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Built environment and mode choice relationship for commute travel in the city of Rajkot, India

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A R T I C L E   I N F O

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A B S T R A C T

Metropolitan areas around the world are looking for sustainable strategies to reduce use of private automobiles, energy consumption and emissions, often achieved by built environment interventions that encourage use of sustainable modes of transport. This study contributes by providing the empirical evidence on the relation between built environment and mode choice in context of Indian city of Rajkot. Using personal interview data and data available from Rajkot Municipal Corporation it is observed that there is a strong tendency among Rajkot residents to preselect their residential location to suit their modal preferences. This is especially true for non-motorized transport users. Among the built environment variables, access to destination and land use related indicators also have significant influence on mode choice. The study Infers that the land use policy should focus on accessibility and mixing of diverse uses, and transport supply will have to be location based to support non-motorized and public transport travel.

Introduction

Land use planning in India is often limited to prescriptive zoning that assigns per-mitted land uses to specific areas (zones) in the city while restricting other uses that may be considered unsuitable, transport planning is mainly providing road infrastructure for private automobiles. On site regulation is poor, therefore land use in Indian cities is of a mixed nature and very different from the rigid zoning proposed as part of the development plan (Brueckner and Sridhar, 2103). The mixed nature of land use makes shorter trips possible which should ideally encourage use of non-motorized modes of transport such as walking and cycling. However, the infrastructure required to sustain and encourage such non-motorized means of transport is not yet in place (Munshi, 2013). As suggested, these cities already suffer from poor urban development planning policies and its implementation. These policies have indirectly (till National Urban Transport Policy was introduced in 2006 (MOUD, 2006)) encouraged the use private automobiles (Pucher et al., 2005; Adhvaryu, 2011) resulting in high growth rate of private automobile ownership. These are not desired trends from low carbon development perspective thus, there is a need to first stop this trend and if possible revert it.

In other parts of the World, the relation between built environment and mode choice has been studied extensively for the past couple of decades. The evidence from these studies has led to a paradigm shift in the goals of urban transport planning policy. A shift from implementing transport projects to supply the ever increasing demand to the "new realism" where the interest and focus is on restricting the demand to travel by Private Automobile (PA) and to promote Non-Motorized (NMT) and Public Transport (PT) as alternate modes (Banister, 1999; Milakis and Barbopoulos, 2008). In India the policy viewpoint

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Fig. 1. Location of Rajkot in Gujarat state, India. *Source:* India Political (Mapsofindia).

is still dependent on the empirical evidence from other parts of the world as very few studies have looked at this relation (Munshi et al., 2008). The objective of this paper is to explore the influence of built environment on mode choice decisions for work purpose travel for a middle sized city in India with an aim to bridge this knowledge gap.

To achieve the above stated objective an empirical study was conducted with Rajkot city, a typical second tier Indian city (city with population ranging from 1 to 5 million), located in the state of Gujarat in western India (as shown in Fig. 1) as a case. The estimated population living in the city corporation limits in 2011 is around 1.2 million. Rajkot has a good small sector industry base and with rapid urban and population growth.

The remainder of this paper is organized as follows: The next section briefly reviews the previous related research. The subsequent section describes the data available for the study, the conceptual model structure, and the estimation methodology. We then present and interpret a multinomial logit model mode choice and the last section summarizes the study and suggests future research directions.

Built environment and its relation with mode choice

Built environment can be defined in several way, however the mostly widely used definition is drawn from the famously termed 6D's by Ewing and Cervero (2010). These are Density (population and jobs), Diversity (land use mix and balance), Design (neighbourhood and street design), access to Destination (distance from downtown, accessibility to jobs), Distance from public transport stops, and Demand Management (parking fees, congesting pricing, *etc.*). Mode choice is the mode chosen by the person to travel. It is considered in empirical literature as a function of trip-makers' characteristics (e.g., age, gender, household income, household size and composition), mode characteristics (travel cost, convenience, safety and security) and built environment characteristics.

A number of studies have analyzed the relation between built environment and travel behaviour. Among these studies are comprehensive literature reviews (Ewing and Cervero, 2001, 2010; Stead and Marshall, 2001; Cao et al., 2009). It is mostly found that built environment has a significant impact on mode choice. It is however also reported that not all of the past studies report significant and consistent influence of built environment on mode choice. The reported work is reviewed below.

Built environment indicators

Density: is represented in two ways: residents and jobs per unit area. In some cases, the density of residents is subdivided into population/households per unit area or dwelling units per unit area (Ewing et al., 1996; Schimek, 1996; Kockelman, 1997; Holtzclaw et al., 2002; Bhatia, 2004; Zegras, 2007; Kuzmyak, 2009; Munshi et al., 2014). The job density is reported to have been represented as total jobs (Boarnet et al., 2004), or retail jobs (Boarnet et al., 2004) or as density of commercial activities (Vance and Hedel, 2007).

Diversity: is represented as land use mix and balance index (explained below). In this initial studies this indicator was quantified as ratio between jobs and household (Frank and Pivo, 1994). More recent studies have used land use mix quantified as entropy index (Frank et al., 2009; Kuzmyak, 2009; Munshi, 2013) and land use balance quantified as dissimilarity index (Cervero and Kockelman, 1997; Munshi et al., 2014). Some studies have also represented diversity indicator as the balance between retail and houses or as proportions of jobs/retail opportunities.

Design: is represented as density of bicycle lanes (Bhat and Eluru, 2009), street to block density (Bhat et al., 2009), density of intersections (Boarnet et al., 2004; Chapman and Frank, 2004; Chatman, 2008; Munshi et al., 2014), street density (Vance and Hedel, 2007; Bhat et al., 2009; Munshi et al., 2014), sidewalk widths and proportion of front and side parking (Cervero and Kockelman, 1997).

Destination (access to): is represented as distance to Central Business District (CBD) (Pushkar et al., 2000; Boarnet et al., 2004; Zegras, 2007), as accessibility to jobs by auto (car) (Ewing et al., 1996, 2009; Shen, 2000; Cervero and Duncan, 2006; Frank et al., 2009; Munshi et al., 2014) and accessibility to jobs by transit (Bhatia, 2004; Kuzmyak et al., 2006; Frank et al., 2009; Kuzmyak, 2009).

Distance (to transit stop): is represented as network distance to transit stop (Bento et al., 2003; Frank and Engelke, 2005), as walk minutes to transit/stop (Vance and Hedel, 2007) or as density of transit stops and routes (Munshi et al., 2014).

Demand management: is represented by measures such which increase travel cost for private automobiles such as taxation on cars and rule, road pricing, parking control, and decreasing speed limits. In addition measure that make public transport attractive like, Park and ride schemes; measure that encourage NMT modes by improving infrastructure for walking and biking and land use planning.

