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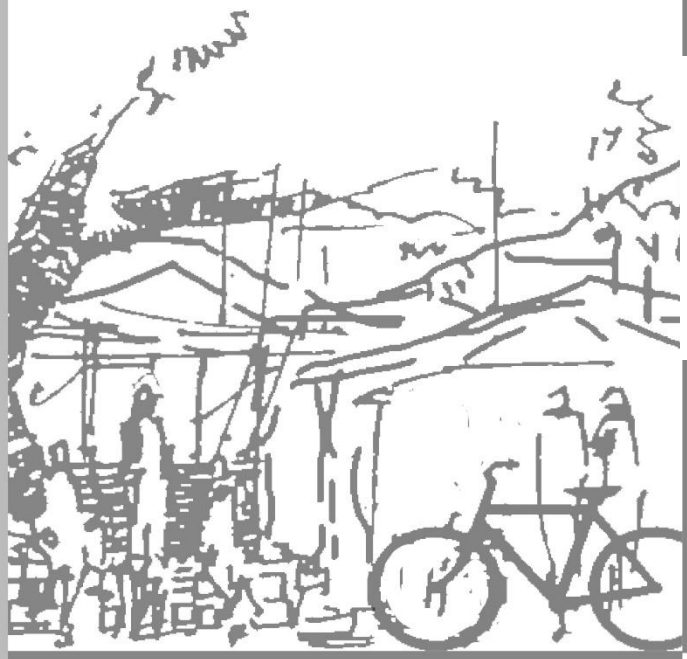
Links between Transit Riders and Built Form: The Case of Ahmedabad (West)



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CUE Working Paper 37
March 2017

CEPT UNIVERSITY
CENTRE FOR URBAN EQUITY

SHAKTI
SUSTAINABLE ENERGY FOUNDATION

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Centre for Urban Equity (CUE)
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About Centre for Urban Equity (CUE)

CUE was established at CEPT University in 2009, evolving from the Urban Poverty Alleviation (UPA) Cell established in 2008. CUE advocates a human-centered and equitable urban development paradigm. CUE undertakes research and advocacy; conducts training and capacity-building; imparts education; and networks with stakeholders on various aspects of human settlements with a focus on urban equity.

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Abstract

Transit-Oriented Development (TOD) presents unique opportunities for Indian cities to meet the challenges of rapid motorization, rising inequity, deteriorating quality of the urban realm and climate change. This paper discusses the methodology used in developing the Inclusive – Low Carbon Transit Oriented Development Model. Through the analysis of built form and travel behaviour, relationships are identified that can influence mode choice. These relationships are used to assess various probable built form scenarios, namely Business as Usual 2027, Ahmedabad TOD 2027 and Inclusive Low Carbon TOD 2027, for varying modal preferences of their inhabitants. The scenarios are compared by calculating the carbon emission that result to identify strategies that are ideal for an inclusive low carbon future.

Acknowledgements

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1. Introduction

Since economic liberalisation in the 1990's, India has witnessed reduced dependence on non-motorised modes, shared modes and public transport, with greater reliance on private modes of transport (Banerjee et al., 2010). The traditional response of urban planning has been to increase supply, than to manage the demand. However, there is growing realisation that the traditional urban and transport planning, associated with a purely supply orientation, leads to negative externalities, on just as transport issues, but also with environment, social and economic problem (Knoflacher, 2007; Schipper et al., 2008).

It is in this context, that Transit Oriented Development (TOD), a form of Smart Growth and New Urbanism is gaining popularity in India. Several terms have been used to define TOD in the past, transit villages (Bernick and Cervero, 1997) and transit supportive development (Federal Transit Administration, 2014) are some of them. Most definitions convey a form of compact, mixed-use development, centred around a transit node, and conducive to transit use. Loose definitions have caused proponents of TOD to distance themselves from other forms of transit proximate development such as "Transit Adjacent Development" (TAD), which is physically near transit but fails to capitalise on its presence (Renne, 2009). More effective definitions focus on the goals of TOD, which is any form of development around a mass transit node, at a macro or micro scale, that induces people to walk, cycle and use public transit (PT) over personal modes of transport (Cervero et al., 2002; DDA, 2012).

The principle idea of TOD is the ability of the built environment to influence our travel behaviour. Five broad built environment variables have been thought to influence travel behaviour. Three of these variables, Density, Diversity and Design, were first suggested by Cervero and Kockelman (1997). Subsequently, destination accessibility and distance to transit were added (Ewing and Cervero, 2001). The influence of built form on travel behaviour, has been supported by a large number of empirical evidence from research conducted largely in the United States of America, Australia and Europe. This research has been summarised by Ewing and Cervero (2010, 2001) and Cao et al. (2009). However, very few studies (Munshi, 2016, 2013; Srinivasan et al., 2008; Srinivasan and Rogers, 2005) have attempted to study this relationship in the Indian context.

This paper attempts to draw upon the linkages between transit riders and built form building upon the inferences from the above studies, but in the specific case of Ahmedabad (West). The following section presents the methodology followed as part of the study.

2. Methodology

The methodology of this study is composed of three parts. The first part identifies the relationships between mode choice and its determinants for Ahmedabad, namely socio-economic characteristics of individuals, build environment characteristics of their surroundings and travel behaviour of the respondent. In the second part, these relationships are used to pre-empt the mode choice of individuals under varying built environment scenarios, namely Business as Usual (BAU), Ahmedabad's Transit Oriented Zone – Local Area Plan (ATOZ) and an Inclusive – Low Carbon Transit Oriented Development (I-LC) scenario. Subsequently, carbon emissions are calculated based on the mode shares resulting from the various built environment scenarios. A comparison of the carbon emissions from the various scenarios, would reveal the strategic measures that may be followed for a more inclusive – low carbon development in our cities.

Figure 1: Inclusive low-carbon TOD model methodology

2.1. Modelling mode choice and built environment relations

The modelling of mode choice and built form relations is informed by theories of consumer choice from economics and psychology. More specifically, the discrete choice model is employed, which is based on the tenet that people make rational choices to maximise their utility from among a finite set of alternatives (Ben-Akiva and Lerman, 1985; McFadden, 1976). Logistic Regression (LR) and its variants are commonly utilised to study the relationship between built form and mode choice.

Over the years, there have been several improvements to built form and travel behaviour studies. Cervero (2002) identified the need for greater inclusion of the effects of generalised cost (travel cost and travel time) on mode choice. Boarnet & Crane (Boarnet and Crane, 2001) argued the need for residential location decisions (self-selection) to be incorporated in the explanation of travel behaviour. Cao et al. (2009) proved empirically the existence of the self-selection bias, in built form and travel behaviour relations. Even so, they found significant associations between the two. Ewing & Cervero (2010, 2001) through their meta-analysis of studies relating built environment and travel behaviour, expanded the list of built environment attributes that where known to explain travel behaviour.

2.1.1. Description of variables explaining Mode Choice

This study has used various types of data to quantify build environment, travel behaviour and socio-economics of users. The following section describes these various types of data used in this study.

Travel behaviour and socio-economic data: The data for travel behaviour comes from household surveys conducted of residents in Ahmedabad. Respondents were asked to recollect their travel from the previous day, and report their mode choice, trip purpose, trip length, trip cost and trip duration. This survey also captured data regarding the respondent's socio-economic characteristics, reported as their household income and vehicle ownership. These data have been described below:

A. Travel behaviour

- Mode choice: The mode used in the trip. These vary from Public Transport, Shared Auto, Autorickshaw, Two Wheeler, Car, Walk and Cycle
- Trip distance: The distance from trip origin to destination
- Travel Cost : Cost of making the trip
- Travel Time : The time needed to reach a destination

B. Socio-economic characteristics

- Motor Vehicle Ownership : Average number of motor vehicles owned by a household
- Household Income: The combined income of various members residing in an independence house or apartment
- Housing Typology: The type of housing occupied by the respondent, classified as Apartment (flat), Row Housing, Bungalow, Tenement, Slum or Chawl

Built environment data: Ewing and Cervero (2010) identified six indicators of built environment that influenced mode choice, compiled from previous empirical studies. These six indicators are density, diversity, design, destination accessibility, and distance to transit and demand management. Due to a lack of demand management measures such as priced parking or congestion charging, this indicator was left out. The remaining indicators and the data used have been described below:

A. Density: In this study, net population density and job density represents Density. Population density is the ratio of population to total area under residential use.

B. Diversity: In this study, land use balance represented Diversity. It was calculated using the floor space entropy index. Five land use classifications were created. The value of the index ranged from 0 to 1. If a perfect mix of land uses existed, the index would have a value of 1, and if there is only a single land use, the value would be 0.

C. Design: Design was represented using junction density. The impact of junction density was best computed by the use of kernel density of junctions. It is computed with a radius of 750 metres indicative of 10 minutes walking distance. The width of the streets (right of way) was used in the population field.

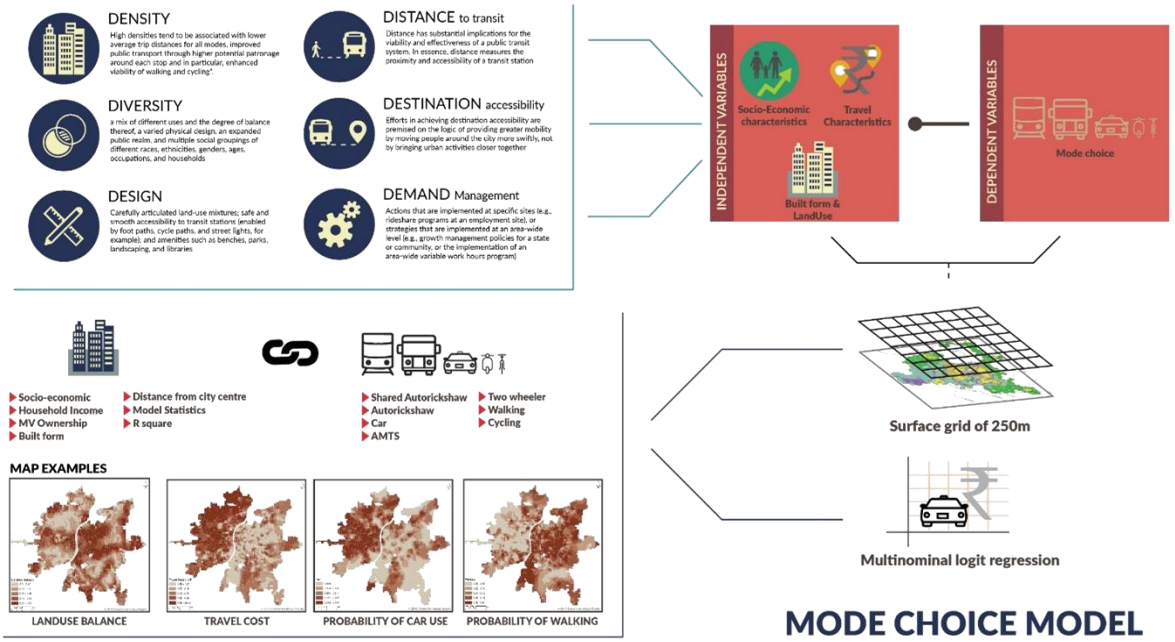
D. Distance to transit stop and AMTS locations

E. Destination accessibility: This variable is represented as the distance to jobs. As most jobs are concentrated in the centre of the city, it was considered the distance to the city centre, considered the Nehru Bridge area.

