et le comportement de voyage dans le contexte de la ville d’Ahmedabad. Un modèle geo-spatial d’utilisation du sol en milieu urbain et du comportement de voyage est construit en utilisant des données urbaines dérivées des sources de données conventionnelles comme des données de recensement, de télédétection et des données de comportement de voyage obtenues des enquêtes de ménages pour la ville d’Ahmedabad. Le modèle développé sera capable de placer et rapporter l’indicateur de forme urbaine et celui de comportement de voyage sur des dimensions stratégiques (planification, économique, sociale), spatiales (bloc, quartier, zone) et d’intégration (indicateurs individuels ou combinés). Le modèle développé sera aussi capable d’expliquer le processus constamment en corrélation d’utilisation du sol en milieu urbain et de transport afin de surveiller l’effet des interventions urbaines et de transport ainsi que les implications de politiques.

INTRODUCTION
Cities are often considered engines of economic and demographic growth. They also represent human spatial and material relationship with nature and the pattern of urban development and growth is a matter of concern within the framework of sustainable development. Transport is considered fundamental to the manner in which urban development and growth takes place. As one of the largest consumers of fossil fuel, it also contributes substantially to air pollution in urban areas. Increasingly many cities, especially those in rapidly developing countries like India are observing changes in spatial spread, economic transformation and the related social processes. These changes put an enormous pressure on sustainable development; and the resulting growth pattern is often incessant. These incessant growth patterns result in wide intra-urban variation of physical and socio-demographic characteristics of urban form.

Review of literature on urban form and travel suggests that physical and socio-demographic elements of urban form affect travel behaviour. Common outcomes examined include distance travelled, travel mode choice, trip frequency and use of transit. However it has been observed that most of these studies have used cities in developed world as case examples where inter-urban variation are not as discrete as in the context of a developing city like Ahmedabad. Most of these studies are also conducted at high aggregate levels and are therefore unable to explain specific context of fast developing cities like Ahmedabad. Moreover, implication of these relations on different strategic scales of planning and policy making has not been studied. The paucity of research in contextual situation sets the need to study urban form indicators that can be related to travel behaviour.

The purpose of this paper is to examine through the study of literature the way in which urban form accommodates transport systems and vice versa at a conceptual level, and to contribute towards quantification of urban form in the context of a developing country. Development of Ahmedabad city is reviewed to see how urban area has evolved over the years and quantification of urban form is discussed and initial ideas are drawn towards the development of a geo-spatial urban form and transport model.

**REVIEW OF THE LITERATURE**

Accumulating evidence suggests that certain characteristics of the built environment are related to people’s travel behaviour. Behaviour such as trip-making frequency, distance and time travelled have been studied for a variety of land use patterns, street networks and streetscape design features. Table 1 gives a synthesis of past research on urban form and travel behaviour relationship. Broadly, it can be observed that studies related to urban form and travel patterns originate from diverse sources and encompass a variety of geographic scale and locations. To add to this diversity, many different characteristics of urban form too have been examined in these studies and travel patterns have been measured in a number of ways. This section brings together the urban form indicators used and results of recent studies concerning urban form and travel patterns.

Travel patterns are a result of individual choice to pursue activity at another location, choice of destination, choice of mode, choice of route and time (Munshi, 2003). Thus travel is a function of characteristics of the base location (origin of the travel) and the environment surrounding the base location. The surrounding environment to the base location has been studied in various terms, e.g. through distance to opportunities, like distance to city centre or sub – centres. Distance to the city centre has been studied in relation to travel distance and transport energy consumption by (Naess and Sandberg, 1996; Stead and Marshall, 2001; Mogridge, 1985). Another indicator of the surrounding environment to the base location is related to the mixing of land use as this is assumed to affect the physical separation of activities in the environment surrounding the base location and therefore is a determinant of travel
demand. It has been mainly measured as the job ratio and has been studied in relation to journey frequency in (Ewing, 1995) as well as in relation to proportion of trips made by non-motorized modes in (Cervero, 1989). The proportion of residential to non residential use has also been studied in relation to a transport mode index in (Zhang and Guindon, 2006). An aggregate measure of land use mix (termed as diversity) was examined by Cervero and Kockelman (1997), who report a link between land use mix and total non-work travel distance. The provision of local facilities and services may clearly reduce travel distance and increase the proportion of short journeys capable of being travelled by non-motorized modes. Winter and Farthing (1997) reported that the provision of local facilities in new redevelopment reduces average trip distances. Hanson (Hanson, 1982) reports similar findings, showing that the proximity to local facilities is positively associated with average distance taking into account average socio-economic characteristics of the trip maker. The type of neighbourhood at the base location is also known to affect travel as reported in Cervero and Kockelman (1997). They found that neighbourhoods with high proportion of four-way intersection and limited on-street parking abutting commercial establishment tended to have an average less drive-alone travel for non-work purposes. The base location is mainly studied at the zonal level and is commonly measured in terms of population density and to a lesser extent employment density as in (Cervero and Kockelman, 1997; Zhang and Guindon, 2006 ; Barnes, 2001). Despite the fairly consistent evidence supporting the relationship between built environment and travel patterns, some limitations remain to be addressed as most of the studies discussed above are applications in developed countries. The causal relations in the developing country context are likely to be different.