Some studies have also looked at effect of transit oriented neighbourhoods (Bhat and Eluru, 2009) or new urbanist neighbourhoods (Khattak and Rodriguez, 2005; Shay and Khattak, 2005) on mode choice.

The relation

Positive elasticity values are desired for non-motorized and public transport mode choices. It is observed that the walking and transit mode choice are influenced positively most by the design indicators measured as intersection or street density, then by land-use mix, and marginally by density variables. The weighted elasticity values for walking and transit choice as reported in Ewing and Cervero (2010) are visually represented in Fig. 2. In general, design elements like intersection and street density, travel distance, land use mix are found to have a significant influence on walking and transit choice (Ewing and Cervero, 2010).

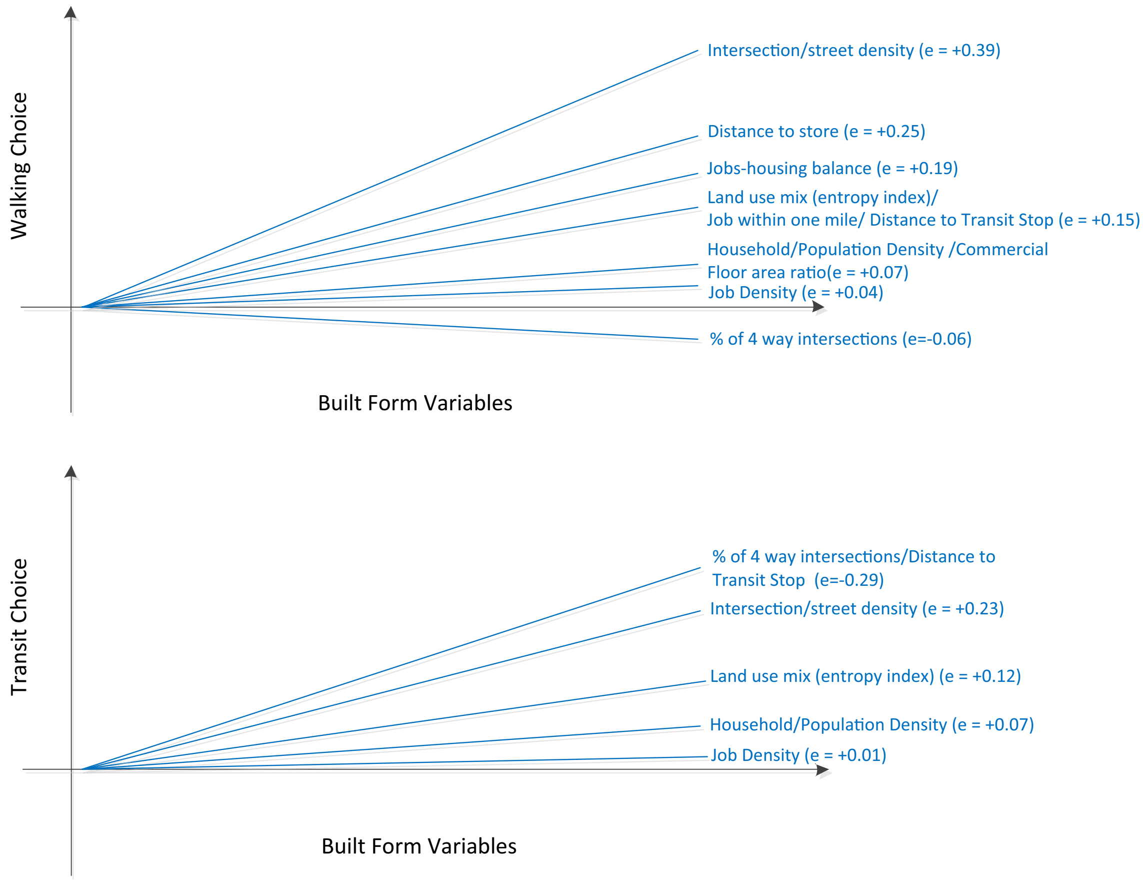

Fig. 2. Weighted Average Elasticity of vehicle distance travelled, walking and transit mode choice with respect to built environment variables (as observed in Ewing and Cervero (2010) and reported in Munshi (2013)).

From Fig. 2 summarized from Ewing and Cervero (2010) and other empirical work it is found that street networks, street scape and design features along with factors like location where individuals reside (distance from the city centre or from their work place) and density of population have a strong influence on choice of bicycle and walking modes (Cervero, 1996; Kockelman, 1997). Pedestrian and bicycle choice increases considerably when street connectivity is good, and when individuals reside near or inside the city centre or close to their work places. Presence of walking and bicycle infrastructure (e.g., presence of sidewalks, bicycle lanes), and its continuity increase the use of walking/bicycle modes (Kitamura et al., 1997; Tiwari and Jain, 2008). Whereas density of employment and population at trip origin and destination has a significant but comparatively lower effect on bicycle and walking mode choices (Cervero, 1996, 2002; Kockelman, 1997; Reilly and Landis, 2002; Bhatia, 2004; Milakis and Barbopoulos, 2008). Land use mix, resulting in close proximity to shopping, work and other non-residential land uses has positive influence on choice of bicycle and walking (Frank and Pivo, 1994) and transit use. It is, however, as stated earlier interesting to note that not all of the past studies have significant influence of built environment attributes, e.g. Crane and Crepeau (1998) found no relation between built environment attributes and mode choice decisions, Boarnet et al. (2008) found that the relation between population density and walk choice was negative, some other studies have also reported very low elasticity values between population and job densities and walk and bicycle choice.

The above stated influence of built environment on mode choice may differ across gender, household composition and socio-economic groups (Badoe and Miller, 2000; Schwanen and Mokhtarian, 2005). Also, households with an inclination towards a certain type of travel "self-select" a residential location enabling them to use the preferred mode of travel (Schawanen and Mokhtarian, 2005). A phenomenon commonly referred to as residential self-selection problem. The urban poor, mainly comprising of captive NMT/PT users are likely to choose a residential location at a location where they negotiate between their affordability to pay the rent or the capital cost and opportunities to choose their desired mode of travel. These could be typical problem in most Indian cities, therefore accounting for residential self-selection in mode choice analysis is important. In most studies this is done by studying the built environment and mode choice using socio-demographics variables as control variables. Schwanen and Mokhtarian (2005) studied the role of travel attitudes towards travel and land use in residential location choice.

