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PROMOTING LOW CARBON TRANSPORT IN INDIA

Low – carbon Comprehensive Mobility Plan: Rajkot

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Foreword

Rajkot, like many other cities in India continues to grow rapidly, with expansion in economy, spatial extent and population. This has led to fast urban growth and urbanization related pressure on infrastructure including urban transport. Even though the present emission levels in Rajkot are within prescribed standards, there is a growing concern about vehicular emissions.

Low-carbon Comprehensive Mobility Plan for the city of Rajkot is one of the initiatives that we have supported with the overall aim of achieving sustainable development. The plan integrates transport, land use and environment for current times as well as models it for the future.

The strategies proposed in the report to support walking, bicycling and public transport are very relevant and well-founded. This has been possible as the consultants have correct and concurrent planning methods and were able to prepare a transport model for the city which has enabled decision-making in the direction of sustainable transport in Rajkot.

It is a pleasure that Rajkot was selected for this initiative by United Nations Environment Programme (UNEP). We are grateful to CEPT University for carrying out the study in such detail, guiding us and driving the future urban and transport development of Rajkot.

Mr. Ajay Bhadoo IAS **20-April-2014**
Municipal Commissioner
Rajkot, Gujarat.

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Last, but not least, we would like to thank the Ministry of Urban Development, Government of India for appreciating this 'Low-carbon Comprehensive Mobility Plan' and including it in the revised toolkit for preparation of comprehensive mobility plans.

Authors

Preface

A low-carbon mobility approach requires clear and innovative thinking about city futures in terms of the reality (what is already there), desirability (what we would like to see), and the role that transport can (and should) play in achieving inclusive sustainable cities. The increasing dependency on motorised vehicles and higher risks to non-motorised and public transport users is restricting the safe mobility and accessibility of all urban residents and specifically people from the lower income group. This is threatening the urban environment and contributing to growing emissions of CO_2 and other greenhouse gases. There is a need for planning that can ensure safe mobility and accessibility for people irrespective of their socio-economic background in a way that does not compromise the environment. India, in its National Action Plan on Climate Change (NAPCC) (2008), has identified sustainable urban planning as one of the levers for reducing emissions. Ongoing initiatives at the city-level that support such planning efforts are the Comprehensive Mobility Plans (CMPs), which are being made a prerequisite for support under the Jawaharlal Nehru National Urban Renewal Mission (JnNURM).

The Ministry of Urban Development (MoUD), Government of India (GoI) provides guidelines for preparing CMPs (Ministry of Urban Development & Asian Development Bank, 2008). The CMPs submitted by cities and approved by MoUD have, however, been unable to address the effectiveness of various strategies in achieving sustainability goals. Further, the CMPs consistently lack strategies for enabling safe and secure mobility and accessibility for all groups of people (TERI, 2011). Detailed analysis of the impact of transport projects on sustainability and meeting the travel demand of all city residents, including the poor, the underprivileged and women, is missing in the CMPs. Sometimes, the CMPs assume that the benefits of large-scale projects percolate equally to everyone in society, irrespective of gender, income or housing conditions. The CMP methodology lacks an approach for the quantification of CO_2 mitigation from the various scenarios. The LCMP was envisaged as an effective decision-making tool that would develop low-carbon mobility scenarios, identify projects that would pave the way, and earmark JnNURM funding for implementation.

The UNEP Transport Unit (www.unep.org/transport) in Kenya, UNEP DTU Partnership (www.unepdtu.org) in Denmark, and partners in India embarked on a new initiative to support low-carbon transport in India. The three-year project was funded under the International Climate Initiative of the German Government, and was designed in line with India's NAPCC. This project aimed to address transportation growth, the development agenda and climate change issues in an integrated manner by catalysing the development of a Transport Action Plan at the national-level and Low-Carbon Mobility plans at the city level. Key local partners included the Indian Institute of Management, Ahmedabad, Indian Institute of Technology, Delhi, and CEPT University, Ahmedabad. Cooperation between the Government of India, Indian institutions, UNEP, and the Government of Germany assisted in the development of a low-carbon transport framework resulting in the formulation of the Low-carbon Comprehensive Mobility Plan (LCMP).

The LCMP methodology was prepared by IIT Delhi, IIM, Ahmedabad, and CEPT University, Ahmedabad. This methodology has been applied in preparing LCMPs for three cities: namely Rajkot, Vishakhapatnam and Udaipur, produced by CEPT University, iTrans and the Urban Mass Transit Company (UMTC) respectively. All three cities had different experiences during the study, and their findings were incorporated into the plan. The proposed LCMP methodology, incorporated into the revised CMP (Ministry of Urban Development, 2014), amends the existing approach and methodology of preparing the CMP. The LCMP adds the additional indicators of inclusiveness and measurements of carbon emissions from transport to the existing methodology of CMP prepared by the MoUD to make urban transport inclusive and low-carbon, and thus truly sustainable.