These causal relations can be better understood by a small but nevertheless growing body of literature on this subject from the developing world. Dissanayake and Morikawa (2008), analysed the household travel behaviour in developing countries by using a nested logit (NL) model of two levels. The upper level is characterized by modal choices. The lower level consists of household related travel choices. In their study they used distance to destination, trips made to CBD and within CBD, car ownership as parameters in the NL model. Estupiñán and Rodriguez (2008) found evidence of the importance of the built environment in BRT station boarding. Specifically, environmental support for walking and personal and environmental barriers to car use were related to higher BRT boarding. In their study they used six sets of variables which included neighbourhood characteristics. Within the neighbourhood characteristics they considered developing country contextual variables like unsatisfied basic need index, schooling, violent deaths, crashes, thefts and unemployment and found these to be related to higher transit use. Srinivasan and Rogers (2005) studied travel behaviour of low income residents in Chennai, India by studying two contrasting locations in the city located in two different parts of the city. One group lived close to the city centre and other at the periphery, so the urban form differentiation used here was distance to the city centre, keeping socio-demographic constant. They analyzed difference in accessibility to employment and services between the two locations and found that residents in the centrally located settlements were more likely to use non-motorized modes of travel (walk and bicycle) that the residents located in the periphery.

It is evident from the above discussion and table 1 that urban form has a significant effect on people’s travel behaviour, but contextual consideration for developing country is needed. Therefore in this study a urban form – travel behavioural model sensitive to urban realities in developing countries would be constructed, particularly using geo-spatial data and tools.

STUDY AREA AND DATA
Ahmedabad is the seventh largest city in India and has a large urban sprawl extending to the nearby rural areas. Different policies adopted by the state and local governments have resulted in a massive urban sprawl which radiates for more than 20 kilometres in all directions. The present area within city municipal limit of 190.84 sq Km. The city has a much bigger urban sprawl (GIDB and CEPT, 2006). Estimated population living in the urban sprawl is around 5 million (GIDB and CEPT, 2006). This growth has not been uniform across the town resulting large variation in densities. The population density in old city areas ranges from 1200 persons/hectare to 2293 persons/hectare. Densities in the western region are comparatively much less. These are within the range of 150 to 370 persons/hectare. Likewise wide variation in income groups can also be found, poor residents live near the industrial areas in the east, whereas the western part of the town is predominantly high and middle-income group. The greater Ahmedabad (agglomeration) area has grown at a moderate rate. Growth rates have declined from 3.2 to 2.2 percent compounded per annum during the past two decades. However, the rates vary across different spatial units. The population within the municipal limits appears to approach stabilization level. The areas outside AMC limits have shown rapid growth (Munshi, 2003).

As per existing land use, more than one third (36%) of the total area is under residential use, followed by 15 percent of the area under industrial use. Large tracts of land (23.44%) are lying vacant. Only 9.5 percent of the total area is under transportation network as against the norm of 15-18 per cent as specified by UDPFI guidelines (GIDB and CEPT, 2006). The process of urban development has not be uniform and proportion of non-residential land use varies spatially. Ilhamdaniah et al (2005) in a study on planning social infrastructure in Ahmedabad found out large locational variation and disparities in provision of social infrastructure.