Methodology

This study is about travel choices individuals made and how built environment influences these choices. As stated in Ben-Akiva and Lerman (1985) the formulation of the mode choice process is that an individual (who makes the travel choices) first determines the available alternatives, evaluates them and chooses an alternative that maximizes his/her utility. The individuals or the decision maker in this study are the residents in the city of Rajkot, the decision maker chooses a mode for travel from set of four alternatives, private automobile (car or a motorized two-wheeler), shared transport modes (shared auto rickshaw or auto-rickshaws) and non-motorized travel options that is walk and bicycle. As discussed earlier the mode choice can be studied as a function of factors determining the residential self-selection problem and built environment characteristics. Therefore, in this study mode choice is considered to be directly influenced by socio-demographics characteristics of the respondent and built environment (at the residence of the individual). A convenient and common functional form for analyzing the influence of potential explanatory variables on a category dependent is multinominal logit (MNL) model (Schwanen and Mokhtarian, 2005). The multi-nominal logit (MNL) model assumes that traveller have unobservable, latent preferences or utilities for different transport modes and they choose the mode providing the highest utility (Ben-Akiva and Lerman, 1985). That is, in the expression below, if the utility of mode alternative is greater than that of mode alternative j mode i will be preferred by the decision over all other alternatives from the set of alternatives C.

$$U(X_{(i)}, \mathrm{St}, \mathrm{Bo}) \geqslant U(X_{(j)}, S_t, B_o) \Rightarrow i \succ j \quad \forall j \in C$$

where

$U()$ is the mathematical function of utility,
X_i, X_j are vectors of attributes describing mode alternatives i and j, respectively,
S_t is a vector of characteristics describing individual t, that influence his/her performance among alternatives,
U_o are built environment characteristics at the point of origin of the trip,
$i \succ j$ means the alternative to the left is preferred to the alternative to the right, and
$\forall j$ means all the cases, j, in the choice set C.

S_t variable used in the above equation also account for the residential self-selection problem, and are therefore introduced fist in the MNL model. In the MNL model a procedure of backward stepwise method and the default selection criteria (with a probability of F at entry level of 0.5 and for exit 0.10) in the statistical software package PASW Statistics is used to introduce variables in the equation. The mode choice is studied for work purpose and choice of all other modes are studied against choice of private automobile as a mode.

Data

Data from different sources have been used to quantify the built environment and mode choice for commute trips. Methods used to collect and process the data for this study is described below.

Travel characteristics and data

Survey was conducted to collect data regarding mode choice and socio-demographic characteristics of individuals residing in Rajkot. Surveys were carried out on weekdays (during the evening so that most household members are available), each person in the house was interviewed, revisits were done to ensure travel details of all members in the household were collected. The respondents were asked to remember their daily travel pattern on the previous day (to the day when the interview was conducted) and were registered in the daily travel diary. The respondents were asked about travel purpose, distance, average travel time, frequency of travel (for the same purpose trip) and mode choice among other things. As stated earlier, modes used for commute purpose were divided into four categories Private Automobiles (car or a motorized two wheeler), Bicycle, Walk and Auto rickshaw (Shared and not shared Intermittent Public Transport (IPT)). As individuals made decisions, in this study the individual is considered as a sample. This survey was conducted during the period August to October, 2012. After correcting the data for irregularities and missing household and personal values, the data consisted of 2050 responses.

In Fig. 3, residential locations of the houses survey are shown. Care was taken to distribute the sample according to the population density, so the inner core area has more samples in comparison to the outer areas. The city of Rajkot is also divided into five areas these differ in terms of their spatial layout and type of development. The core of city Rajkot (City core) is typical pre-colonial period development, attached building, narrow street, high residential and commercial density. To the west of City core area (Rajkot west) is the most effluent area in the city of Rajkot, with good road network and civic amenities. The northern portion of the city is where the population is mixed and the quality of infrastructure and amenities is slightly lower in comparison to Rajkot west. Rajkot also has two distinct industrial areas, the residential development around these areas mainly comprises of slums and poor residences, development is organic therefore mixing of land use is good, but provision civic amenities like gardens, *etc.* is poor.

The personal interview questionnaire contained an exhaustive list, which was used to collect respondent's socio-demographic information. This data and socio-economic classification shown in Table 1 prepared by Market Research Society of India (MRSI, 2011) used to determine the consumption preferences, and purchasing power of the respondents. This was subsequently used to classify the respondents in three socio-economic groups. The upper most segment of the consuming class (A1, A2 and B1), the middle segment (B2 and C) and the lower most segment (D, E1, and E2).

The socio-demographic situation of the respondents was also used to create the following family typologies.

1. Nuclear family without children
2. Nuclear family[1] with children and one working member
3. Nuclear family with children and two working members
4. Joint family[2] with one worker
5. Joint family with more than one workers
6. Pensioners family

In Table 2 the descriptive statistics of the above listed family typologies and location where they reside are presented. City core is where most residents are from the middle consumer segment. In west Rajkot most residents are from the upper most consumer segment, whereas industrial flanks and peri-urban areas of Rajkot mainly comprises of lower most consumer segment. This indicates that socio-economic consumer groups live in clusters and possibly also self-select their residential locations. The lower most segment of the population choose to reside near industrial areas, where most unskilled and skilled labour jobs are located. Whereas middle consumer segment resides in the core areas of the town where most trade and commerce activities are present. The rich choose to reside in areas where best infrastructure and services are available in the town.

Built environment

As stated earlier, in empirical literature, six indicators are used to represent the built environment, these are, density, design, diversity, destination accessibility, distance to transit stop (transit access) and demand management. Travel demand measures like parking management, congestion pricing are not present in the Rajkot and are, therefore, not considered. Accordingly, five indicators, namely, density, diversity, design, distance to transit stop and destination access are considered in this study. The variable used to represent these indicators and the methods used to operationalize are listed in Table 3.

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[1] Nuclear family is family group consisting of a pair or adults and their children.
[2] Joint family is the extended family with two or more that two parents.