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Abbreviations

BAU	Business as Usual
BRT	Bus Rapid Transit
CAGR	Compound Annual Growth Rate
CNG	Compressed Natural Gas
EXP	Exponential
EWS	Economically Weaker Section
GPCB	Gujarat Pollution Control Board
HB	Home Based
HH	House Hold
IPT	Intermediate Public Transit
LCMP	Low-carbon Comprehensive Mobility Plan
LCV	Light Compact Vehicle
LNG	Liquefied Natural Gas
MTW	Motorised Two-Wheeler
NH	National Highway
NHB	Non-Home-Based
NMT	Non-Motorised Transit
OD	Origin Destination
PT	Public Transit
RMC	Rajkot Municipal Corporation
RTO	Regional Transport Office
ROW	Right of Way
RUDA	Rajkot Urban Development Authority
SEG	Socio-Economic Group
TAZ	Traffic Analysis Zone
TERI	The Energy and Resources Institute
TMC	Turning Movement Counts
UNEP	United Nations Environmental Programme

Executive Summary

Cities in fast developing countries like India continue to grow rapidly in terms of their economies, spatial extents and populations, making for fast urban growth and urbanisation (Adhvaryu, 2010). Urbanisation has in turn led to an increase in the number of vehicles and energy consumption. The travel trends of previous decades indicate that the use of bicycles and public transport has declined, while the share of two-wheelers and cars has increased. This has significantly contributed to the consumption of fossil fuels by the transport sector, as well as resultant air pollution from vehicular emissions. The transport sector in India accounts for about 33 per cent of total oil consumption in the country (World Energy Council, 2011), of which a large share is consumed for intra-urban trips (Infrastructure Development Finance Company et al., 2006; TERI, 2006). Thus, there is a need for strategic intervention in terms of policies or planning methods in addition to reducing emissions and energy conservation techniques.

In India, after 2005, mobility issues in urban areas have been addressed by the preparation of mobility plans, which are detailed in a toolkit prepared by the Ministry of Urban Development, the Government of India and the Asian Development Bank (Ministry of Urban Development & Asian Development Bank, 2008). Even though these Comprehensive Mobility Plans (CMP) have assisted cities in planning and channelling resources and investment, they have not be able to address issues related to inclusiveness, land use transport integration and promotion of non-motorised and public modes of transport. The CMPs consistently lack the provision of strategies to enable safe and secure mobility and accessibility for all groups of people (TERI, 2011). Further, the CMP methodology lacks an approach to CO_2 mitigation through the development of various scenarios. The Low-carbon Comprehensive Mobility Plan (LCMP) focuses on the reduction of greenhouse gas (GHG) emissions without compromising the accessibility and mobility[1] needs of all people. LCMP incorporates into the existing methodology of CMP the additional factors of inclusiveness and measures that would lead to lower carbon emissions from transport.

Preparation of LCMP

Rajkot is one of three Indian cities participating in UNEP's project on 'Promoting Low-Carbon Transport' as a case study for preparation of a Low-carbon Comprehensive Mobility Plan (LCMP). The LCMP, with a horizon period of twenty-years (2011-2031), would consider the development of a Municipal Corporation area as well as the villages and industrial areas coming up around the city. Thus the Rajkot Urban Development Authority (RUDA) area has been considered as the study area. The twenty-year horizon period has been divided into three sub-horizons that are considered for

[1] Accessibility is the extent to which the land use transport system enables individuals to reach activities or destinations by means of a (or a combination of) transport mode(s). On the other hand, mobility is a measure of physical movement of people and goods from origins to destinations.

planning programs and projects. It includes a five-year horizon period (2011-2016) for short-term plans for the RMC area, and a ten-year period (2011-2021) for medium-term interventions for the RMC and outgrowth areas. The RUDA area consists of 483km^2, which includes the 104km^2 area of Rajkot Municipal Corporation (RMC). The RMC consists of 59 wards, which were further divided into 394 smaller units called Traffic Analysis Zones (TAZs), each covering an average area of 0.72km^2.

The LCMP was prepared in four major steps: analysis of the existing situation; development of 'Business as Usual' (BAU) and alternate scenarios; prioritisation of a mix of infrastructure and technologies; and a proposal of policy measures, projects and financial requirements to achieve a low-carbon scenario. The first step involved the study of the existing urban and transport conditions, which was done by analysing the existing city profile, land use pattern, transport network, and travel patterns, and by measuring the access to important transport infrastructure and the access the transport system provides to different activities. The second step was the development of the BAU and alternate scenarios. Urban growth was simulated for five and ten-year periods, and for the year 2031. These periods correspond to estimates of transport mobility scenarios for short-term demand (five years), medium-term demand (ten years) and demand of the horizon year of 2031. A transport demand model was developed using the four-stage urban transport demand model, which was modified to incorporate the influence of built form (land use and transport infrastructure) and socio-demographic indicators on travel behaviour, trip generation, choice of mode and route choice (explained in detail in Chapter 5).

In the BAU scenario, transport demand and mobility patterns were analysed assuming the city follows past trends, whereas in alternate scenarios, it was assumed that interventions were phased in terms of land use structure, Non-Motorised Transport (NMT), Public Transport (PT) infrastructure and adaptation of advanced technologies. Four alternate scenarios were thus developed. In the first scenario, the influence of Land Use (LU) interventions on mode choice travel behaviour and the overall mobility scenario in the city was analysed. In the second scenario, the study was expanded to the land use interventions aspects of infrastructure supporting NMT, and how they influence travel behaviour and transport demand. In the third scenario, in addition to the LU and NMT intervention, PT strategies were developed and their influence on the mobility patterns in the city was analysed. For all four scenarios (BAU + 3 alternate scenarios), the impact on the environment and on health and safety was also studied. A fourth alternate scenario was also analysed that considered the environmental benefits of using alternate fuel. The next step involved a prioritisation choosing and prioritizing from the interventions, which was done in a workshop with the stakeholders in the city of Rajkot. The last step involved the identification of projects and financial requirements for the scenarios, including short, medium and long-term strategies.