The new policy guidelines in India like the National Urban Transport Policy (NUTP) accentuate the need for coherent land use and transport plans. The model described in this paper would build on the understanding and analysis of the interrelated components of the urban development process. This would facilitate the decision makers to prioritise and devise sets of policies which would guide sustainable urban and transport initiatives in the urban areas. The model would be used to review scenarios of land use and transport policy interventions and its’ effect on travel behaviour and relate the same at different aggregation levels within the urban fabric. Most of the studies lack spatial interoperability and are therefore not able to explain certain spatial variations in the relationships, like disparities and variations in urban form. It is clear from earlier discussion that cities like Ahmedabad have wide spatial diversities in socio-demographics and urban form characteristics and therefore the developed model should be able to explain the relations at different aggregation scale, different spatial scales and also explain the implication of the relations on aspects of urban planning and management.

Developing a geo-spatial relation between urban form and travel behaviour needs very detailed spatial land use, socio-economic and transport data. These data are spatial in nature and therefore have to be represented spatially. The transport data, mainly travel behaviour data, relates to modal use, trip lengths and frequency is mostly non-spatial. The challenge therefore, is to link the two. Such data for Ahmedabad is available through the household survey which was recently conducted for the BRTS study and can be used to quantify the travel behaviour variables. Urban form variables mainly relate to use of and intensity of use of land and distances. Data from Census of India at enumeration block level (census track) contains detail on population, and use of house. This data in combination with road network and Traffic Analysis Zone (TAZ) data from IPTS study can be used to quantify the urban form indicator.

Table 1: Synthesis of past research on urban from and travel behaviour relation
It can be observed from Table 1 that the unit of analysis varies depending upon the focus of the study. Many studies also use traffic analysis zones or census tracks as the smallest unit of analysis, as most data is available for these statistical units. This method of representation can visualize spatial variations in urban form for the current situation, but offers limited analytical or modelling capabilities, and as most statistical units are not equal, cross comparison and relationship development is a difficult task (Wegener, 2001).

There is a growing body of literature on the use of GIS in spatial models. The main advantages of data organisation in GIS are the ease of data capture or data entry, data manipulation and visualisation. Another important advantage is the possibility to co-process data stored in different data models (Wegener, 2001). Time Geographic Simulation System developed at the University of Paris used hybrid raster type and all geographical objects and could handle several hierarchies of scales and, with procedures of aggregation and disaggregation, and is able to associate data corresponding to different geographical scales in the same model (Wegener, 2001). Since the model developed here also attempts to
handle several hierarchies of scales and therefore, raster type grid model is considered as an appropriate representation.

Use of a regular grid representation in GIS also facilitates a number of remote sensing applications that have shown the potential to map land use and urban phenomenon (Barnsley et al., 1993, Jensen and Cowen, 1999) and to help estimate a variety of socio-economic variables (Henderson and Xia, 1997, Imhoff et al, 1997). In order to disaggregate the census tracts and filter out areas that are non-built and non-residential, remotely sensed data is found to be a convenient source. Where image data falls short, census data can be used to determine the residential land use (Meserv 1998). Zhang and Guindon (2006) for example use Landsat image to derive land and transport based indicator for cities in Canada.

The arrangement and use of spatial data for this study as mentioned earlier should be such that it can perform both analytical operations (neighbourhood, spatial overlay) and network algorithms (e.g. Distance to city centre). The land use related indicators developed for this study should also not arise from land use in the development plan, as ground realities are often different than what is present in the development plan land use map. Combining remote sensing source with census data source can provide all the data required for quantifying urban form indicators (i.e. built up + land use + population + employment). To facilitate the use of combined data set it is implicit that the representation of the data should be in a regular sized grid. The size of the grid cell should be such that observed variations in urban form characteristics are not lost. The smallest traffic analysis zone (Luis Berger Study & BRTS study) in the densely populated wall city area is 0.013 sq kms, and in the municipal corporation area is 0.28 sq kms. Implementation of the development plan in the city is controlled by town planning schemes (TPS) (Ilhamdaniah et al, 2005). These schemes are usually 100 hectares (1 sq. km.) in area, with each consisting of 70 to 80 plots. Therefore a grid cell size of 0.01 sq Kms (100 mts x 100 mts), i.e. a size slightly smaller than the smallest TAZ and also similar to the each plot in a town planning scheme; which is also similar to (Wagner and Wegener, 2007; Cervero and Kockelman, 1997) seems to be the most appropriate representation and would be used to quantify urban form indicators in the study. The different levels of spatial data used are shown in figure 1.