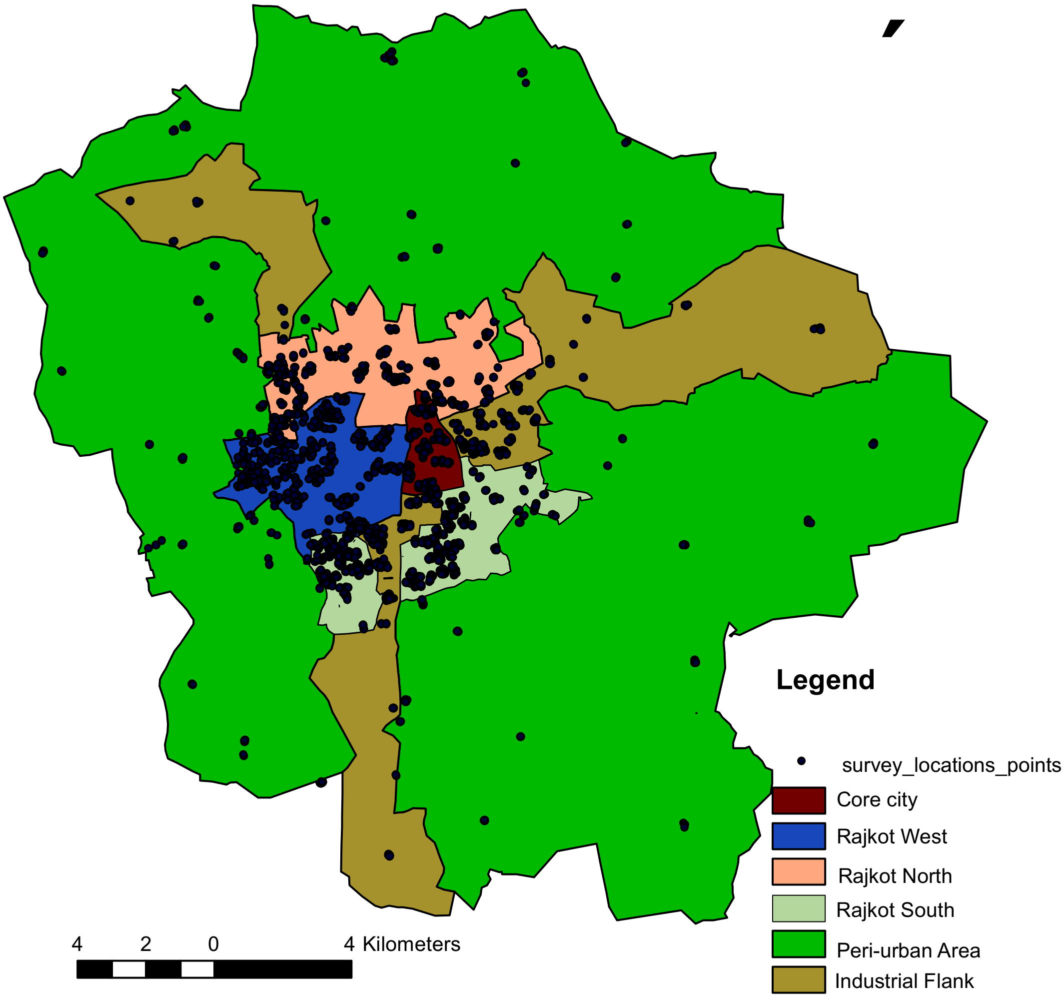

Fig. 3. Rajkot location clusters and household survey locations.

To quantify the Built environment indicators a 100 m equal size grid covering the entire area of Rajkot is used (see Fig. 4). Building footprint data (which includes data on quality of structure, use and assets owned by residents); data of road and road infrastructure was available from Rajkot Municipal Corporation and was used for the purpose.

The density of population around the surveyed respondents is computed as sum of population residing in building footprints that have their centre within the grid cell. The job density is computed by estimating the floor area under a particular activity (for example industry) in a grid cell. The proportion of area under that activity in this grid cell to total area under the same activity in Rajkot is used estimate the jobs in the particular sector. Sum of job in all activities within grid cell gives total jobs in the cell.

In Rajkot, the job and residential density are expected to be high and likewise, land uses are expected to be heterogeneous and mixed, with small units, involving horizontal and vertical mix. Therefore, for land use diversity (dissimilarity index) and balance (entropy index), as described in Table 1 and Fig. 5, floor area (floor area used per activity) is considered instead of land use. Design measure is represent as density of road intersections. Access to transit stops is taken as distance reported by the respondents, as the bus service was not operational the reported distance is the distance to nearest IPT stop, access to destination is represented as potential accessibility measure. This measure is computed in a manner that availability of jobs are weighted against number of residents in the area. The commute distance, which is the actual distance that respondents have reported as travel to work distance, is also considered as an indicator representing access to destination.

Descriptive analysis

Typical to most cities in India, in Rajkot, the shares of private automobile is high relative to other modes used for commute trips: 57.9% of the respondents commute to work either using a car or on a motorized two wheeler. The share

Table 1
Socio-economics and purchasing power of respondents.

	Illiterate	School up to 4 years	School 5–9 years	Secondary/ Higher Secondary School	Some college but not graduate	Graduate/ Postgraduate general	Graduate/ Post Graduate professional
Unskilled	E2	E2	E1	D	D	D	D
Skilled Workers	E2	E1	D	C	C	B2	B2
Petty traders	E2	D	D	C	C	B2	B2
Shop Owners	D	D	C	B2	B1	A2	A1
Businessmen with No employees	D	C	B2	B1	A2	A2	A1
Businessmen with 1-9 employees	C	B2	B2	B1	A2	A1	A1
Businessmen with 10+ employees	B1	B1	A2	A2	A1	A1	A1
Self Employed professional	D	D	D	B2	B1	A2	A1
Clerical/Salesman	D	D	D	C	B2	B1	B1
Supervisory Level	D	D	C	C	B2	B1	A2
Officers/Executives-Junior	C	C	C	B2	B1	A2	A2
Officers/Executives-Mid/Senior	B1	B1	B1	B1	A2	A1	A1

Lower most consumer segment
Middle consumer segment
Upper most consumer segment

Table 2
Location clusters and sociodemographic of the respondents.

	City area											
	City core		West Rajkot		North Rajkot		South Rajkot		Industrial flanks		Peri-urban	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Age	44	13	44	13	40	13	39	12	40	13	38	10
Income/HH member (INR)	6.7	10.1	17.6	39.3	7.1	21.7	6.1	12.9	5.1	8.99	4.1	8.8
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Gender												
Females	9	4.48	49	10.34	41	11.95	27	5.29	17	4.67	5	3.13
Males	194	95.52	425	89.66	299	88.05	487	94.71	347	95.33	155	96.88
Socio-economic consumer classification												
Lower most segment	45	22.17	86	18.14	183	53.98	208	40.47	203	55.77	80	50
Middle segment	135	66.5	220	46.41	119	35.1	278	54.09	140	38.46	61	38.13
Upper most segment	23	11.33	168	35.44	37	10.91	28	5.45	21	5.77	19	11.88
Family classification												
Nuclear family without children	16	7.88	46	9.7	31	9.14	33	6.42	52	14.29	12	7.5
Nuclear family with children one worker	75	36.95	137	28.9	121	35.69	220	42.8	129	35.44	68	42.5
Nuclear family with children two workers	27	13.3	65	13.71	37	10.91	72	14.01	50	13.74	26	16.25
Joint family with one worker	33	16.26	74	15.61	44	12.98	61	11.87	47	12.91	23	14.38
Joint family > one worker	47	23.15	125	26.37	95	28.02	110	21.4	73	20.05	30	18.75
Pensioner family	5	2.46	27	5.7	11	3.24	18	3.5	13	3.57	1	0.63
n	203		474		339		514		364		160	

of non-motorized modes that is walking and bicycle is also large, 32.1% of the sampled individuals either walk or use bicycle to reach their work place. The differences within the areas shown in Fig. 3 are also distinct. In Rajkot west, the share of private automobile use is 83.4%, whereas only 4% commute trips are on a bicycle and shares of walking and Auto rickshaw modes is also very low. In north Rajkot and in peri-urban areas of Rajkot, the use of private automobile is significantly lower than the city average. In north Rajkot the use of Auto rickshaw is high when compared with the city average. In peri-urban Rajkot the shares of bicycle and walking trips are relatively high. In the industrial areas identified as Industrial flanks and

Table 3
Independent variables. *Source:* Adapted form (Munshi, 2013).