2.1.2. Data Processing

Data on street network, built-up area and building uses were mapped on GIS, as lines and polygons. The household survey data was represented spatially in GIS as points that indicated the residential location of the respondent. Subsequently indicators such as distance to transport, to the centre of the city, kernel densities were calculated using geostatistical analytical tools in GIS. The various disaggregate types of spatial data, were brought together for each respondent, using a uniform grid of 250 m. x 250 m. Overlay function was used to combine the built form, travel behaviour and socio-economic data.

Figure 2: Mode-choice model



2.1.3. Analysis

Eleven socio-economic and built form variables were identified to have a significant correlation with the dependent mode choice variable. This was after removing those variables that did not have a significant correlation with mode choice, or had multi-co-linearity with other variables. Binomial logistical regression was used to analyze the mode choice probabilities of the population of Ahmedabad. A step-wise logistical regression method was used, that introduced the various variables in three blocks, in forward step. The first block consists of socio-economic variables that's address the issue of residential self-selection. Hence, this block becomes the control block for this analysis. The second block introduces the built form variables. These variables together with the control variables make the build-form model. In the last step, distance to city centre was introduced.

3. Results

3.1. Relations between built form and mode choice

Mode choice of six different modes of transport used in Ahmedabad was analyzed. These includes public transport modes of AMTS, intermediate public transport modes of shared auto and autorickshaws, private vehicular modes of two-wheelers and cars, and lastly the non-motorized modes of walking and cycling.

3.1.1. Shared Autorickshaw

Shared auto rickshaw is a form of Intermediate Public Transport present in the city of Ahmedabad. It is an auto rickshaw, which can be hired simultaneously by multiple users travelling in the same direction, much like a stage carrier. These autos run on relatively fixed routes and fares, with undesignated pick up points and notional drop off points. The model explains about 23% of the variability in shared autorickshaw choice. The control variables for shared autos reveal relationships on expected lines, with lower household income and those without motor vehicles preferring it.

Table 1: Binary logistic model estimate for shared autorickshaw

Particulars	*B*	*Std. B*	*Sig.*
(Constant)	.117		.000
Socio-economic variables			
MV Ownership	-.025	-.290	.000
Household Income	-.016	-.146	.000
Built form variables			
Population Density	-4.291E-5	-.157	.000
Junction Density	.000	-.138	.000
Distance from City Centre	.002	.119	.000
Model statistics			
R Square	.232		

Of the three significant built form variables, population density had an inverse relationship with shared autorickshaw. This may be because, shared auto rickshaws are mostly found on the outskirts of city, in areas that have low densities than central portions. Junction density had little to no-effect on the model with a zero beta value. Shared auto usage increases with increase of distance to city centre. This relationship was also on expected lines, as shared autos generally ply on the outer parts of the city, along its arterials and highways.

3.1.2. Autorickshaw

Autorickshaws are a form of taxi service that may be hired by an individual or a group of individuals, to provide point-to-point service. The model can explain about 2.3% of the variability in shared autorickshaw choice. The control variables for autorickshaw reveal a significant negative relationship with household income.

Table 2: Binary logistic model estimate for autorickshaw

Particulars	*B*	*Std. B*	*Sig.*
(Constant)	.056		.000
Socio-economic variables			
Household Income	-.010	-.105	.000
Built form variables			
Distance from City Centre	.001	.067	.000
Junction Density	-5.775E-5	-.069	.000
Population Density	1.053E-5	.045	.005
Model statistics			
R Square	.023		

Among built form indicators, greater distance from city centre, and population density were found to increase usage of autorickshaw. Greater junction density on the other hand decreased autorickshaw usage.

3.1.3. AMTS

Ahmedabad Municipal Transport Service (AMTS) is the bus service run by the Ahmedabad Municipal Corporation. The model can explain 4.3% of variability in AMTS mode choice. Only one control variable, Motor Vehicle ownership - had significance to AMTS mode choice.

Table 3: Binary logistic model estimate for AMTS

Particulars	*B*	*Std. B*	*Sig.*
(Constant)	.056		.000
Socio-economic variables			
MV Ownership	-.051	-.208	.000
Built form variables			
Distance from City Centre	-.002	-.047	.001

Model statistics			
R Square	.043		

Of all built form variables, Distance from city centre, was the only significant variable, with an inverse relation to AMTS mode choice. This indicates that AMTS use increase when the distance to city centre decreases. Does this have to do with the density of AMTS network distribution, concentrated at the centre?

3.1.4. Car

Cars in this classification include any privately owned four-wheel transport mode, such as cars and jeeps. The model can explain 22.7% of the variability of mode choice for cars. Two control variables of Household Income and Motor Vehicle Ownership have a significant relationship with car mode choice. As expected, both variables are positively linked to car ownership.

Table 4: Binary logistic model estimate for car

Particulars	***B***	***Std. B***	***Sig.***
(Constant)	.056		.000
Socio-economic variables			
Household Income	.003	.282	.000
MV Ownership	.002	.240	.000
Built form variables			
Distance from City Centre	-9.258E-5	-.058	.000
Model Statistics			
R Square	.227		

Among build form variables, Distance from City centre was the only variable with a significant relationship with Car mode choice. It has a negative relationship with car mode choice, indicating that the choice of car as a mode of travel increase with decrease in distance to city centre. Does this have to do with the location of higher income groups in the city?

3.1.5. Two-wheelers

Two-wheeler in this classification includes motorcycles, scooters and mopeds. This model can explain a high 48% of the variability of mode choice. Two control variables of Motor Vehicle ownership and household income have a significant relation with two-wheeler mode choice. As with car mode choice and in line with expectations, two wheeler mode choice is positively related to these variables.

Table 5: Binary logistic model estimate for two-wheelers

Particulars	***B***	***Std. B***	***Sig.***
(Constant)	.198		.000
Socio-economic variables			
MV Ownership	.153	.548	.000
Household Income	.063	-.146	.000
Built form variables			
Land Use Balance	-.065	-.070	.000
Junction Density	.000	.058	.000
Distance from City Centre	-.003	-.052	.000
Model statistics			
R Square	.480		

Three build form variables of Land Use Balance, Junction Density and Distance from city centre were found to be significant. The relations reveal that two wheeler choice would be high in areas closer to the city centre, with high junction density and poor mix of land use.

3.1.6. Walking

The built form model for walking can predict 38.1% of the variability of walking as a mode choice. The control variables of motor vehicle ownership and household income were significantly related to walking. It reveals that walking choice is high for those who don't own a motor vehicle and /or have low household incomes. While a lack of motor vehicle ownership is related to a low household income, it also reveals that those that are walking do not have sufficient income to access PT and IPT services, or even a bicycle.

Table 6: Binary logistic model estimate for walking

Particulars	*B*	*Std. B*	*Sig.*
(Constant)	.198		.000
Socio-economic variables			
MV Ownership	-.027	-.462	.000
Household Income	-.017	-.216	.000
Built form variables			
Junction Density	4.534E-5	.068	.000
Land Use Balance	.009	.046	.000
Model statistics			
R Square	.381		

Junction density and land use balance are the two build form variable found to have a significant relationship with walking choice. They are both positively related to walking choice. It indicates that walking choice increase in areas with higher junction density and higher mix of land use. These finding were on expected lines.

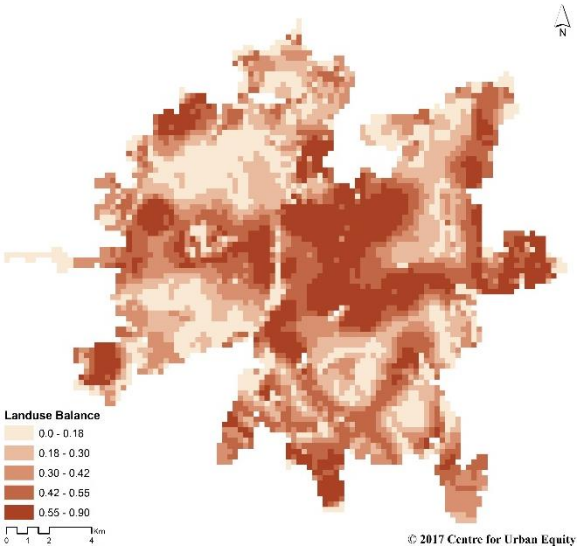
3.1.7. Cycling

The built form model for cycling choice can predict variability in cycling choice by 24.8%. Similar to walking, Motor vehicle ownership and household income were the two control variables that were significantly related to cycling choice, with a negative relation. It indicates that cycling choice is higher among those who don't own a motor vehicle and those that don't have the incomes sufficiently high to access either PT or IPT services.