![Spatial data resolutions](image)

**Figure 1: Spatial data resolutions**

**DEVELOPING THE GEOSPATIAL URBAN FORM AND TRAVEL BEHAVIOR MODEL**
In order to design and analyze the relation between the set of urban form and travel behaviour indicators, a method for developing urban geo-spatial urban form and travel behaviour model is proposed. It consists of following stages

1. Define the objective of the model
2. Create the indicator set
3. Quantify the indicators
4. Position and analyze the indicator set
5. Modify the indicator set
6. Final indicator set and
7. Implementation of the relational model

Defining the objective of the model: The objective of developing the model is to explain the relationship between urban form and travel behaviour. It can be used to review scenarios of land use and transport policy interventions in terms of its effect on the travel behaviour. Also the constructed model should be able to explain the spatial dimensions of the effects, and how different variables of urban form related with travel behaviour should give indications to drive urban and transport development strategies. The other important element is the aggregation element, even though the quantification of the urban form is done at a spatial level of 100 mt x 100 mt grid cell, the developed modes should be able to explain the relationships at higher spatial scales, like at the census ward level or zonal level. This is important from the point of view of locational variations and disparities in large cities like Ahmedabad. The model should also be able to explain effects of the basic indicator or a combination of indicators. The three dimensions have been explained in figure 2. As can be seen from the figure, the movement on strategic axis from planning implementation impacts to social impacts would require different positioning of indicators, and likewise on the indicator aggregation and spatial aggregation axis. Positioning indicator sets at all intersection points of the three dimensional cube generated by the three axis would allow the model to study the implication of interventions at different strategic and spatial scales.

![Figure 2: Dimensional components of the relational model](image)
Creating the set of indicators: From the sets of urban form indicators and travel behaviour used in past research are discussed earlier, the comprehensive list is as shown below.

<table>
<thead>
<tr>
<th>Urban form Indicators</th>
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<tbody>
<tr>
<td>1. Distance to the City Centre</td>
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<tr>
<td>2. Density of development</td>
</tr>
<tr>
<td>• Net residential densities (Total population in the cell/area under residential use)</td>
</tr>
<tr>
<td>• Net employment densities (Total employment in the cell/area under commercial use)</td>
</tr>
<tr>
<td>3. Floor Space use (Build up volume/Ground Area)</td>
</tr>
<tr>
<td>4. Mixing of Land Use</td>
</tr>
<tr>
<td>• Transport Mode Index (as in (Zhang and Guindon, 2006))</td>
</tr>
<tr>
<td>• Dissimilarity Index (Dissimilarity Index = (No of dissimilar land use in the neighbouring cell) / 8)</td>
</tr>
<tr>
<td>5. Neighbourhood type</td>
</tr>
<tr>
<td>• Available of basic service index (weighted index on availability of water supply, sewerage and banking)</td>
</tr>
<tr>
<td>• Income group index (weighted index of availability of housing quality and modal availability, television, radio and telephone)</td>
</tr>
<tr>
<td>• Transport risk index (no of accident in the neighbourhood (radius of 0.8 kms)/population (resident + employed))</td>
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<tr>
<th>Travel Behaviour Indicators</th>
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<tbody>
<tr>
<td>1. average or total travel distance</td>
</tr>
<tr>
<td>2. frequency of journey</td>
</tr>
<tr>
<td>3. proportion of journey by car or other modes and</td>
</tr>
<tr>
<td>4. energy consumption in trip making</td>
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Quantifying urban form indicators: Measuring the distance to the city centre, first of all requires the identification of the city centre itself. The cities, however can be mono or poly nuclei depending upon the way they have been planned. City centre and sub-centres can be identified using methods adopted by (Giuliano and Small, 1999). In their studies they used clusters in adjacent tracts to build sub-centres based on employment density and total employment threshold. McMillen (2001) estimated broad spatial trends in employment density and then looked for deviations to identify sub centres. Redfearn (2006) proposes a nonparametric approach to identify sub-centres. The works of McMillen and Redfearn can be replicated for the case of Ahmedabad as lower limits of the employment thresholds are defined scientifically and they capture a far more complex system of sub-centres than the other regression-based methods. The network distance from the centre of each grid cell to the nearest grid cell from the city-centre/sub-centre would be used as an urban form variable to represent distance to the city centre.