The LCMP incorporated both primary and secondary data in its preparation. Data on socio-demographic and travel behaviour were collected through household survey. Inventory surveys were conducted for: pedestrian, NMT, cycle-rickshaw and auto-rickshaw infrastructure; classified volume counts for traffic volume; other surveys including a petrol pump survey, speed and delay survey, air and noise level surveys, etc. Secondary data on public transport, traffic safety, pollution, emission, and registered vehicles were provided by RMC, Rajkot police, the Regional Transport Office (RTO) and Gujarat Pollution Control Board (GPCB).

An Introduction to Rajkot

Rajkot, the fourth-largest city in the state of Gujarat, has experienced significant growth in recent years. In the last two decades, the urban population has more than doubled to around 1.4 million in 2011, and is expected to reach about 3 million in 2031. Since over half the city's population is in the productive age category, the city is expected to continue to grow rapidly in the future. The city is divided into 23 wards with an average density of 12,735 people/km^2. Densities in the inner city are much higher than the rest of the city. The central portions of the city are dense and have mixed land uses, and the majority of residents live in the central area of the city. The residences in the central portion of the city comprise of row houses and low-rise apartments, packed closely in a fine-grain urban fabric. The newer developments are typical of high-rise apartments, being loosely packed alongside wider roads. The major commercial area remains in the old city, and along the major radial and connecting radial in the outer parts of the city. Industries are located in the Bhaktinagar Industrial Estate and Aji Industrial Estate, which were developed by the Gujarat Industrial Development Corporation (GIDC), while the Sorathiawadi plot area was developed at a later stage.

Present travel infrastructure and travel patterns

The total road network length in the study area is approximately 2291km, of which the RMC area accounts for 1799km and the RUDA area 492km. The road network in the RMC area is very dense, particularly in the old city area, where the network does not follow a particular pattern like the regular grid networks in the newer developments. The city roads form a ring-radial pattern, with six radials and one major ring. Most of the city roads have an intense ribbon development of commercial activities, forming a mixed use type of development along the arterials as well as some sub-arterials. Roads are narrow in certain places with varying widths, and the presence of bottlenecks constrains the free flow of motorised vehicles. Most city roads (97 per cent) have a right-of-way (ROW) of up to 30m. The average speed of all modes in the city is 16km/hr, and is much lower in the old city area due to delays from narrow streets and people walking on the streets. Most arterial roads have average speeds higher than 20km/hr. The local streets have an average speed of 10km/hr due to a number of intersections after every kilometre, which makes them more pedestrian and bicycle-friendly.

Footpaths are present on all major roads in the city, but in most areas the width is less than 1.5m and is encroached upon by street furniture, telephone boxes, trees, make-shift shops etc. Rajkot has a dedicated cycle lane on one stretch along the Bus Rapid Transport (BRT) corridor, but it is difficult to use bicycles on most city roads. City buses previously operated by RMC and a private operator (VTCOS) failed, and therefore the majority of public transport requirements are met through auto-rickshaws[2]. The Bus Rapid Transit (BRT) system is under construction using JnNURM funding; however only a 10.7km stretch is currently operational.

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[2] By December 2013, RMC had recommenced city bus operations through Rajkot Mass Transport Service (RMTS). Since these are initial days, its effect on the mode share in the city is hard to tell.

An average individual residing in Rajkot makes 1.3 trips per day, and when walk trips are excluded, it comes down to 0.81 trips/day. The average trip length for the city is approximately 3.8km, inclusive of walk trips. Walking and two-wheelers account for a little over one-third each of all trips, followed by auto-rickshaws (11 per cent), bicycles (10 per cent), buses (3 per cent), cars (2 per cent) and others (1 per cent). Non-motorised trips account for nearly half of all trips (48 per cent). A little over half (53 per cent) of all trips are work trips, while educational trips account for 26 per cent, followed by shopping (16 per cent), religious (4 per cent) and other trips (1 per cent). Over 25 per cent of road accidents reported in Rajkot over the past five years involved people using NMT.

Business as Usual scenario

Two urban development scenarios are analysed: the BAU scenario and the Sustainable Strategy (SS) scenario. In both scenarios, socio-economic projections for the city were kept constant. Population, vehicular ownership and transitions in land use were projected for the years 2016, 2021 and 2031 with the base year taken as 2011, which were fed into the transport demand model. The model, which involves four steps (trip generation, trip distribution, mode choice and assignment), was run using data disaggregated by social group, gender and purpose, while assignment was done separately for NMT and PT modes. Environment modelling was conducted using Sim-Air software and these travel projections. Emissions were based on the number of vehicles and other factors related to the type of vehicles, such as the type of engine, type of fuel, age of the vehicle, kilometres travelled by the vehicle, efficiency of vehicle, etc.

In the BAU scenario, by 2031 it is estimated that the share of trips made by private automobiles (two-wheeled motorised vehicles and cars) will be 57 per cent, about 29 per cent will use NMT, and 13 per cent will use public transport (auto-rickshaw and bus). Although there was no bus (PT) service in Rajkot when the study was conducted, it is assumed that the RMC will be able to operate PT on the present routes in the next five years. The average trip is estimated to increase to 6.0km, with an average travel time of 27 minutes (significantly higher than the present average), leading to an estimated 2,04,218 vehicle kilometres travelled, and consequently, estimated CO_2 emissions of 29.7 million tonnes.

It was found that the majority of trips are made from the western side of the river, especially from the southern side of the city along Gondal Road. Trip rates are high in the old city area (locations with high residential density), and the number of trips made outside the RMC area are not very high. Because of the presence of commercial and industrial areas, a high concentration of trips are attracted to the city core, as it is the commercial hub of the city and near the GIDC area (Atika industrial area, Mavadi Road area and near the marketing yard). By 2031, the BAU scenario shows that most of the road network will be congested and have bottlenecks, necessitating road infrastructure improvements to support the mode choices individuals are expected to make in Rajkot in the future.