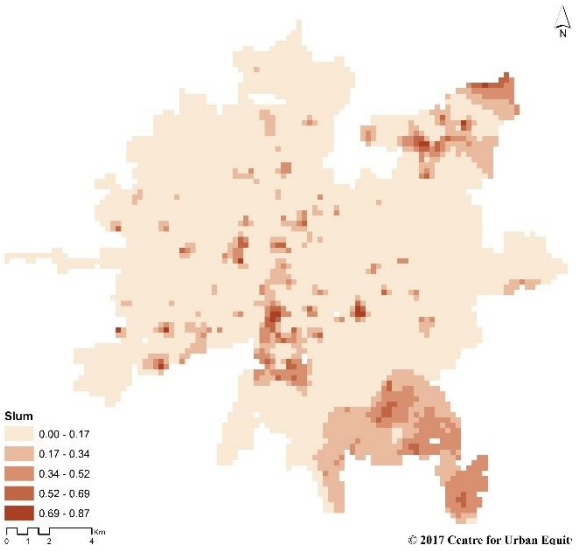
Table 7: Binary logistic model estimate for cycling

Particulars	*B*	*Std. B*	*Sig.*
(Constant)	.218		.000
Socio-economic variables			
MV Ownership	-.053	.548	.000
Household Income	-.022	-.146	.000
Built form variables			
Land Use Balance	.044	.095	.000
Distance from City Centre	.002	.085	.000
Population Density	1.706E-5	.038	.000
Junction Density	6.033E-5	.037	.000
Model statistics			
R Square	.248		

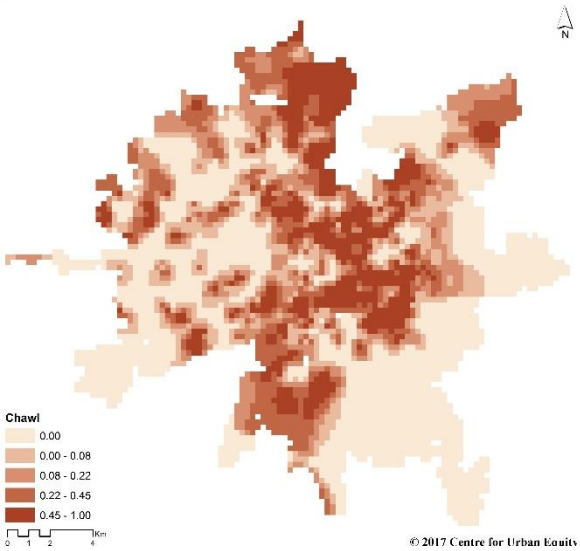
Four built form variables, land use balance, distance to city centre, population density and junction density were significantly related to cycling mode choice. They were all positively related to cycling choice. It reveals that, cycling is a preferred mode choice in areas with a high mix of land use, further from the city centre, with higher population density and junction density.