Independent variable used			
a. Personal and household variables			
Age		This is age in years as reported by the respondent	
Sex		Sex of the respondent recoded as male/female	
Family classification		Type of family the respondent comes from	
Socio-economic consumer classification		Consumption and purchasing power of the respondent	
Variable		Definition	Operationalization
b. Built environment variables			
Density	Net Population Density, Net Job Density	The density of development is computed as net residential and net job densities. That is ratio of population to total developed area under residential use. The connotations of densities in this study are similar to what is used by Frank and Engelke (2005) and Newling (1969)	This is operationalized as Net Residential Density $= D_r = \frac{P_r}{A_r}$, where D_r = Net Residential Density (10,000 persons/square kilometre), P_r = Residential Population (No of persons/ 10,000), A_r = area under residential land-use in the grid cell d (square kilometre) Net Employment Density $= D_e = \frac{J}{A_{ea}}$, where D_e = Net Employment Density (10,000 jobs/square kilometre), J = total jobs available in the area (No of Jobs/ 10,000), Area = area under economic activities in the grid cell (square kilometre)
Diversity	Floor space dissimilarity index (land-use mix). Floor space entropy index (land-use balance)	Entropy index was developed by Cervero and Kockelman (1997) and is used to measure the balance of land-use (1 signifies that balance is perfect and 0 signifies that there is only one land-use in the neighbourhood area. Dissimilarity Index is an index that measures the degree to which land-uses come into contact with one another is also important (Cervero and Kockelman, 1997)	Entropy Index is computed as Entropy $= E_{\mathrm{i}} = \Sigma_{\mathrm{j}} \frac{F_{\mathrm{j}} \times \ln(F_{\mathrm{j}})}{\ln(J)}$, where J is the number of land-use classes (5 land-use classes have been considered in this study: residential, commercial, institutional, industrial and recreational), F_j is the proportion of the total developed floor space area under the jth land-use type. An area within a radius of 800 m. (8 grid cells) is considered as the neighbourhood. Dissimilarity Index $= F_i = \Sigma_j^k F_j \Sigma_i^8 \frac{f_{jk}}{A}$, where k = number of land-use classes in the grid cell, F_j = proportion of area under jth land-use category, $f = \Sigma^d$, where d = floor space under dissimilar land-use to the jth land-use in the 8 neighbouring grid cells to the grid cell under consideration and A = the total floor space area in all the 8 neighbouring grid cells to the grid cell under consideration
Design	Road junction kernel density	The kernel density function is used, which is based on Tracy et al. (2011)	The kernel density of junction around each grid cell is computed using a 750 m radius (equal to radius of a neighbourhood). In computing kernel density of roads, road width (right of way) is used as the population fields
	Road safety	Kernel density of fatal road accidents	The kernel density of fatal road accidents around each grid cell is computed using a 750 m radius (equal to radius of a neighbourhood)
Distance from transit stop	Distance to the nearest transit stop	Network distance to the nearest transit/IPT stop as reported by the respondent	As reported by the respondents in the questionnaire survey
Access to destination	Potential accessibility to jobs		The accessibility model is potential accessibility model and computes potential accessibility scores using a gravity based spatial interaction model as described in Geurs and Eck (2001). $a_i = \frac{1}{\sum_{j=1}^{n} DjF(d_{ij})}$, where a_i (used as balancing factor in gravity model) is a measure of accessibility at zone i to all opportunities (activity floor space) D at zone j, $F(d_{ij})$ is function of d_{ij} in this case exponential function is used, where d_{ij} is the distance between i and j. Accessibility values are index from 0 to 100
	Commute distance		This is measure as commute distance as reported by responded in the questionnaire survey

Fig. 4. 100 m grid approach.

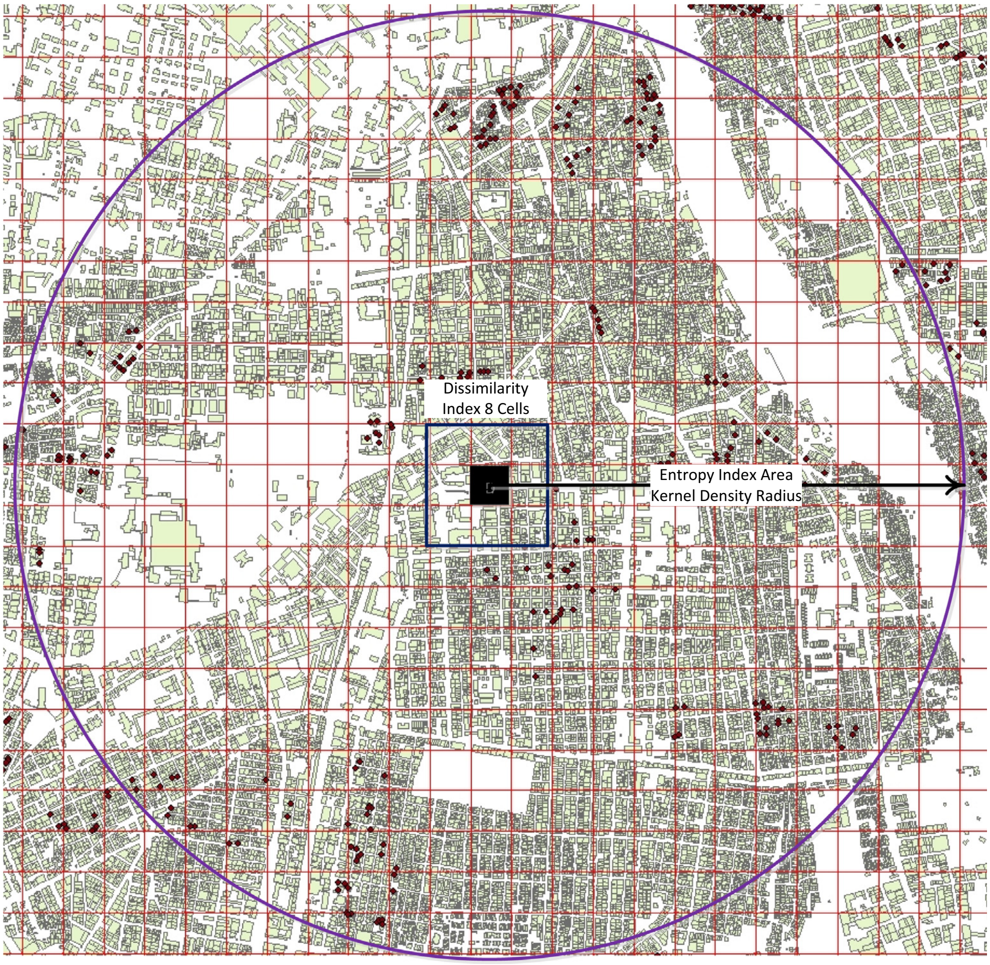

Fig. 5. Land use mix and design indicator considerations.