Low-carbon scenario

The Low-carbon Scenario (LCS) aims to lower carbon emissions by shifting to non-motorised modes of transport and changing land use patterns, and thereby improving accessibility to destinations. The types of interventions or strategies this study considers are land use, NMT, PT and technological interventions. In the LCS, 'stated preference' surveys[3] were conducted alongside household surveys to understand people's demand. This provided insight into the mode that would be used if the current mode were not available, and the preferred mode for each purpose if walk, cycle and bus infrastructure were in place. A short question was also asked, giving scenarios for improvements of infrastructure. This resulted in new mode choice probabilities, which were assigned to routes. This exercise resulted in estimating the demand for transport infrastructure on the city's network. The high-demand routes were selected as the corridors of infrastructure development in the city.

For achieving low-carbon emissions through lower mobility and higher accessibility, it is important to integrate land use and transportation. The identification of high demand travel routes led to the selection of nodes and corridors of development for controlling the sprawl of the city. The strategy behind this is to plan the densities and diversities of land use, supporting lower mobility and, in turn, lower carbon emissions. Concentrating developments in these nodes and corridors can help control urban sprawl and bring opportunities closer to people. Thus, travel behaviour can be changed by running the land use simulation and allotting new commercial and residential densities, as well as determining a job-housing mix to concentrate development near the centre. Combining the improvement in the road infrastructure and the land use interventions gives the integrated land use transport plan. However, for lowering carbon emissions, it is important to suggest changes in the type of fuel and vehicles to reduce overall transport emissions. All these four strategies (named land use strategy, NMT strategy, PT strategy and technology strategy) are modelled to discover the best strategy for the Low-carbon Comprehensive Mobility Plan.

Land use strategy

Analysing the relationship between land use and the manner in which individuals travel in Rajkot, it was found that accessibility to jobs, polycentric development and a balanced job-housing ratio encourage individuals to travel and use NMT and PT modes. Thus, a strategy is proposed that ensures increased accessibility to jobs and polycentric development with major and minor nodes. The major nodes would have a Floor Space Index (FSI) of 4 and minor nodes an FSI of 2.5. These nodes will have a good land use mix, ensuring a balanced job-housing ratio. As a result of this strategy, it was projected that the share of the public transport mode would increase to 22 per cent, and the estimated average trip length would drop to 3.9km from the 6.0km of the BAU, resulting in 36 per cent lower CO_2 emissions.

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[3] Stated preference surveys were conducted to identify estimates of relative utility weights, rather than absolute values, avoiding the problem of stated intention.

Non-motorised transport strategy

In the NMT strategy, it was proposed that on all major roads, and on roads where demand for walking is high, footpaths greater than 2m wide will be provided. By doing so, it is estimated that the NMT share will hold its current share of 48 per cent going into 2031, rather than decrease to 29 per cent as under the BAU scenario. Potential dedicated bicycle routes were identified in areas along all major roads where individuals stated they would prefer using bicycles if dedicated corridors were provided. As a consequence, the bicycle share in LCS is projected to increase from the current five per cent to 12 per cent. Overall, it was found that a significant number of trips (including all short trips, educational trips and some of the work trips) would shift to NMT, thus decreasing vehicle use and in turn, reducing CO_2 emissions by 41 per cent in comparison to the BAU scenario.

Public transport strategy

A three-stage approach was adopted for the public transport strategy. This included the use of lower-capacity buses on routes that have low public transport demand, city buses on roads with sufficient demand, and BRT on corridors where the city bus service is unable to cater to demand even if it is run at a higher frequency. But adopting this strategy, it was projected that the combined trip share of public transport, including BRT would be 29 per cent, and the motorised mode would significantly decrease to 27 per cent. This strategy results in a 47 per cent drop in CO_2 emissions in comparison to the BAU scenario.

Low-carbon Comprehensive Mobility Plan

The Low-carbon Comprehensive Mobility Plan aims to achieve improved air quality, fewer accidents, improved accessibility and lower carbon emissions from the transport sector. This will be achieved by promoting greater use of non-motorised transport and the public transport system. The LCMP proposes to modify the General Development Control Regulations (GDCR) and Development Plan (DP) for higher residential and commercial densities and higher job-housing ratios at identified major nodes and corridors. Design elements include: higher intersection density; commercial or retail on the ground floor and first floor with residential on the upper floors to make streets active and safer; and designs of bus stations for all, including low income groups and the disabled. A pedestrian plan consisting of a 180km-long network, a bicycle network and a public transport network has also been identified through the use of a demand-based model.

In the short term (i.e. by 2016), the priority will be NMT infrastructure projects such as footpaths and cycle lanes, followed by PT investments. Investments in 2016 are estimated to cost INR 4,474 million, of which NMT and PT account for 23 per cent and 63 per cent respectively. In the medium term (i.e. by 2021), emphasis will be on developing BRT, as well as other investments such as footpaths, junction improvements, etc. These investments are expected to cost INR 3,809 million, of which PT would account for 83 per cent. Long-term projects (i.e. for 2031) include significant spending on developing new roads and BRT, as well as other infrastructure. This phase is expected to cost INR 11,274 million, of which road works and PT would account for 33 per cent and 63 per cent respectively.