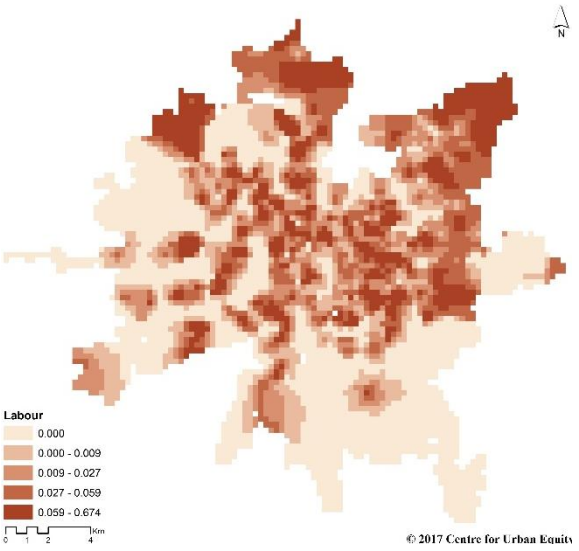
a) Land use balance



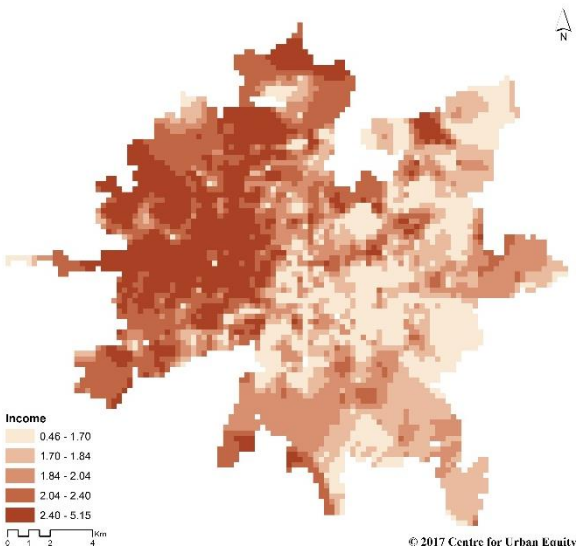
b) Slums



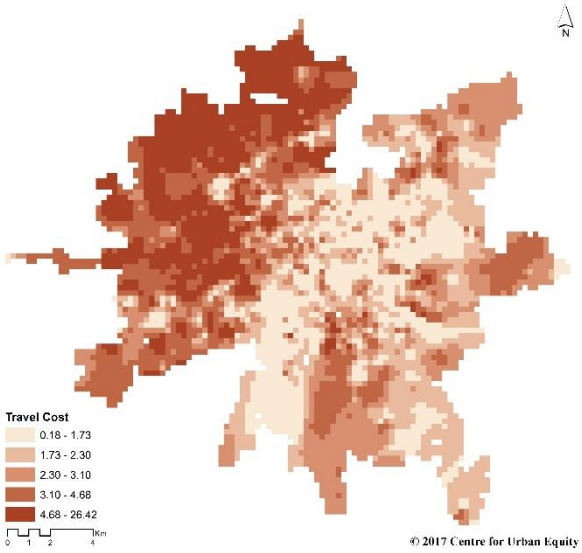
c) Chawls



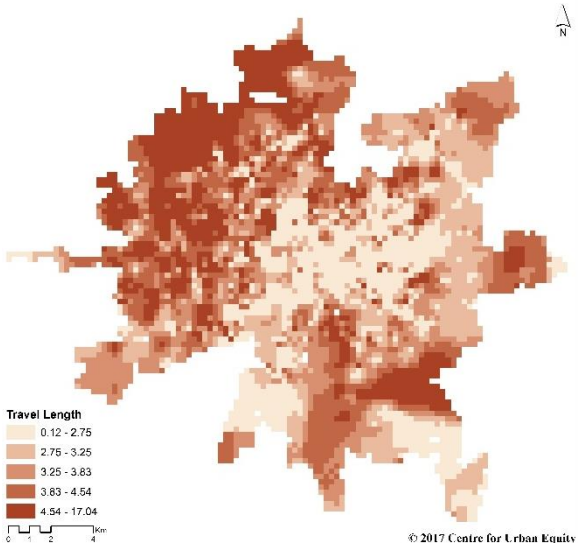
d) Labour



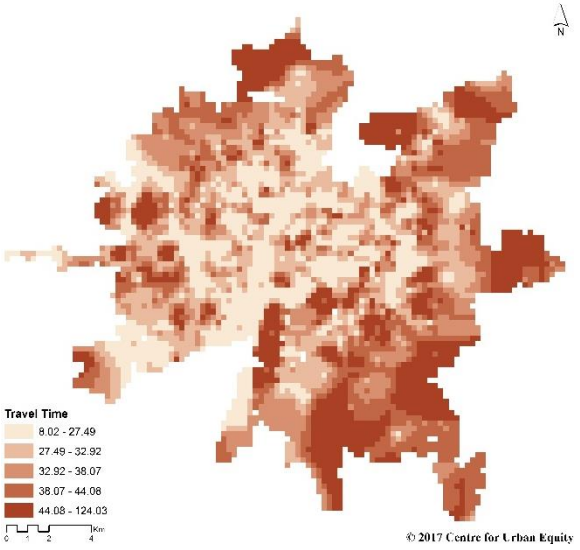
e) Income levels



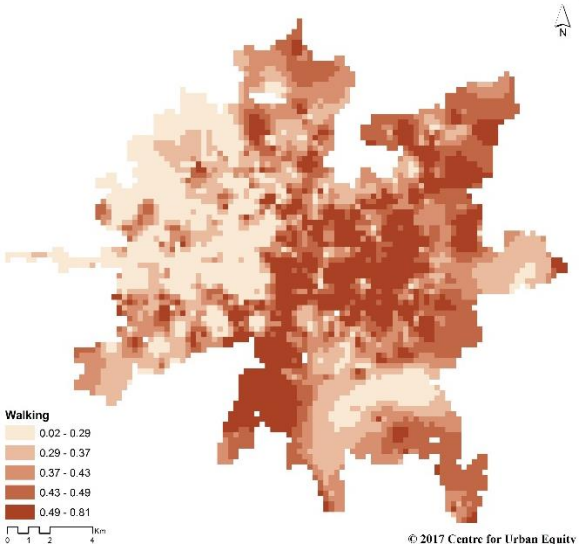
f) Travel cost



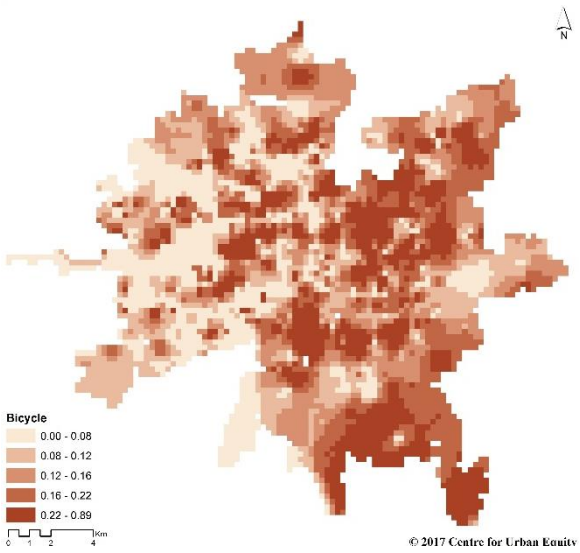
g) Travel length



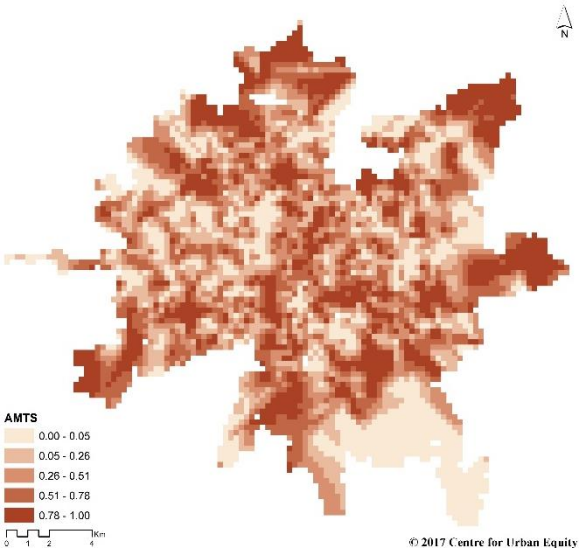
h) Travel time



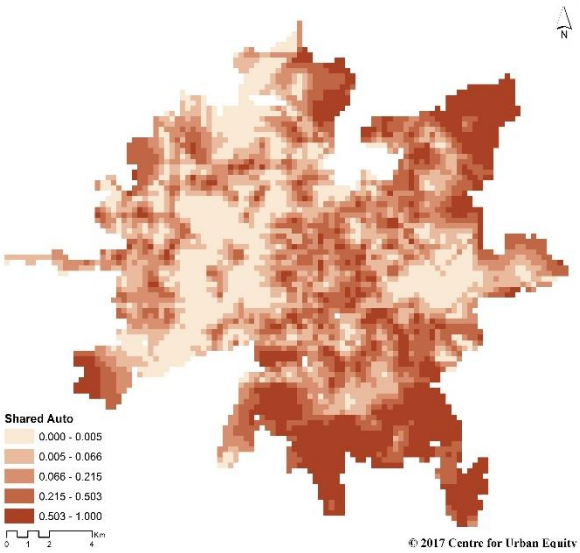
i) Probability of walking



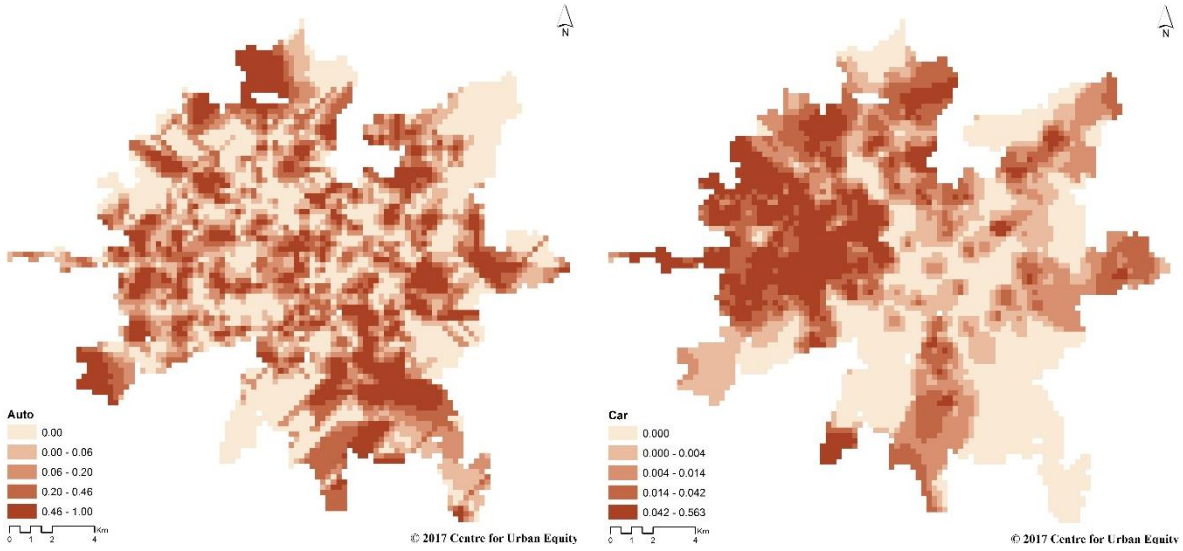
j) Probability of cycling



k) Probability of AMTS use



l) Probability of use of shared auto



m) Probability of auto-rickshaw use **n) Probability of car use**

Figure 3: Results of the LCTOD model for the existing scenario

4. Understanding housing and transit riders in Ahmedabad (West)

In order to understand the linkages between housing and transit riders, a household survey was conducted in the western part of Ahmedabad. Ahmedabad is a city of 6 million (2011) with an area of around 400 square kilometres. The western part of Ahmedabad consists of the wards mentioned in the table below. The densest ward is Vejalpur with a population density of 788 ppHa as against the density of 183 ppHa across Ahmedabad.

Table 8: Population in Ahmedabad (West), 2011

Zone	Ward	Population		Area [Ha]		Population Density [ppHa]
		Numbers	Per cent	Numbers	Per cent	
1	Sarkhej	67,022	4%	3,687	17%	20
	Vejalpur	2,71,933	15%	374	2%	788
	Vasna	1,13,458	6%	507	2%	243
2	Thaltej	90,536	5%	2,052	9%	48
	Bodakdev	70,571	4%	1,249	6%	61
	Jodhpur	87,961	5%	2,210	10%	43
3	Gota	1,11,743	6%	5,150	23%	24
	Kali	86,696	5%	849	4%	111
	Chandkheda_Motera	88,717	5%	1,395	6%	69
	Sabarmati	63,187	3%	542	2%	126
4	Chandlodiya	92,285	5%	376	2%	266
	Ranip	1,01,511	6%	321	1%	344
	Ghatlodiya	1,44,586	8%	299	1%	525
	Naranpura	81,127	4%	329	1%	268
	Nava Vadaj	62,496	3%	212	1%	320
	Juna Vadaj	60,536	3%	341	2%	193
5	SP Stadium	69,165	4%	337	2%	222
	Aambawadi	51,526	3%	644	3%	87
	Navrangpura	51,282	3%	723	3%	77
	Paldi	76,591	4%	459	2%	181
	Total	**18,42,926**	**100%**	**22,058**	**100%**	**84**

Source: (Registrar General of India 2011)

4.1. Sampling

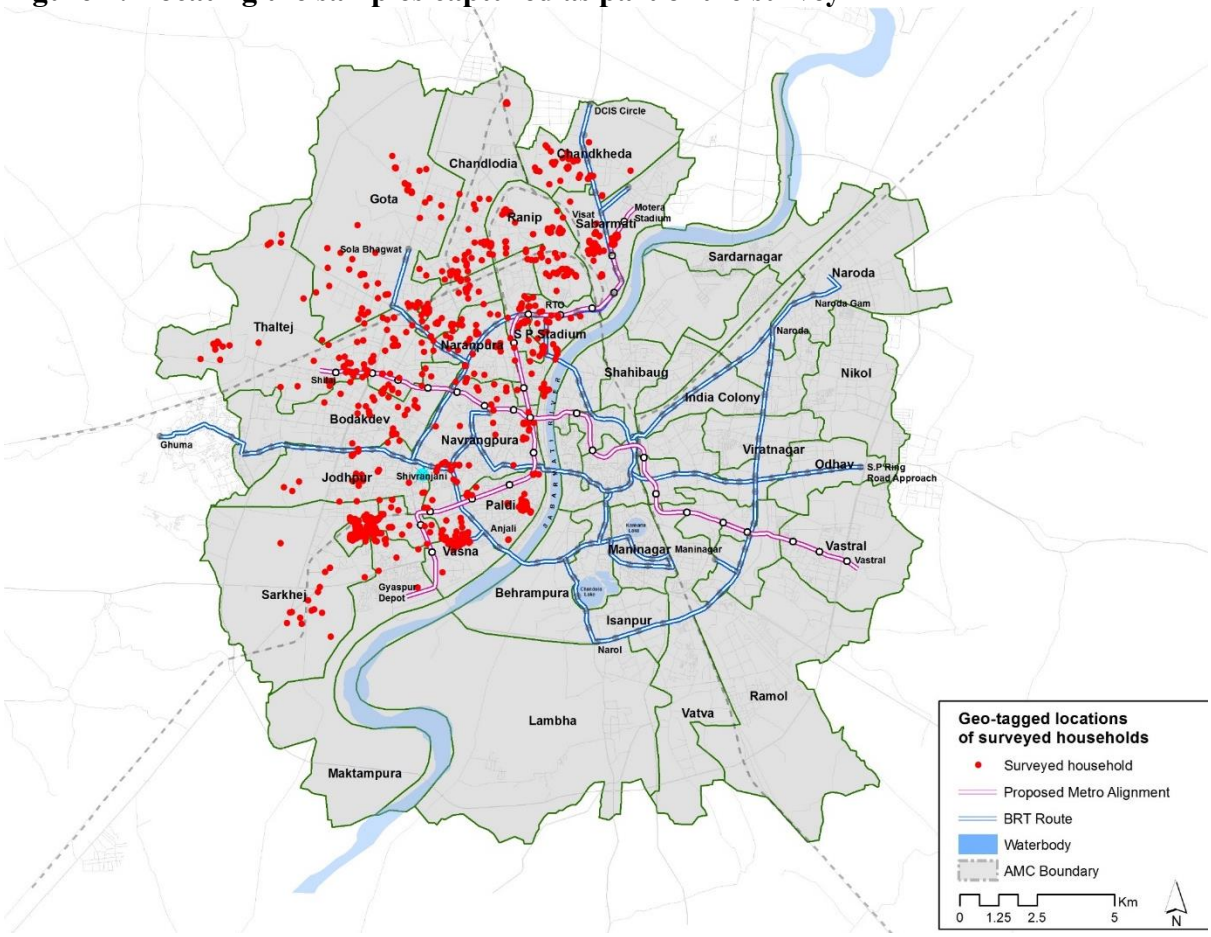
The sampling was done on the basis of data from the Census of India housing series[1] of 2011. It is generally agreed that housing is a good proxy of spending capacities and incomes. Therefore, the selection of people from different income groups was based on the number of rooms in their house. The following table presents the breakup of households in Ahmedabad by number of rooms. Based upon the proportion of households by number of rooms, samples were selected in the respective wards as seen in the map below.

Table 9: Breakup of households in Ahmedabad by number of rooms, 2011

Ownership status	Number of households	Households by number of dwelling rooms						
		No exclusive room	One room	Two rooms	Three rooms	Four rooms	Five rooms	Six rooms and above
Owned	9,01,077	16,934	2,51,992	2,97,895	2,03,372	79,378	29,104	22,402
	(77%)	(2%)	(28%)	(33%)	(23%)	(9%)	(3%)	(2%)
Rented	2,39,853	12,691	1,44,362	56,774	19,453	5,153	1,003	417
	(20%)	(5%)	(60%)	(24%)	(8%)	(2%)	(0%)	(0%)
Others	23,582	1,968	13,518	4,458	2,576	726	197	139
	(3%)	(8%)	(57%)	(19%)	(11%)	(3%)	(1%)	(1%)
All	**11,76,055**	**32,133**	**4,14,375**	**3,62,333**	**2,27,258**	**86,374**	**30,558**	**23,024**
	(100%)	**(3%)**	**(35%)**	**(31%)**	**(19%)**	**(7%)**	**(3%)**	**(2%)**

Source: (Registrar General of India 2011)

Figure 4: Locating the samples captured as part of the survey



Source: Primary survey, 2017

The table below presents the number of samples selected in each ward.