south Rajkot in Fig. 3 lower than average use of private automobiles at 55.1% and 44.4% respectively were observed. The peri urban areas, city core, industrial flanks and south Rajkot also have high use walking as a mode for work purpose.

The above descriptive analysis of commute travel in Rajkot gives out some interesting inferences. The conventional thought (at least in the Western cities) that there is higher use of private automobile in the peripheral areas is not true. Higher use of walking and bicycle modes in the peripheral areas of Rajkot indicates small travel distance to work place locations from these areas. This is also an indication that individual residing at these location are not dependent upon activities

Table 4
Consumer segment and mode choice.

Mode choice	City centre Consumer segment						Rajkot West Consumer segment						North Rajkot Consumer segment					
	Low		Middle		Upper		Low		Middle		Upper		Low		Middle		Upper	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Private automobile	10	22.22	96	71.11	17	73.91	39	45.35	190	86.36	157	93.45	64	34.97	67	56.30	32	86.49
Bicycle	6	13.33	10	7.41	1	4.35	12	13.95	5	2.27	1	0.60	32	17.49	10	8.40	1	2.70
Walk	26	57.78	24	17.78	5	21.74	21	24.42	13	5.91	5	2.98	45	24.59	26	21.85	1	2.70
Autorickshaw	3	6.67	5	3.70	0	0.00	14	16.28	12	5.45	5	2.98	42	22.95	16	13.45	3	8.11
Pearson chi-square	37.97						97.23						40.37					
P	0.00						0.00						0.00					
	South Rajkot Consumer segment						Industrial flanks Consumer segment						Peri urban areas Consumer segment					
	Low		Middle		Upper		Low		Middle		Upper		Low		Middle		Upper	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Private automobile	69	23.75	190	67.21	24	57.89	59	33.17	91	68.35	15	85.71	19	29.06	41	65.00	11	71.43
Bicycle	47	22.50	28	9.84	0	10.53	29	22.60	11	10.07	0	0.00	18	14.29	6	7.86	2	0.00
Walk	70	38.75	40	13.11	4	26.32	84	33.65	26	14.39	5	14.29	31	41.38	8	18.57	5	23.81
Autorickshaw	22	15.00	20	9.84	0	5.26	31	10.58	12	7.19	1	0.00	12	15.27	6	8.57	1	4.76
Pearson chi-square	29.33						73.73						50.66					
P	0.00						0.00						0.00					

Table 5
Built environment variables mode share.

Variable		Mean	Std. dev.
Population density (persons/square kilometre)		24,626	22,950
Job density (Jobs/square kilometre)		35.74	63.73
Entropy index		0.38	0.18
Dissimilarity index		0.20	0.20
Distance to IPT stop (km)		0.29	7.13
Kernel density of junctions		399.95	182.51
Kernel density of fatal road accidents		4.14	7.31
Potential accessibility to jobs		65.56	25.135
Commute distance (km)		3.10	2.51
Mode	Mode share (%)	Trip length (km)	
		Mean	Std. dev.
Walk	26.0	0.90	1.91
Private automobile	53.1	3.77	2.68
Bicycle	9.7	3.44	2.42
Shared auto	9.2	4.50	3.12
Others	2.0	5.45	3.78

in central parts of Rajkot. The correlation values in Table 4 are significant for all areas of Rajkot indicating a strong impact of consumer segment a person belongs to on his/her commute mode choice. The co-relation values are found strong relative to other areas, that is in Rajkot west, in Industrial flanks in Peri-urban Rajkot. A strong preference for motorized modes among the upper most and middle consumer segment is observed, especially in west Rajkot. Thus there is a propensity among individual willing to use private automobile to reside in west Rajkot. The other two areas where relatively strong significance values are found were industrial areas, wherein most residents are from the lower most consumer segment. Even though, a significant number these residents commute by private automobile the share of walking especially in the lower most consumer segment is relatively very high.

As can also be observed from Table 4 there is a distinct pattern of mode choice and a clear divide among the consumer segments. Individual with higher levels of education and with high paying jobs do not prefer to walk or bicycle. Whereas the proportions are mixed for the middle and lower most consumer segments. A large section of lower most consumer segment still prefer to walk or bicycle. As is the case in Peri-urban Rajkot and in South Rajkot. In the Industrial areas and south Rajkot. It is clear that a large portion select their residence close to their work place location so that they can commute by walking to work place. In the peri-urban areas of Rajkot which is more rural, individual choose to work in activities and around their residential location.

Table 5 shows the descriptive statistics of all quantified built environment measures. Like many other cities in India, the officials in the city of Rajkot have opted to maintain uniform density (Cervero, 2013). However, the per capita use of residential space and the built up density varies across the city. As a result wide variation in residential density values can be observed. The mean Net Residential Density value 24,626 persons/square kilometre and the net job density is 3574 jobs/

square kilometre are substantially higher than the density recommendation for even transit oriented development in Western Countries. For example, the guidelines published by the Centre for Urban Transportation Research (CUTR) at the University of South Florida, recommend a population density of more than 85 person/acre (or 2890 persons/square kilometre) and 500 jobs/acre (or 17,000 jobs/square kilometre) in core urban areas to promote transit use. Thus, even though the urban development policies promote sprawl and restrict the development of floor space, the per capita use of floor space for residence and employment in Rajkot is very low and the city is therefore naturally compact. The land use is a heterogeneous mix in many parts resulting in a dissimilarity index value close to 1, the mean dissimilarity index value observed for Rajkot is 0.20 which is lower than the observed value for the city of Ahmedabad that is 0.29, but this is still substantially higher than the mean dissimilarity index value of 0.13 as observed by Cervero and Kockelman (1997). This heterogeneous development possibly stabilizes the land use balance. The Mean Entropy Index value for Rajkot is 0.38, which is almost equal to the values observed in Ahmedabad and a little higher than the mean Entropy Index values (0.325) observed in Kockelman (1997), but lower than the mixed use entropy value of 0.471 observed in Frank and Pivo (1994).