Chapter 1: Introduction

The chapter gives a brief idea of the project, encapsulating the rationale behind it as well as laying down the project aim, objective and the methodology used to prepare the 'Low-carbon Comprehensive Mobility Plan'[4] for the city of Rajkot. This chapter is divided into eight sections. The first section gives a background to the study, followed by the planning area and horizon of the LCMP, the vision, objectives and the methodology of the LCMP, followed by a delineation of the study area, data collection approach and a conclusion.

1.1. Background

Cities in fast developing countries like India continue to grow rapidly in terms of their economies, spatial extents and populations, making for fast urban growth and urbanization (Adhvaryu, 2010). Urbanisation has in turn led to an increase in the number of vehicles and energy consumption. The travel trends of previous decades indicate that there is a decline in the use of bicycles and public transport, but on the other hand, an increase in the share of two-wheelers and cars. These trends have significantly contributed to consumption of fossil fuels by the transport sector, and also to air pollution resulting from vehicular emissions. Consequently, the transport sector is also the largest consumer of fossil fuels and a big contributor to air pollution, as land transport accounts for roughly 73 per cent of the sector's total CO_2 emissions (Sundar et al., 2010). The transport sector alone accounts for around 45 per cent of total oil consumption in the country, of which a large share is consumed for intra-urban trips (Infrastructure Development Finance Company et al., 2006; TERI, 2006). Thus, there is a need for strategic intervention in terms of policies or planning methods to reduce emissions and conserve energy.

In India, after 2005, mobility issues in urban areas have been addressed by the preparation of mobility plans. The structure of these mobility plans has been elaborately explained in the toolkit prepared by the Ministry of Urban Development, Government of India and Asian Development Bank (Ministry of Urban Development & Asian Development Bank, 2008). Even though these Comprehensive Mobility Plans (CMP) have helped cities to plan and channel resources and investment, they have not been able to address the issues related to inclusiveness, land use transport integration and measures that would promote the use of non-motorised modes and public modes of transport. The CMPs consistently lack strategies to enable safe and secure mobility and accessibility for all groups of people (TERI, 2011). Further, the CMP methodology does not include a CO_2 mitigation approach or modelling of alternate scenarios. LCMP emphasises the reduction of greenhouse gas (GHG) emissions without compromising the accessibility and mobility needs of all people.

[4] The Low-carbon Comprehensive Mobility Plan (LCMP) is a revision of the CMP. It takes a more scientific and disaggregated approach for understanding the transportation demand and strategizing interventions of NMT and PT infrastructure, and integrating it with land use to reduce emissions from the city's transport sector.

LCMP incorporates into the existing methodology of the CMP the additional factors of inclusiveness and measures for lower carbon emissions from transport. Within the LCMP framework, this initiative aims to address transportation growth, development challenges and climate change issues in an integrated manner proposed by UNEP[5] DTU Partnership. The Ministry of Environment and Forests in India (in consultation with IIT Delhi, CEPT University and IIM, Ahmedabad) has published a methodology for preparing the LCMP. They, collectively, will provide plans for three diverse cities of India, i.e. Vishakhapatnam, Rajkot and Udaipur. These plans will address the need to ensure safe mobility and accessibility to people irrespective of their socio-economic background in a way that does not compromise the overall quality and health of the environment. The LCMP is also envisaged to be an effective decision-making tool, which will help to develop low-carbon mobility scenarios, and identify projects that will pave the way and earmark Jawaharlal Nehru National Urban Renewal Mission (JnNURM) funding for implementation. While doing so, it will ensure improved accessibility for the low-income households and women in the cities, who have constraints on accessibility. This report presents the LCMP plan for Rajkot.

1.2. Planning horizon of LCMP

To date, studies conducted for Rajkot have been planned with a time horizon of twenty years. The Comprehensive Mobility Plan too was planned for 20 years, with the horizon year being 2021. The same holds true for the City Development Plan and the Traffic and Transportation Improvement Plan, also prepared for 2021.

Similarly, in consultation with the Rajkot Municipal Corporation (RMC), it was decided that the LCMP of Rajkot would be prepared for the horizon year 2031. Within this horizon period of 20 years, three sub-horizons were to be considered. The two proposed intermediate horizons considered for the planning programs and projects include a five-year horizon period (2011-2016) for short-term plans, and a ten-year period (2011-2021) for medium-term interventions.

The programs proposed for the five-year horizon would be specifically for the RMC area, and would be based on the need for immediate intervention. Interventions for the ten-year horizon would be for the RMC area as well as its outgrowth areas, and would be projects that have a gestation period of five to ten years. For the twenty-year horizon, the entire RUDA Area would be included, and programs suggested might include large-scale projects that have a gestation period of over ten years and/or interventions that would require changes in the structure of the city.

1.3. Planning area for LCMP

The LCMP, with a horizon period of twenty years, would consider the development of the Municipal Corporation area as well as the villages and industrial areas coming up around the city. Based on administrative boundaries, the RUDA area has been determined as the study area. Rajkot, located in the centre of Saurashtra region, is Gujarat's fourth largest city after Ahmedabad, Vadodara and

[5] United Nations Environment Program (UNEP) DTU Partnership, Denmark, enables nations to improve their quality of life without compromising that of future generations. UNEP DTU Partnership has funded this LCMP project.

Surat. It is a major industrial city of the State, having a large number of foundries, diesel engines, automobiles, machine tools and bearing units. There are proposals for developments in the city like a Special Economic Zone (SEZ) for the engineering sector, IT parks, townships and their connectivity. Land prices in the city are some of the highest in the State as the city has huge potential for investments. Rajkot is a fast-growing medium-sized city, making it worth studying and proposing new strategic interventions in terms of planning.