[1] http://censusindia.gov.in/2011census/hlo/HLO_Tables.html

Table 10: Breakup of households in Ahmedabad by number of rooms, 2011

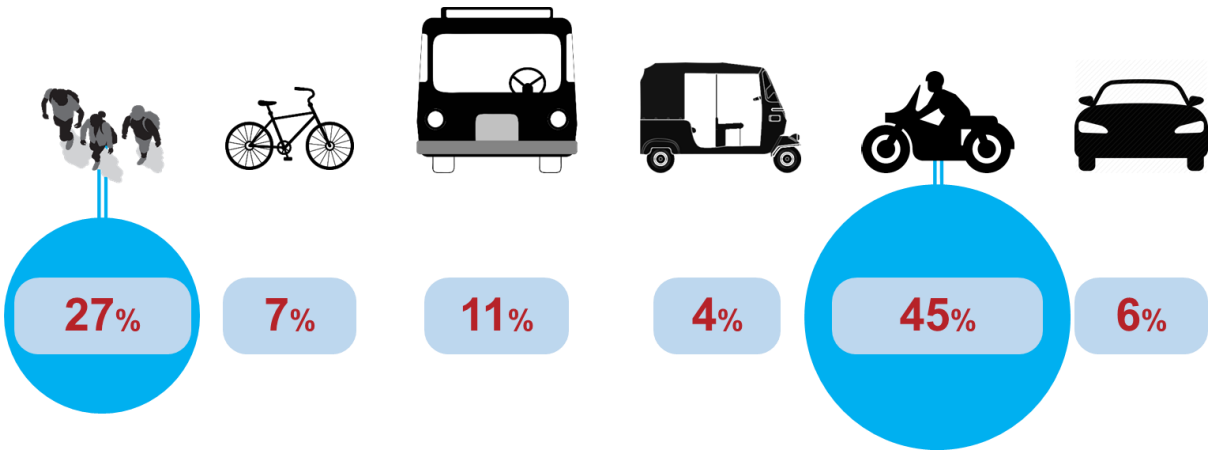
Ward*	Zone [see map]	Number of HHs [2011]	Area [Ha]	Population Density [ppHa]	Number of samples to be captured							
					No exclusive room	One room	Two rooms	Three rooms	Four rooms	Five rooms	Six and more	Total samples per ward
					Mostly slums	Low-income housing	1 Room Kitchen	1 BHK	2 BHK	3 BHK	4 BHK and more	
Sarkhej	1	14,260	3,687	20	1	14	12	8	3	1	1	40
Vejalpur		57,858	374	788	4	57	50	31	12	4	3	162
Vasna		24,140	507	243	2	24	21	13	5	2	1	68
Thaltej	2	19,263	2,052	48	1	19	17	10	4	1	1	54
Bodakdev		15,015	1,249	61	1	15	13	8	3	1	1	42
Jodhpur		18,715	2,210	43	1	18	16	10	4	1	1	53
Gota	3	23,775	5,150	24	2	24	21	13	5	2	1	67
Kali		18,446	849	111	1	18	16	10	4	1	1	52
Chandkheda_Motera		18,876	1,395	69	1	19	16	10	4	1	1	53
Sabarmati		13,444	542	126	1	13	12	7	3	1	1	38
Chandlodiya	4	19,635	376	266	2	19	17	11	4	1	1	55
Ranip		21,598	321	344	2	21	19	12	4	2	1	61
Ghatlodiya		30,763	299	525	2	30	27	17	6	2	2	86
Naranpura		17,261	329	268	1	17	15	9	4	1	1	48
Nava Vadaj		13,297	212	320	1	13	11	7	3	1	1	37
Juna Vadaj		12,880	341	193	1	13	11	7	3	1	1	36
S.P Stadium	5	14,716	337	222	1	15	13	8	3	1	1	41
Aambawadi		10,963	644	87	1	11	9	6	2	1	1	31
Navarangpura		10,911	723	77	1	11	9	6	2	1	1	31
Paldi		16,296	459	181	1	16	14	9	3	1	1	46
Total		3,92,112	22,058		30	388	339	213	81	29	22	1,100
					3%	35%	31%	19%	7%	3%	2%	

4.2. Travel behaviour

4.2.1. Mode share

The graphic below shows that across Ahmedabad (West), the mode share by trips is dominated by two-wheelers with a share of 45 per cent. Walk trips tend to form around 27 per cent of the total trips. PT modes including AMTS and BRTS together attribute for only 11 per cent of the total trips. Cycling trips account for 7 per cent, motorized four wheelers 6 per cent and IPT trips account for only 4 per cent of all trips.

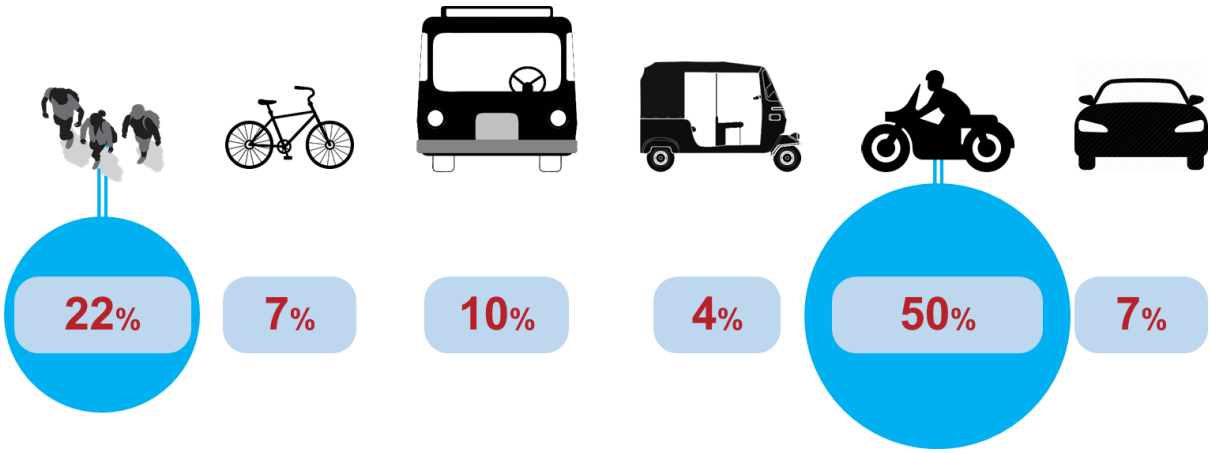
Figure 5: Mode share across the samples surveyed



Source: Primary survey, 2017

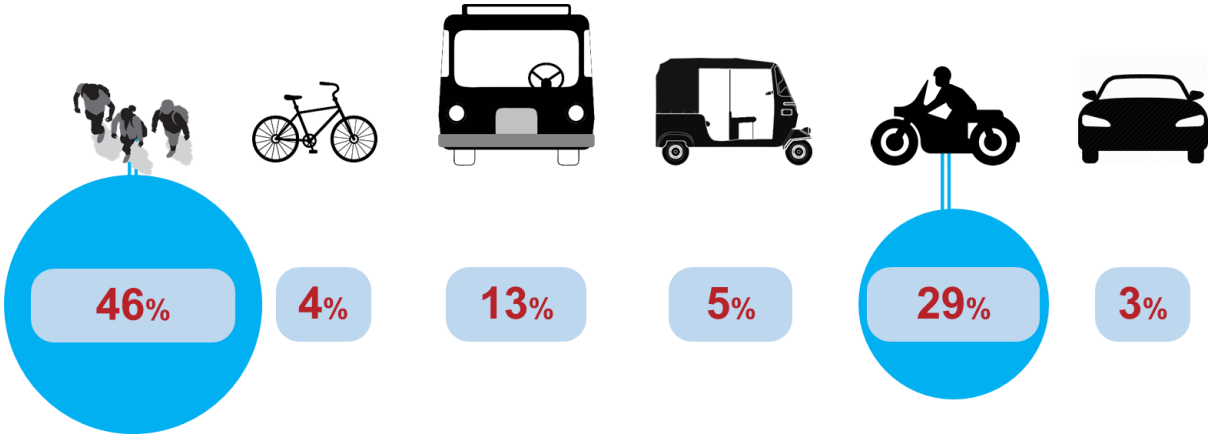
The figures below show that there is a great variance between the mode shares across gender. Men tend to use two-wheelers (50 per cent) more while women are reliant on walking (46 per cent) to get across the city. Similarly, while only 10 per cent trips made by men are done using PT, the same figure stands at 13 per cent for women. Men also tend to cycle a lot more than women. A total of 7 per cent of trips made by men are done using cycles whereas the same figure stands at 4 per cent for women.

Figure 6: Mode share across the samples surveyed (male)



Source: Primary survey, 2017

Figure 7: Mode share across the samples surveyed (female)



Source: Primary survey, 2017

The following table shows the mode share by trips across income groups. As expected and in line with what was learnt from literature, the lower-income groups tend to rely more on walking. But there is a large section that has moved on to using motorised two-wheelers in order to satisfy their aspirations of achieving greater mobility.

Table 11: Mode share by trips across income groups

Category (as per GHB guidelines)	Walk	Cycling	PT	IPT	M2W	M4W
Less than ₹ 8,000 per month (EWS)	47%	11%	18%	5%	18%	1%
Between ₹ 8,001 and ₹ 20,000 (LIG)	26%	8%	12%	6%	46%	2%
Between ₹ 20,001 and ₹ 80,000 (MIG)	9%	1%	2%	1%	70%	15%
Above ₹ 80,000 (HIG)	26%	0%	0%	0%	21%	53%
Overall	**27%**	**7%**	**11%**	**4%**	**46%**	**6%**

Source: Primary survey, 2017

Table 12: Mode share by trips across housing typology

Category	Walk	Cycling	PT	IPT	M2W	M4W
Slum	44%	6%	16%	1%	31%	2%
Chawl	37%	12%	13%	7%	29%	2%
Row House	30%	5%	14%	4%	43%	5%
Tenement	17%	4%	6%	4%	56%	12%
Apartment	5%	2%	4%	2%	77%	10%
Bungalow	3%	0%	0%	0%	64%	33%
Overall	**27%**	**7%**	**11%**	**4%**	**46%**	**6%**

Source: Primary survey, 2017

The above table shows the mode share across housing typologies and it is revealed that people living in slums, chawls and row houses are more likely to use modes like walking and public transport including AMTS and BRTS. Similarly, when one inspects the below table, it is apparent that with an increase in floor area consumption, there tends to be a move to modes like motorised two-wheelers and four wheelers. These tables give us an idea of the affordability of those that use nonmotorized modes and public transport modes for getting around cities.