Rajkot did not have an operational public transport service, when this study was carried out, the shared mode of transport used were mainly the shared auto rickshaws (IPT). The distance individuals have to travel to these stops suggest there are few areas which are serviced by IPT. The kernel density of road junctions is significantly lower than the value observed in Ahmedabad but higher that the kernel density of junction computed for the general prescribed block size of 600 m $\times$ 800 m. In Rajkot, it not surprisingly that more than half of the total work purpose travel is performed using private automobile. This is mainly because of high use motorized two wheelers. The share of NMT mode for work purpose travel in Rajkot is also fairly high.

The multi-collinearity and spatial autocorrelation among the built environment variable is presented in Table 6. The spatial auto correlation values are presented as Moron's I values. Strong co-relation is observed between dissimilarity index and job density: accessibility to jobs and entropy index: kernel density of junction and accessibility to jobs. Thus location that have balanced (equally distributed in the five uses considered) use of activity floor space are areas where the road network is also dense. Similarly location that have higher density of road junction are also areas that have better access to job locations. The correlation and spatial auto correlation results shown in Table 6 can affect the significance of the results as a result some relevant built environment variable might show lower elasticity values, as some of the covariance is either represent in the relation socio-demographic variables have with mode choice or by some other built environment variable. For example, accessibility to jobs and entropy index. Similarly some of the socio-demographic variables mentioned earlier are also likely to have strong correlation with built environment variables. For example lower most consumer category with population density.

Multinomial logit analysis

As can be seen from Table 4 some socio-demographic indicators have a strong impact on mode choice and there is also relative high multi-collinearity and also spatial auto-correlation amongst the built environment variables. Thus the question remains to be seen if, first the effect of built environment still holds true after socio-demographic factors are taken into account and second which are the most significant built environment variable effecting mode choice.

For the current paper MNL models have been developed in which indicators of socio-demographics (age, sex, consumer category and family class the respondent belongs to) were allowed to be included as control variables in addition to the built environment parameters.

The variables listed in Table 1 were used in the calibration process of the model. Several options were tried and the results of the estimation are shown in Table 7. In general, the McFadden R^2 greater than 0.4 can be interpreted as a very good goodness of fit (Müller et al., 2008), in this study, lower goodness of fit values are reported. The McFadden R^2 is 0.26, however, considering the goodness of fit report for other similar studies mentioned in (Ewing and Cervero, 2002; Ewing and Cervero, 2010) and in the case Ahmedabad (Munshi, 2013), the results of the MNL models were accepted and the model is considered to have reasonably good explanatory qualities. Most of the variables in the estimated mode choice models had significant parameter estimates. However, a few variables did not have very high significance across all mode choice models, but are still included as part of the model. These variables can be interpreted as important variables, which providing less or no information for the mode where its significance is found to be low.

Private automobiles are the most preferred mode (Table 5) for commute trips, therefore the intercept values for all other modes is negative where private automobile choice is taken as a reference category.

From Table 4 it was clear that there is a strong connection between socio-economic consumer segment that the respondent comes from and his/her commute mode choice. The results presented in Table 7 are largely consistent with the descriptive statistics. The probability of commuting using a bicycle over private automobile is very high if the person is from lower most consumer segment, relatively less but still significantly strong if the person is from middle consumer segment. The lower most consumer segment also has positive and very high coefficient values for walking and auto rickshaw use compared to the private automobiles. The inference is that the chance that a person from upper most consumer segment will use bicycle to commute is next to zero. However, there is a small portion of individual from the upper most consumer segment that walks or uses auto-rickshaw to reach their work places. No statistically significant effect for family type on mode choice could be detected. Gender of the person did effect mode choice, it was found that if the person travelling is

Table 6
Multi-collinearity and spatial auto-correlation.

		Population density	Potential accessibility to jobs	Kernel density junctions	Dissimilarity index	Entropy index	Commute distance	Kernel density accidents	PT stop
Job density	*R*	0.02	.307**	.134**	.616**	.324**	−.035	.119**	.025
	Moron's *I*	0.23	0.54	0.39	0.39	0.4	0.003	0.112	0.004
Population density	*R*		.407**	.287**	0	.398**	−.063**	.138**	.001
	Moron's *I*		0.56	0.74	0.17	0.48	.008	0.131	.000
Potential accessibility to jobs	*R*			.675**	.152**	.708**	.020	.218**	.039
	Moron's *I*			0.76	0.25	0.67	.310	0.23	.126
Kernel density junctions	*R*				−0.02	.362**	.047*	.129**	.007
	Moron's *I*				−0.31	0.67	.013	0.129	.002
Dissimilarity index	*R*					.233**	−.018	.023	.020
	Moron's *I*					0.39	.005	.001	.008
Entropy index	*R*						−.004	.173**	.069**
	Moron's *I*						.015	.178	.086
Commute distance	*R*							.067**	−.044*
	Moron's *I*							.112	.095
Kernel density accidents	*R*								.001
	Moron's *I*								.000

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

a male he finds higher utility value (in the order from high to low) in using car/motorized two wheelers over shared auto-rickshaw, walking, bicycle and for work purpose travel. With increase in age it is expected that individuals choose to prefer private automobile and shared modes over other modes. In line with expectations, it is found that there is very small negative utility of walking and bicycle modes for work and shopping purpose travel in comparison to private and shared modes of travel with increase in age.

"Density of Population" is expected to concentrate trip origins, and therefore is likely to favour higher use of transit (PT) if available and NMT modes, which is also based on past empirical evidence (Chatman, 2009; Bhatia, 2004; Boarnet et al., 2008; Greenwald, 2009; Gim, 2012). In Rajkot, increase in population density, has a small but positive influence on the choice of walking, bicycle and use of shared auto over the use of private automobiles. The higher density areas are occupied by individual with lower income, thus some of the socio-demographic variables mentioned earlier could also have accounted for part of the elasticity of relation between residential density and mode choice.

Location indicator, "Access to Destination", as reported in Ewing and Cervero (2010) and in other studies (Boarnet and Sarmiento, 1998; Dijst and Vidakovic, 2000; Stead, 2001) have a strong positive influence on choice of NMT modes. In this study two access to destination indicators are used, that is, "Potential Accessibility to Jobs" and "Commute distance". High potential accessibility indicates higher availability of jobs in comparison to the population residing a particular area, likewise low potential accessibility indicate poor job availability. Potential accessibility to jobs variable had a very small and negative effect on the probability of choosing bicycle and auto rickshaw over private automobile. But, locations with high potential accessibility to jobs have higher probability of walking to work over use of private automobile. Likewise if the work place was far it is likely that individuals will use bicycle or auto rickshaw over private automobile and walking. The use bicycle over private automobile for longer commute trips is a bit surprising as usually one can expect longer trips to be made by private automobiles. Bicycle use for commute is mainly by lower most consumer segment, who walk when commute distance is small, and use either bicycle or auto rickshaw when the work place is not within a walkable distance.