Figure 1-1: Rajkot district in the Indian state of Gujarat
Source – Compare InfoBase maps

1.4. Vision and Objectives

The LCMP's vision is "to provide technological as well as planning strategies to meet the mobility and accessibility demands of all people irrespective of their socio-economic profile and gender by the least carbon emitting modes of transport" (Tiwari & Mahadevia, 2011). The objectives aligned to the vision of the LCMP are:

- To map the existing transport situation, including NMT & PT infrastructure with road infrastructure,
- To map the carbon emission levels due to transport in the city,
- To map the existing land use/built form and economy of the city, and understand the impacts on transport or travel patterns of the city,
- To develop scenarios for the future development of the city, and assess travel demand in each scenario for different modes and socio-economic conditions,
- To develop scenarios for low-carbon emissions from urban transport mobility by integrating land use, transport and socio-economic characteristics,
- To propose a set of policies, interventions and projects based on the scenarios to achieve low-carbon mobility, and
- To prepare an investment plan and implementation program for successful execution.

1.5. Methodology[6]

- **STEP 1: Analyse the existing situation**

This step involves the study and analysis of existing urban and transport conditions. This is done by analysing the existing city profile, land use pattern, transport network and travel patterns, by measuring the access to important transport infrastructure, and the access it provides to different activities. The major output of this task will be to describe the existing system and identify some initial issues.

- **STEP 2: Develop 'Business as Usual' and alternate scenarios**

Scenario-based methodologies provide a very useful means for analysing and predicting future development. In the first scenario, transport demand and mobility patterns are analysed where the city growth follows the existing pattern. Conversely, in the alternate scenarios, the phasing of interventions are assumed in terms of land use structure, NMT and PT infrastructure and adaptation of advanced technologies. The task includes the simulation of urban growth and development of Rajkot city for the short, medium and long-term horizon years. This is followed by developing a transport demand model for the present situation, as well as for the three different horizon years. The transport demand model is constructed using the conventional four-stage urban transport demand model, as explained elaborately in Ortuzar & Willumsen (2011). However, the methods used here differ from the conventional transport demand models in India. These differences are discussed in the BAU scenario chapter, but essentially these incorporate the influence of built form (land use and transport infrastructure) in addition to the influence of socio-demographic indicators on travel behaviour, trip generation, choice of mode and route choice.

Scenario 1: Improved walk and PT infrastructure

The BAU scenario demonstrates the transport problem if city development is allowed to follow past trends and if no interventions are made. In Scenario 1, infrastructure for both public transit and pedestrians will be improved through routing, operations, frequency, level of service, as well as wide and continuous footpaths with traffic-calming measures at intersections for public transit users and pedestrians respectively. This is based on existing demand and revealed and stated choices (from the household survey). This will provide a safe and secure environment, ultimately leading to an increased use of public transit and walking.

Scenario 2: Improved walk and bicycle infrastructure

In Scenario 2, infrastructure for cycling will be improved in terms of separated cycle lanes, increasing cycle speeds and safety, while pedestrian infrastructure will be improved by removing obstructions, lighting up footpaths for pedestrian safety, widening the footpath and introducing traffic-calming

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[6] The LCMP methodology was framed by IIM (Ahmedabad), IIT (Delhi) and CEPT University (Ahmedabad) collectively, during the first phase of the project. In the second phase, the methodology was showcased for three cities, namely Rajkot, Vishakhapatnam and Udaipur. The methodology was adapted as per city-specific characteristics.

measures at intersections for both pedestrians and cyclists. This will, ultimately, lead to an NMT-friendly environment and fewer conflicts between pedestrians and private vehicle users.

Scenario 3: Improved PT, walking and cycling infrastructure

This scenario assumes that the improvement in infrastructure and operations for all three modes will increase the usage of these modes to the maximum possible extent. At the same time, this scenario assumes increased travel time for private vehicles.

Scenario 4: Urban structure

The cities are sprawling even to the point of changing the type of development and the position of urban centres. This might result in increased trip lengths. This scenario will, thus, look at the strategies for decreasing the trip lengths with consideration to the land and housing policies.

Scenario 5: Technology scenario

Improving technology is a dynamic process, and as the day passes we constantly move towards better and better technology that helps in reducing vehicular emissions. The adaptation of these technologies is determined at the national level, and cities have to follow them to fulfil national objectives. This scenario will basically look at the changes in emissions when there is a positive change in fuel and vehicle technology (changes in fuel consumption, fuel mix, etc.) from BAU to the low-carbon scenario.

- **STEP 3: Prioritise a portfolio of infrastructures and technologies**

After running the model, what is important is the output and choosing between the two scenarios. The decision regarding the prioritisation of the set of indicators for the desired outputs will be the next step. The scenarios provide a strong analytical basis for selecting a portfolio of technologies and infrastructures. The scenario and model outputs help in quantifying indicators related to modal shares, emissions of CO_2 and local pollutants, investments, etc. However, many indicators are difficult to quantify. Therefore, the final portfolio selection, based on all indicators, will be done using a multi-criteria assessment (MCA). The indicators for which quantification has been conducted using the scenarios will be normalised into a score. The remaining indicators will be scored using the expertise of stakeholders.

- **STEP 4: Propose policy measures, projects and financial requirements to achieve low-carbon scenario**

Based on the overall prioritisation for technologies and infrastructures, project ideas and policy measures should be prepared and proposed. Detailed procedures for implementing the proposed projects and plans will be shown in an 'Implementation Program', which includes a timeframe, financing options and implementation agencies/organisations for each project.