Table 13: Mode share by trips across dwelling unit sizes

Category	Walk	Cycling	PT	IPT	M2W	M4W
0-30 sq m	38%	13%	17%	7%	25%	1%
31-50 sq m	18%	5%	9%	4%	60%	4%
51-95 sq m	28%	1%	8%	3%	51%	9%
>95 sq m	12%	0%	2%	1%	49%	37%
Overall	**27%**	**7%**	**11%**	**4%**	**46%**	**6%**

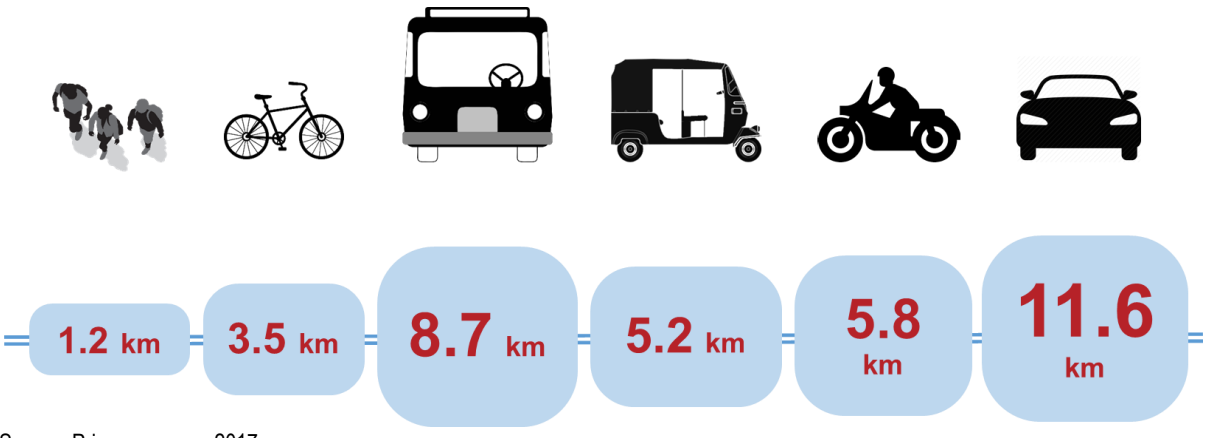
Source: Primary survey, 2017

Sustainable mobility practices: Overall, it was found that within those that identified themselves as belonging to Economically Weaker Sections (EWS), 76 per cent used sustainable modes of transport. Close to 47 per cent of this section used walking while 11 per cent used cycling while another 18 per cent used public transport. Within those that identified themselves as part of the Lower Income Group (LIG), 26 per cent walked while 8 per cent cycled and 12 per cent used public transport, accounting for over 46 per cent of all belonging to the LIG segment.

4.2.2. Trip lengths

Trip lengths help understand how long people travel in the city using various modes. The average trip length in the city was found to be 5.1 kilometres. It was found that people used four-wheelers to cover an average distance of 11.6 kilometres, if such modes were available to them. The public transport modes were used for covering average distances of 8.7 kilometres. The following figure also reveals that the average trip length via walk was around 1.2 kilometres which can be considered encouraging in an environment like Ahmedabad (West) where infrastructure is not convenient.

Figure 8: Trip lengths across various modes

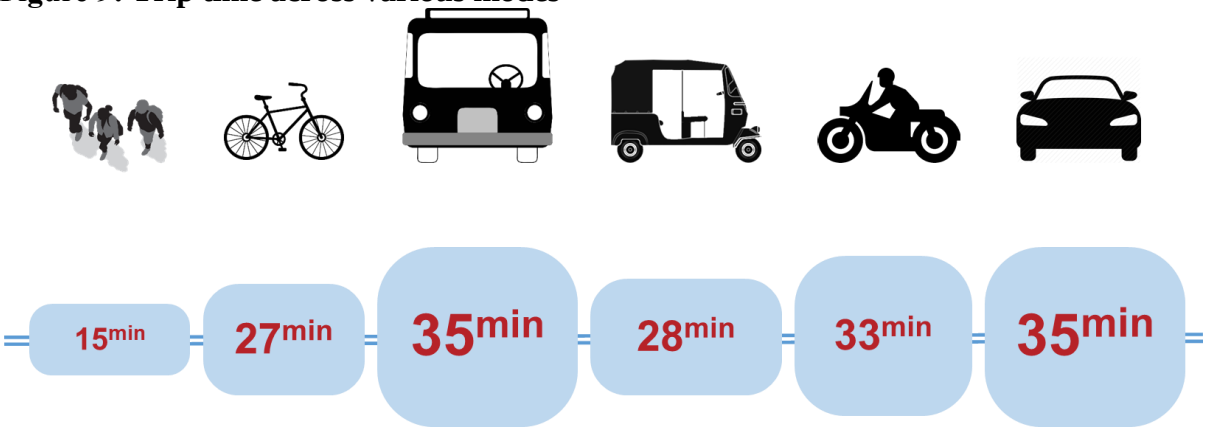


Source: Primary survey, 2017

4.2.3. Trip time

The average trip time for Ahmedabad (West) was found to be 28 minutes. It is interesting to note that people spent an equal amount of time travelling via public transport and motorized four wheeler modes as seen in the figure below.

Figure 9: Trip time across various modes

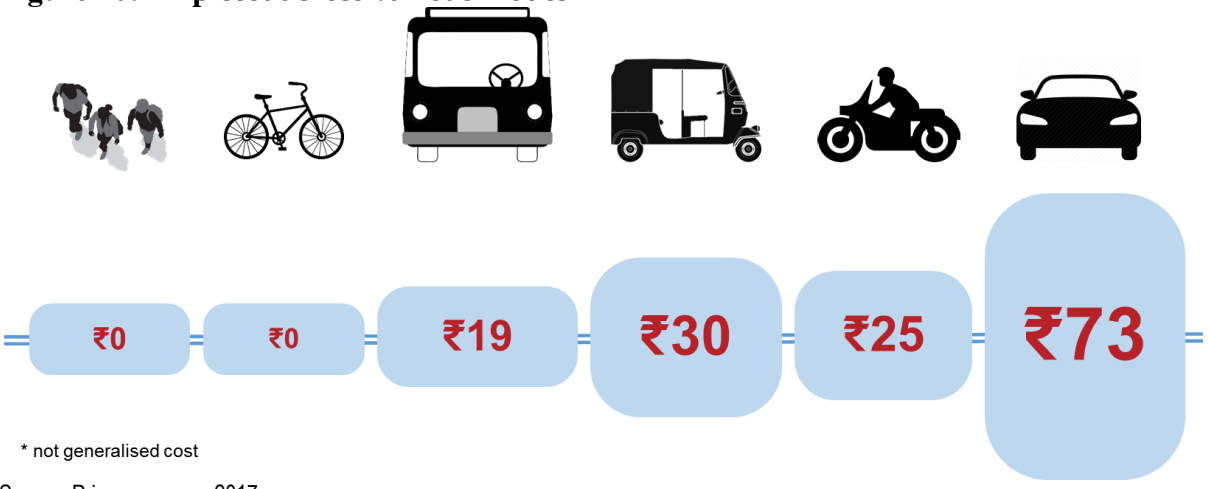


Source: Primary survey, 2017

4.2.4. Trip cost

The average trip cost was found to be 19 rupees which when compared to the average trip time can be considered cheap. A detailed look at the trip costs across modes as shown in the graphic below reveals that four-wheelers tend to spend the most on their travel at 73 rupees on account of high fuel costs. PT users spending 19 rupees for an average trip length of 8.7 kilometres reveals that PT costs are high in the city.

Figure 10: Trip cost across various modes



* not generalised cost

Source: Primary survey, 2017

4.3. Housing and transport scenario

The following table reveals the obvious direct relation between incomes and floor space consumption with their being an increase in the amount of floor space consumed with rising incomes. Overall, it was found that 75 per cent of the population lived in housing unit not exceeding 50 sq m in the floor space area.

Table 14: Consumption of carpet area within income groups

Category (as per GHB guidelines)	0-30 m^2	30-50 m^2	51-94 m^2	> 95 m^2	Total
Less than ₹ 8,000 per month (EWS)	84.2%	8.8%	6.9%	0.0%	**100.0%**
Between ₹ 8,001 and ₹ 20,000 (LIG)	27.2%	56.5%	14.7%	1.5%	**100.0%**
Between ₹ 20,001 and ₹ 40,000 (L-MIG)	3.5%	48.2%	41.6%	6.6%	**100.0%**
Between ₹ 40,001 and ₹ 80,000 (U-MIG)	1.7%	6.8%	55.9%	35.6%	**100.0%**
Above ₹ 80,000 (HIG)	0.0%	0.0%	25.0%	75.0%	**100.0%**
Total	**36.1%**	**39.1%**	**20.6%**	**4.2%**	**100.0%**

Source: Primary survey, 2017

The housing typology most common in Ahmedabad (West) is chawls, row houses and apartments. Tenements are also popular but these are fast converting to more efficient apartments. The following table reveals that with rising incomes, people are more likely to be living in apartments and bungalows in the city.

Table 15: Income group versus housing typology

Category (as per GHB guidelines)	Slums	Chawl	ow House	Tenement	Apartment	Bungalow	Total
Less than ₹ 8,000 per month (EWS)	6.9%	57.7%	26.8%	6.0%	2.5%	0.0%	**100.0%**
Between ₹ 8,001 and ₹ 20,000 (LIG)	3.4%	38.8%	28.9%	10.1%	18.8%	0.0%	**100.0%**
Between ₹ 20,001 and ₹ 40,000 (L-MIG)	0.8%	12.5%	32.3%	11.3%	40.1%	3.1%	**100.0%**
Between ₹ 40,001 and ₹ 80,000 (U-MIG)	0.0%	3.4%	6.8%	23.7%	45.8%	20.3%	**100.0%**
Above ₹ 80,000 (HIG)	0.0%	0.0%	0.0%	75.0%	25.0%	0.0%	**100.0%**
Total	**3.6%**	**36.2%**	**27.9%**	**10.1%**	**20.5%**	**1.7%**	**100.0%**

Source: Primary survey, 2017

The following table reveals an interesting trend with regards to parking behaviour. Owing to lack of space, people from the lower income groups tend to park on public ROWs and as incomes rise, parking shifts to internal lanes of the housing society and later to their own compounds.

Table 16: Income group versus parking behaviour

Category (as per GHB guidelines)	Public ROW	Society Road	Own Compound	Not Applicable	Grand Total
Less than ₹ 8,000 per month (EWS)	31.1%	27.0%	10.5%	31.4%	**100.0%**
Between ₹ 8,001 and ₹ 20,000 (LIG)	45.0%	36.3%	5.6%	13.1%	**100.0%**
Between ₹ 20,001 and ₹ 40,000 (L-MIG)	27.2%	60.3%	10.1%	2.3%	**100.0%**
Between ₹ 40,001 and ₹ 80,000 (U-MIG)	11.9%	59.3%	28.8%	0.0%	**100.0%**
Above ₹ 80,000 (HIG)	0.0%	75.0%	25.0%	0.0%	**100.0%**
Total	**35.6%**	**40.3%**	**9.1%**	**15.0%**	**100.0%**

Source: Primary survey, 2017

The following table shows how parking behaviour changes along with housing typology. People living in the housing typologies generally associated with the lower income groups such as chawls and slums can be seen to be parking on the public ROW while those from the typologies of tenements and apartments tend to park within the society parking and own compound.