Quantifying net residential and employment densities. This would firstly require the identification of the developed area under each grid cell, along with its use and the subsequent division of the total population or total employment in the area with the computed developed area. Indian remote sensing LISS 4 data would be used to identify the built up and non- non built up areas and for the built up area the net densities would be computed using the enumeration block data, which contains data on use of census house in combination of population and employment data for the particular block. Cartosat – 1 image would also be used to create a digital surface area model which can be used amongst others to find total floor space area.

Land use mix and integration indicator was developed by using concept of transport mode index used by (Zhang and Guindon, 2006). Variables on dissimilarity Index is developed on line of (Cervero and Kockelman, 1997) wherein the ratio of dissimilar land use in the immediate neighbourhood of each grid cell is normalized by the total number of neighbouring cells, which is eight.

Estupiñán and Rodriguez (2008) used variables like basic needs index to represent neighbourhood type,. It is represented on similar lines by this study as well. Three sets of variables have been quantified; the
first index related to availability of basic services, second is an index related to income group categories and last is transport risk index. For the former two data from enumeration blocks and for the later data on accidents from police department will be used.

**Travel Behaviour Variables:** The most common travel behaviour variables used in urban form travel relation literature are: average or total travel distance, frequency of journey, proportion of journey by car or other modes and energy consumption in trip making. As mentioned earlier there are recent transport studies in the city, the most recent being the BRTS study. The household survey for the study constituting of about 6000 household responses is available. For this particular study trip distance, modal use, trips by mode would be used as travel behaviour variables.

**Position and analyze the indicator set:** The main purpose of developing this model is to understand the impact of urban form on travel behaviour and its impacts on planning, economic, social and strategic dimensions. Thus in the third step each urban form indicator and travel behaviour indicator and their relationship would have to be understood in terms of their positioning with respect to other indicators, that is how they are related internally and externally (urban form – urban form relationship and urban form - travel behaviour relationship). This would lead to positioning the indicators on the graph shown in figure 2 and include detecting structure in the relationships between variables. That is to classify variables within the sets (urban form or travel behaviour), and to develop relations amongst sets. The relationships between the sets are likely to take form of co-relations for determining trip attributes like distances etc and Nested Logit (NL) for mode choice. Of course, the relationships should be studied for strategies related to answer planning dimension and like wise economic dimension and social dimension. It also needs to be studied if the same relations are valid for a higher spatial groupings. The process would also help to modifying indicators sets if required and to choose the final set of indicators for the model.

Implementation of the relational model: The developed model takes inputs from future scenarios which are urban form interventions to develop urban form characteristics for the given scenario and predicts the changes in travel behaviour on the basis of present relationship. An interface would be developed which would allow inputs in terms of urban form intervention, for example change in development regulations for a give area. The model would be able to compute the implications of the given change on the employment and resident population of the given area, and its implication on the urban form indicators which are quantified using neighbourhood function. Given the existing urban form travel relations the future changes of the given development can be predicted. To visualize the affects on the urban form intervention a tool would be developed which would allow the decision maker to visualize the affect at different aggregation scale and understand its effect on different strategic scales mentioned earlier.

The development relational model can become an operational tool for the government to understand the implication of the land use and urban form related intervention in the present and future scenario. This would help to anticipate harmful consequences on the urban system at different aggregation levels and possibly help to identify action points.

**CONCLUSION**

Predicts the changes in travel behaviour on the basis of present relationship.. So there arises a need to monitor or understand how one system reacts to changes made in the other system, Particularly in the context of fast developing cities in India. The relational model described in this paper is one step towards understanding the relationship, but it needs to be developed and tested first over the case city of
Ahmedabad. Developing the relational model is important, because this would enable the policy makers understand the implications of their interventions and allow them to adapt or make decisions with knowledge of its positive or negative effects on the travel behaviour. The developed model uses data sets from conventional sources like census and remote sensing sources and therefore can easily be replicated for another case city. Developing and implementing the model would pose a few methodological challenges, the biggest being how to position urban form and travel behaviour indcitors and develop relations at different spatial scales so as to develop and understanding on what implications these draw for the three strategic dimension that is urban planning, economic and social.

REFERENCES