1.6. Study Area Delineation

The Low-carbon Comprehensive Mobility Plan will look into the development of transport infrastructure to meet the mobility needs of individuals irrespective of their economic status, making the environment sustainable for people living in the city. For achieving this project goal, it is mandatory to define a study area based on the existing administrative boundaries, urban and rural areas, economic zones and major industrial areas around Rajkot. However, it will also be necessary to look into the individual travel patterns as well as road network and land use in considerable detail, which makes it necessary to delineate the study area to be appropriate for that kind of study. RMC is mainly developed into residential and commercial zones, but outside RMC talukas, namely Kotadasanghani, Jardan and Lodhika, are areas where Government subsidies are given to promote industrial growth. Other proposals include an industrial park in the Metoda village of Lodhikataluka, and an economic corridor along the Surendranagar-Rajkot-Morbi-Kandla link on NH-27. RUDA has also proposed industrial development along major highways, connecting Jamnagar and Ahmedabad to Rajkot. Thus, industrial growth is expected to trigger off in the southern part of the city and along major highways.

RMC has proposed future residential development mainly on the western side, in the villages of Motamava, Munjka and further west. There has been considerable mixed development recently along the Kalawad Road and Raiya Road, which is expected to develop further. Therefore, the expected residential development is along the west as well as south due to its industrial development. There is a little residential development also expected along the east and north of the river. Outside the RMC area, except for highways, roads have not been constructed, as the demand is not so high in those parts of the city. Residential pockets have come up at distant areas in all directions because of industrial development and the good connectivity of highways. So, the focus of the five-year projects will be the RMC area where demand is high, while that of the ten-year projects will include the outgrowths of RMC along the highways where industrial and some residential developments will be taking place.

As stated earlier, the twenty-year horizon projects will include RMC and the villages outside RMC, which are likely to grow and depend on the economy as well as infrastructure of Rajkot, together forming the RUDA boundary. There has not been any substantial development outside the old RUDA boundary for years, and there are still some vacant areas in the RMC boundary as well as in the old RUDA boundary. Thus, for looking at a compact development, the old RUDA boundary has been selected as the study area. The greater area of Rajkot was delineated for the regional planning, RUDA Area, administered by the Rajkot Urban Development Authority (RUDA) constituted under section 22 of the Gujarat Town Planning & Urban Development Act, 1976 on 1 February 1978. The total area is 483km^{2,} covering 39 villages in the periphery of the Rajkot Municipal Corporation, including the RMC area itself (104.86km^2). RUDA is divided into 59 wards, where 23 wards are under the RMC area (Figure 1-2).

All the 59 wards of RUDA and RMC area are further divided into smaller areas for analysis at the individual-level, capturing the details of each and every road section with the movement of an individual. Fifty-nine wards have been further divided into 394 traffic analysis zones (TAZs)[7], starting from the walled city in the eastern part of the river and spreading further west and towards other outgrowths of the city (Figure 1-3). To conduct a detailed analysis, considering even the short trips by pedestrians and cyclists, the RMC area has been divided into smaller TAZs of around $1km^2$, whereas the outgrowth area beyond the RMC boundary was divided into TAZs of around $1.5km^2$. The average size of a TAZ is $0.72km^2$ where the smallest is $0.2km^2$ and the largest, outside RMC, is $11km^2$, based on the ward boundaries and physical features like the Aji River, lakes and roads. Table 1-1 shows the details regarding the administrative divisions in the study area along with the area and population.

Table 1-1: Population of study area

Boundaries	Wards	TAZs	Area (km^2)	Population	
				2001	2011
RMC	23	183	104.86	7,98,031	1,288,599
RMC outgrowth	36	211	151.82	2,07,973	3,75,707
RUDA (study area)	59	394	256.68	10,06,004	14,78,265

[7] The analysis of transportation demand by wards in the city is difficult due to their large size. Therefore, for this kind of study, the wards are further divided into smaller areas called Traffic Analysis Zones, which can capture all kinds of trips, including smaller ones.