Table 17: Housing typology versus parking behaviour

Category	Public ROW	Society parking	Own compound	Total
Chawl	74.1%	15.6%	10.30%	100.0%
Slum	68.8%	25.0%	6.30%	100.0%
Row House	44.4%	45.5%	10.00%	100.0%

Tenement	**20.9%**	**58.3%**	**20.90%**	**100.0%**
Tenement (LIG)	21.2%	75.8%	3.00%	100.0%
Tenement (MIG)	20.8%	55.6%	23.60%	100.0%
Tenement (HIG)	20.0%	20.0%	60.00%	100.0%
Apartment	**3.9%**	**95.2%**	**0.90%**	**100.0%**
Apartment (LIG)	3.6%	96.4%	0.00%	100.0%
Apartment (MIG)	4.4%	94.7%	0.90%	100.0%
Apartment (HIG)	0.0%	80.0%	20.00%	100.0%
Bungalow	0.0%	10.0%	90.00%	100.0%
Total	**41.8%**	**47.4%**	**10.80%**	**100.0%**

Source: Primary survey, 2017

4.4. Willingness to use public transport

The questionnaire also explored the willingness of the people to use PT for trip and as the tables below reveal, qualitative improvements in the environment encouraged people to undertake more trips on public transport modes.

Table 18: BAU scenario: Willingness to use PT for shopping trips (stated preference)

Category	Yes		No		Can't say		Total	
	No.s	%	No.s	%	No.s	%	No.s	%
Slum	13	33%	24	62%	2	5%	39	**100%**
Chawl	93	24%	254	67%	33	9%	380	**100%**
Row House	80	28%	190	66%	17	6%	287	**100%**
Tenement	17	18%	71	75%	7	7%	95	**100%**
Tenement (LIG)	3	10%	25	86%	1	3%	29	**100%**
Tenement (MIG)	14	25%	37	65%	6	11%	57	**100%**
Tenement (HIG)	0	0%	9	100%	0	0%	9	**100%**
Apartment	27	13%	175	85%	5	2%	207	**100%**
Apartment (LIG)	21	19%	88	79%	2	2%	111	**100%**
Apartment (MIG)	6	7%	82	90%	3	3%	91	**100%**
Apartment (HIG)	0	0%	5	100%	0	0%	5	**100%**
Bungalow	0	0%	20	100%	0	0%	20	**100%**
Total	**230**	**22%**	**734**	**71%**	**64**	**6%**	**1,028**	**100%**

Source: Primary survey, 2017

Table 19: TOD scenario: Willingness to use PT for shopping trips (stated preference)

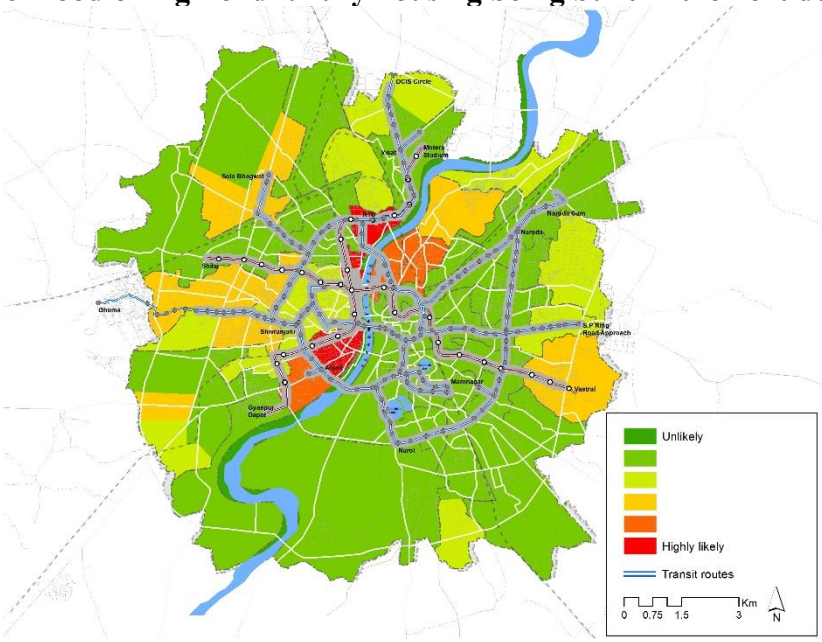
Category	Yes		No		Can't say		Total	
	No.s	%	No.s	%	No.s	%	No.s	%
Slum	15	38%	23	59%	1	3%	39	**100%**
Chawl	139	37%	227	60%	14	4%	380	**100%**
Row House	131	46%	152	53%	4	1%	287	**100%**
Tenement	23	24%	71	75%	1	1%	95	**100%**
Tenement (LIG)	7	24%	22	76%	0	0%	29	**100%**
Tenement (MIG)	16	28%	40	70%	1	2%	57	**100%**
Tenement (HIG)	0	0%	9	100%	0	0%	9	**100%**
Apartment	28	14%	174	84%	5	2%	207	**100%**
Apartment (LIG)	23	21%	86	77%	2	2%	111	**100%**
Apartment (MIG)	5	5%	83	91%	3	3%	91	**100%**
Apartment (HIG)	0	0%	5	100%	0	0%	5	**100%**
Bungalow	0	0%	20	100%	0	0%	20	**100%**
Total	**336**	**33%**	**667**	**65%**	**25**	**2%**	**1,028**	**100%**

Source: Primary survey, 2017

4.5. Developers' inputs

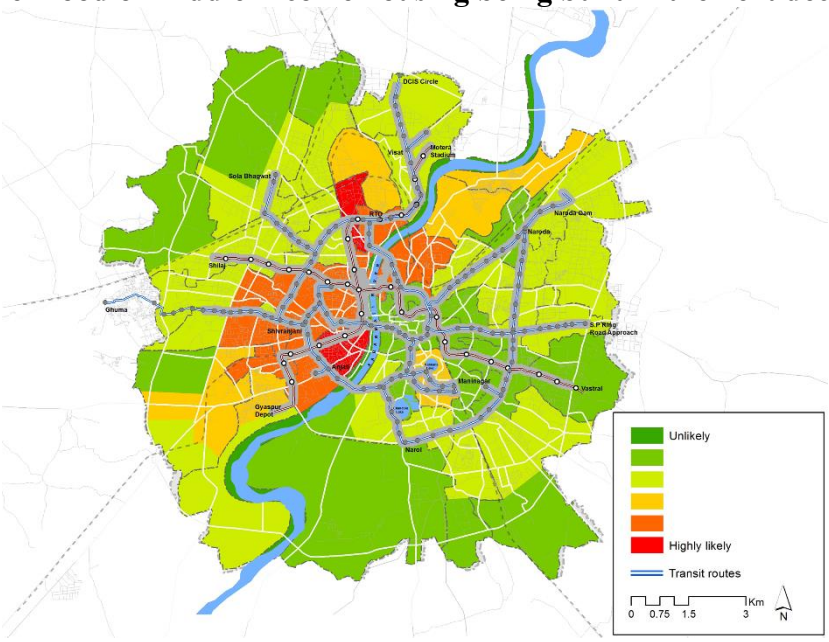
A wide variety of developers were consulted to understand their take on how the housing market would behave in the coming decade. The following maps reveal the likelihood of a) high-end luxury housing, b) middle-income housing, and c) affordable housing coming up in various parts of Ahmedabad.

Figure 11: Likelihood of high-end luxury housing being built in the next decade



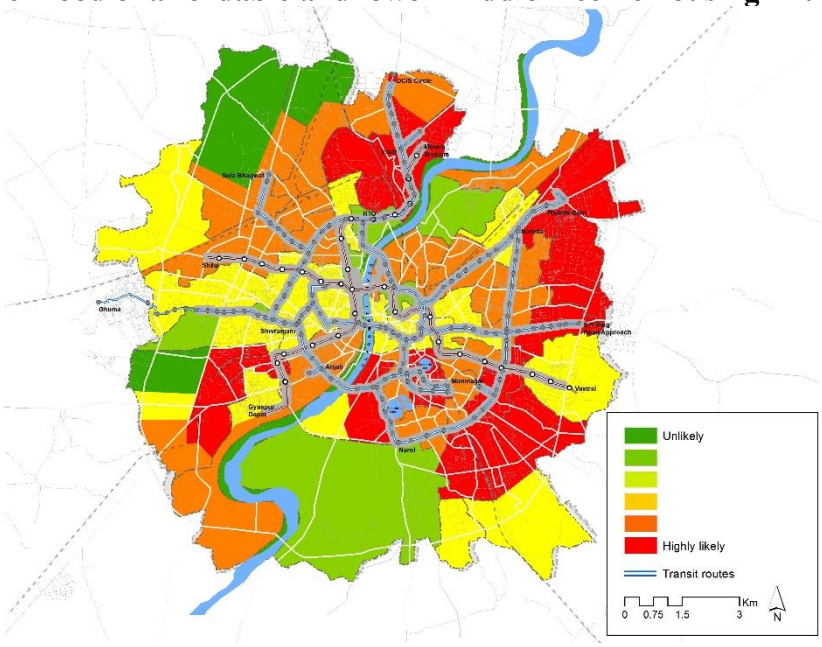
Source: Survey of developers, 2017

Figure 12: Likelihood of middle-income housing being built in the next decade



Source: Survey of developers, 2017

Figure 13: Likelihood of affordable and lower-middle income housing in the next decade



Source: Survey of developers, 2017

4.6. Model results

The three scenarios developed for the purpose of testing the model described in Section 3 are described below. Vehicle population projections are based on past trends and with inputs from literature. The prediction of income groups is based on secondary literature while floor space calculations are based on the DCRs (FSI, road widths linked DCRs) as well as developers' inputs on typologies in different areas.

Table 20: Describing the scenarios

Parameter	Particulars	Business-as-Usual 2031	Ahmedabad TOD 2031	Low-carbon TOD 2031
Motor vehicle ownership	Vehicles per 100 people	36	60	40
Household income	EWS	27.2%	17%	17%
	LIG	45.6%	37%	37%
	MIG	26.9%	42%	42%
	HIG	0.3%	4%	4%
Housing typology	Chawl	36.2%	16.0%	16.0%
	Slum	3.6%	1.0%	1.0%
	Row House	27.9%	15.0%	15.0%
	Tenement	10.1%	5.5%	4.0%
	Tenement (LIG)	3.2%	2.0%	2.0%
	Tenement (MIG)	6.1%	3.0%	1.9%
	Tenement (HIG)	0.9%	5.0%	0.1%
	Apartment	20.5%	45.0%	63.3%
	Apartment (LIG)	10.3%	15.0%	25.0%
	Apartment (MIG)	9.7%	30.0%	30.0%
	Apartment (HIG)	0.4%	16.8%	8.3%
	Bungalow	1.7%	0.7%	0.7%

Table below shows the probability of use of various modes for every unit increase in supply of a certain housing typology. The table reveals that for every unit increase in the availability of row houses, the probability of use of public transit increases by 1.24 times. Similarly, decrease in vehicular ownership and increase in the availability of LIG tenements can have positive impacts on the ridership of AMTS and BRTS.