Two variables represent the mixing of land use, the dissimilarity index represents mix of land use and the entropy index represent the balance of land use. Both entropy index and dissimilarity index have positive relative high coefficient values in comparison to the other built environment variables considered in this study. These variables largely improved the probability of walking, bicycle use and auto rickshaw for commute trips. Dissimilarity index was particularly found significant to walk choice, indicating that intense mix of land use increases the probability of walking for commute trips when compared with private automobiles in the city of Rajkot, whereas, entropy index has high parameter coefficient values for auto rickshaw choice.

Road safety indicator represented as density of road accidents (fatal accidents) has very little but negative effect on choice of walking, bicycle and auto rickshaw modes against private automobile, thus more people walk and use bicycle where road and streets are safe and and where large vehicle do not mix with bicycle and pedestrian modes.

From the above results the following generalized inferences can be drawn:

1. Socio economic variable have a strong influence on mode choice for commute trips. Moreover individuals tend to preselect their residential locations to suit their modal preferences.

Table 7
Multi-nominal logit model estimates.[a]

	B	Sig.	Exp(B)
Bicycle mode choice			
Intercept	−4.207	0.000	
Respondents age	0.004	0.550	1.004
Gender			
Female	0.623	0.108	1.864
Male	0[b]		
Socio-economic consumer classification			
Lower most segment	3.516	0.000	33.649
Middle segment	1.816	0.000	6.149
Upper most segment	0[b]		
Built environment			
Population density	0.010	0.029	1.010
Entropy index	0.397	0.593	1.487
Dissimilarity index	0.622	0.185	1.863
Commute distance	0.068	0.097	1.070
Potential accessibility to jobs	−0.010	0.061	0.990
Kernel density accidents	−0.043	0.002	0.957
Walk mode choice			
Intercept	−0.258	0.519	
Respondents age	−0.001	0.856	0.999
Gender			
Female	1.006	0.001	2.735
Male	0[b]		
Socio-economic consumer classification			
Lower most segment	2.422	0.000	11.269
Middle segment	0.370	0.164	1.448
Upper most segment	0[b]		
Built environment			
Population density	0.020	0.000	1.020
Entropy index	0.547	0.400	1.729
Dissimilarity index	1.212	0.003	3.360
Commute distance	−1.266	0.000	0.282
Potential accessibility to jobs	0.637	0.117	1.693
Kernel density accidents	−0.022	0.039	0.978
Autorickshaw mode choice			
Intercept	−3.257	0.000	
Respondents age	0.006	0.379	0.994
Gender			
Female	1.572	0.000	4.816
Male	0[b]		
Socio-economic consumer classification			
Lower most segment	2.557	0.000	12.899
Middle segment	1.012	0.006	2.752
Upper most segment	0[b]		
Built environment			
Population density	0.017	0.000	1.017
Entropy index	2.885	0.000	17.905
Dissimilarity index	−0.457	0.372	0.633
Commute distance	0.109	0.009	1.115
Potential accessibility to jobs	−0.023	0.000	0.977
Kernel density accidents	−0.066	0.000	0.936
Model statistics			
−2 log likelihood intercept only	4541.970		
−2 log likelihood final	3340.719		
Chi-square	1201.251		
Pseudo R-square (Cox and Snell)	0.442		
Pseudo R-square (Nagelkerke)	0.496		
Pseudo R-square (McFadden)	0.264		

[a] The reference category is: Private Automobile.
[b] This parameter is set to zero because it is redundant.

2. Among the built environment variables land use mixing and balance strongly influence mode choice. Locations that have higher mixing of activities and more equal distribution of activity floor space near the residential location of individual making commute more choice are more like to have higher walking, bicycle and auto rickshaw trips.
3. Density and design variables have very little or no influence on mode choice. Density of junction was actually was not found to have any significant influence on choice of walking or bicycle choice.
4. Access to destination, commute distance has strong influence on walk mode choice, however very little influence on bicycle and auto rickshaw choice. Potential accessibility has comparatively little influence on mode choice.
5. The idea that individual living the periphery will travel longer distances is also not true, most individual living in the periphery prefer walk and travel shorter distances.

In line with findings by Munshi et al. (2004) and Munshi (2013) it is observed in this study also that the results for design indicators are indifferent from the results represented in Fig. 2. The effect of access to destination and land use indicators are much stronger in comparison. From land use and transport policy planning prospective, the effect of design indicators on mode choice can be a bit surprising but as observed in Munshi (2013), the problem is of poor design and also of not providing infrastructure where it is required. Emphasis should be laid at providing appropriately designed infrastructure to support pedestrian bicycle travel where these are need the most and not where it is easiest to provide these (Datey et al., 2012). Also, as stated above accessibility of jobs is an important parameter influencing mode choice, is it not practical to provide possible equity in access to jobs across the city, jobs will cluster (Munshi et al., 2014). If methods suggested by Munshi et al. (2014) can give direction on growth and development of land use in the city, location based infrastructure provision (this also supports the earlier argument) should be possible in such a manner that these areas have good access by NMT and PT. Density parameters do not show enough influence on mode choice, but this has been true in other studies also, therefore, the increasing densities to support walking, bicycle and PT choices in India might not be the immediate solution. As stated the focus should be to provide location based support for these modes and on maintaining the mix and balance of land uses.

Conclusions

The main purpose of this study was to establish the relation between built environment and mode choice for commute trips in the city of Rajkot. It is found that there is strong tendency to pre-select residential locations to enable the use a particular mode. The influence of built environment on mode choice for commute trips is comparatively marginal, but significant. The results from this study provide few definite directions from policy perspective. The residential self-selection problem is a important consideration, relation between activity type – worker – mode choices can help in taking decision regarding provision of transport infrastructure. Land use mixing and balance helps in encouraging NMT and PT modes thus should be encouraged. But how this can be achieved still remains a question, should planners persist with present laisse-faire type or development or have more control on development? The study also raises other contextual questions like does increasing density in an already dense environment make sense? Even though junction density has no relation with walk and bicycle choice would increase in number of junction with better transport infrastructure give a different result? What can be done so that individuals are encouraged to walk in the peripheral areas?

The results from this study can be considered as a beginning, this will have to be followed up with a large body of research especially for cities like Rajkot that must improve infrastructure for pedestrians, bicyclist and for public transport users.

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