Table 21: Probability of use of modes rises/falls by Exp(B) factor

Particulars	Auto choice		Cycle		PT Choice		2W Choice		4w Choice		Walk choice	
	B	*Exp(B)*	*B*	*Exp(B)*	*B*	*Exp(B)*	*B*	*Exp(B)*	*B*	*Exp(B)*	*B*	*Exp(B)*
Chawl	0.13	1.14	0.74	2.09	0.01	1.01	0	1	-1.19	0.3	-0.09	0.92
Row House	-0.09	0.91	-0.36	0.7	0.21	1.24	0.4	1.49	-1.11	0.33	-0.05	0.95
Apartment (LIG)	0.18	1.2	-1.15	0.32	-0.39	0.68	1.28	4.87	-1.71	0.18	-0.55	0.35
Apartment (MIG)	-1.49	0.23	-1.81	0.16	-2.37	0.09	1.18	5.95	-0.18	0.84	-0.99	0.05
Tenement (LIG)	1.13	3.09	-0.59	0.56	0.14	1.15	0.55	1.73	-2.06	0.13	0.52	1.68
Tenement (MIG)	-0.15	0.86	-0.49	0.61	-1.25	0.29	0.8	2.23	-0.49	0.61	-0.38	0.68
Distance to city centre	0.01	1.01	-0.1	0.9	0.11	1.11	0.02	1.02	0.11	1.12	-0.96	0.26
1/Veh. Availability	1.45	4.27	-2.3	0.1	1.49	2.43	-3.79	0.02	-1.8	0.16	1.66	5.25
Constant	-3.67	0.03	-2.09	0.12	-3.02	0.05	-0.32	0.73	-2.34	0.1	2.01	7.5
-2 Log likelihood	945.416		1271.346a		1896.681a		3289.176a		1191.143		1376.582	
Cox & Snell R Square	0.024		0.05		0.057		0.248		0.074		0.466	
Nagelkerke R Square	0.084		0.132		0.114		0.33		0.195		0.702	

** All B value have significance level less than 0.05*

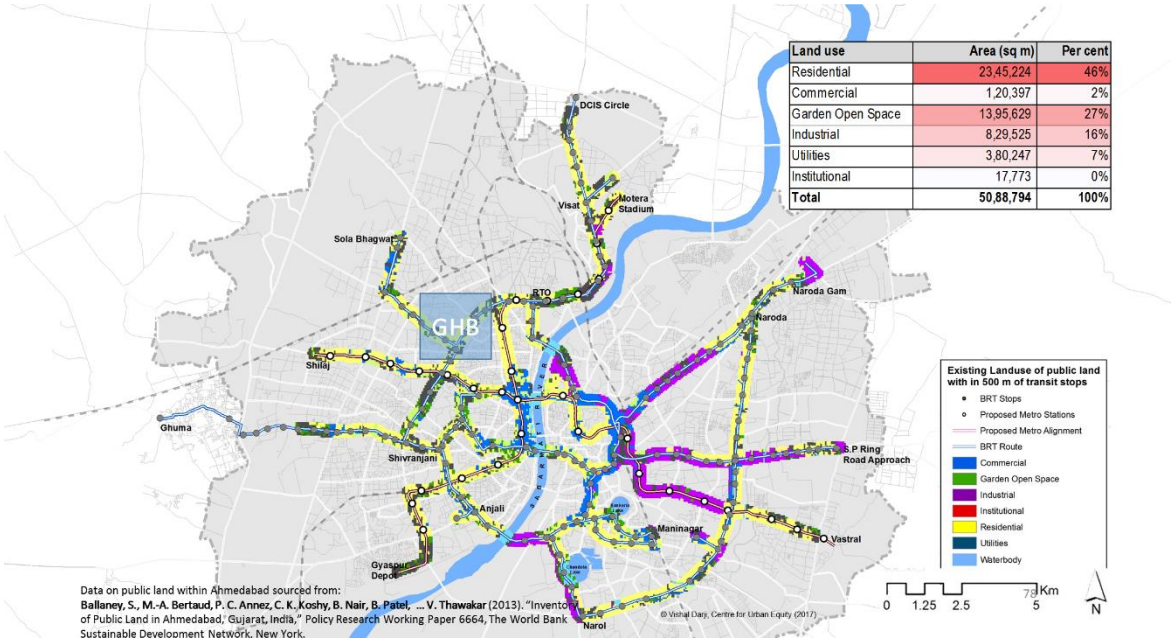
4.7. Discussion

In order to make TOD work in Ahmedabad and elsewhere, careful interventions are needed in but not limited to the following aspects.

4.7.1. Affordable housing

The principle idea that many researchers agree on is that transit needs to go to those that are more likely to use it. However, it is seen in the case cities that while transit routes are planned, speculative markets take over due to which the poor residing in the core city, often along the proposed alignments are forced to move out and are replaced by high-end luxury housing or commercial land use. These uses are seldom suited to the best interests of the transit, whether it be metro rail or BRTS. There is a need for the state to intervene in the market in a way to increase the supply of LIG apartments and low-cost, affordable housing. Experts and developers agree that land-related cost is the most important game-changing component that contributes towards making a housing scheme affordable.

Figure 14: Public land within 500 m of transit stops under various land uses



The above map shows public land in close proximity to the transit corridors in Ahmedabad (West). If these lands could be used for social housing as several European cities have done, it would be possible for the state to ensure that those that are more likely to use transit stay in proximity of transit stations.

4.7.2. Parking as travel demand management

There is potential for use of parking regulations as a means of achieving TOD objectives. Zoning regulations often dictate the number of parking slots available off-street. Traditionally, there has been a tendency to over-supply parking both off-street and on-street. What is worse is that the on-street parking available in Indian cities is often cheaply available, if not free of cost. These tend to encourage the use of motorized vehicles while discouraging the shift to transit. Therefore, the need to disincentivize driving by making parking chargeable in line with real-time market rents.

Figure 15: An example of good parking management, Bengaluru

4.7.3. Walkable neighborhoods and commercial areas:

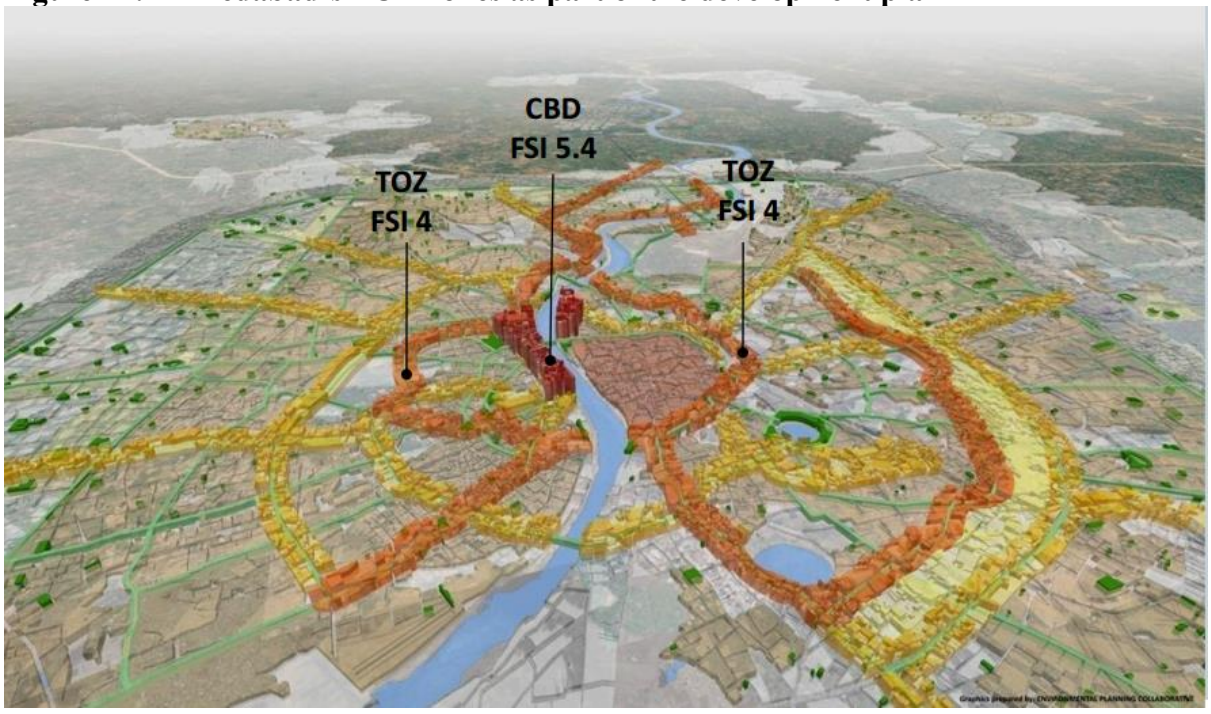
Mainstreaming urban design would help create walkable and cycle-able neighbourhoods that would serve the first-mile and last-mile connectivity needs of transit. Neighbourhoods and commercial districts that prioritize the pedestrian and the cyclist over motor vehicles through effective design of the public realm results in higher footfalls which can be mutually beneficial for all parties involved.

Figure 16: An example of walkable neighbourhoods, Bengaluru

4.7.4. Governance

Make TOD part of statutory plans and infrastructure provision goes a long way in getting all stakeholders to come to the table and making their concerns known. Ahmedabad's development plan is a case in point. It has not only made the developers interested in getting the TOD fructify, but it has also through the local area plan mechanism, presented a way for achieving the TOD objectives.

Figure 17: Ahmedabad's TOD zones as part of the development plan



4.7.5. Finance

TOD financing needs innovative tools and incentives so as to ensure that transit becomes viable and serves its ends. Land-value capture can be used to fund effective interventions towards making TOD work.

5. Conclusion

This paper attempted to draw upon the linkages between transit riders and built form in the specific case of Ahmedabad (West) to understand what kind of built form interventions help increase transit ridership. The model used as part of the research revealed the need for cities to invest in affordable housing and parking management while creating TOD-friendly walkable neighbourhoods. Additionally, through making TOD plans as part of statutory planning mechanism, the mainstreaming of TOD can be achieved which would help in achieving TOD objectives. At the same time, the paper highlighted the need for evolving innovative tools for financing TOD in order to achieve TOD objectives. Overall, there is a need to look at TOD plans in unison rather than in silos as several cities seem to be doing in order to achieve TOD objectives.

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