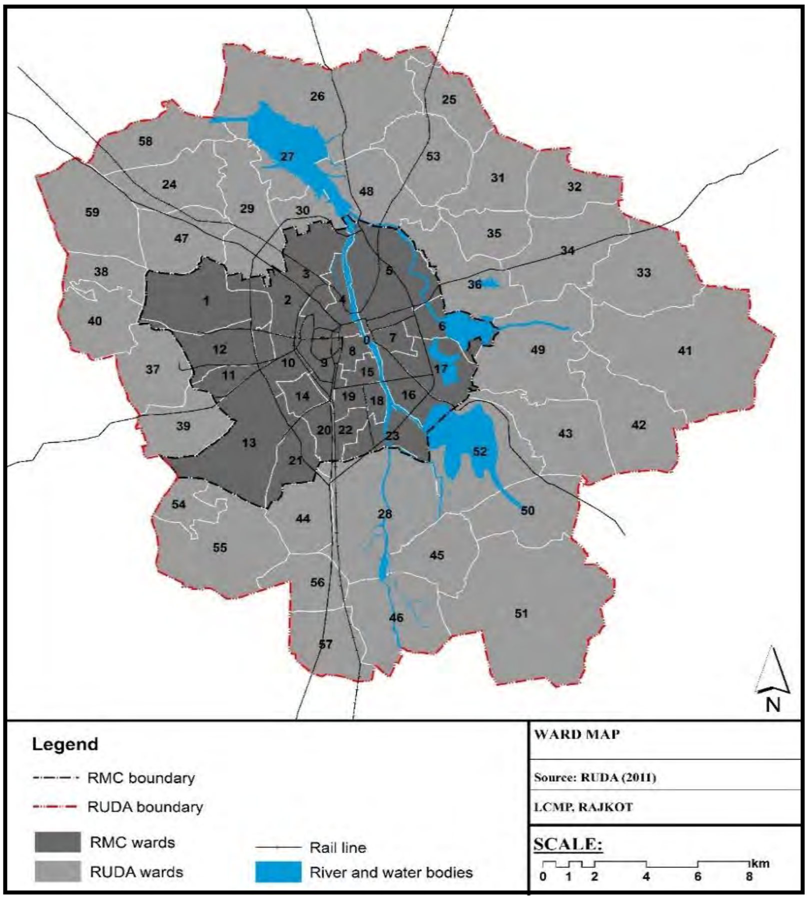

Figure 1-2: Ward map of Rajkot

Source: (Rajkot Urban Development Authority, 2011)

1.7. Data Collection Approach

The data required for the study were collected based on the methodology prescribed in the toolkit for preparing the LCMP.

Primary and secondary data

Household surveys estimated the existing travel pattern of individuals and the transport demand. Road inventories and volume counts give the existing on-the-ground condition of roads, abutting land use and condition of supply-side transport infrastructure.

Secondary data, including socio-demographic data, existing and proposed land use plans, and future developments were used to gain a holistic picture. Cross-checking was done using primary data collected on site for predicting the supply side of infrastructure facilities. The primary and secondary data collectively provided the existing situation of pedestrian, cycling, road and public transit infrastructure, and the facilities related to safety, security and carbon levels in the city. The indicators identified in the methodology were analysed using the secondary data and data from the following surveys. Table 1-2 lists the sources of data collected as part of this project.

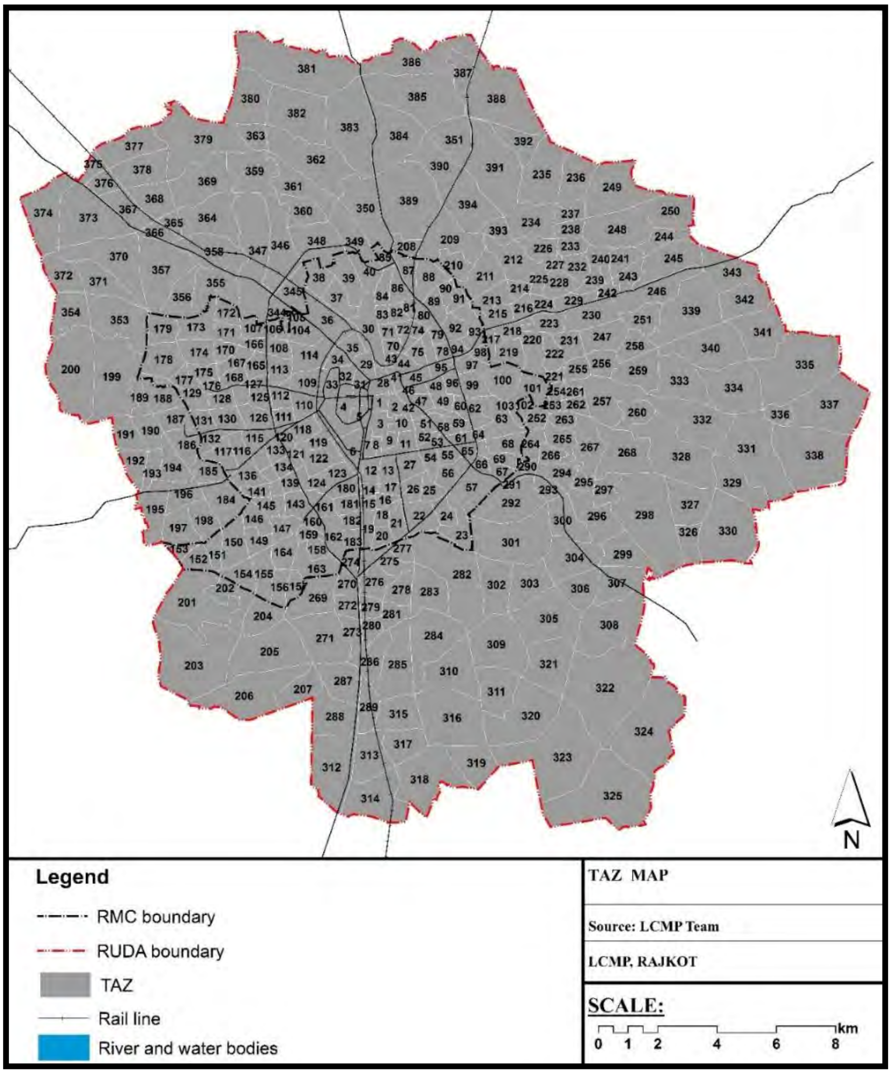

Figure 1-3: **Traffic analysis zones in Rajkot**
Source: Authors

Methodology for data collection

Compared to conventional methods, the LCMP study followed a very extensive methodology for collecting various data on the city's transport sector. Special efforts were taken to include all factors affecting transportation, including land use in the city, so that the resulting plan would produce highly integrative strategies for the city's future. There was also an attempt to make the plan as context-responsive as possible. The various data sets, and the methods by which they were collected and recorded, are mentioned below:

Socio-demographic data

Socio-demographic data was collected basically in the form of household information. Household information was collected during the primary surveys and interviews, and included household size, vehicle ownership, and type of vehicle, household income and individual information. Individual information included gender, education and employment details.

Methods: The sampling selection technique was based on detailed property-level data obtained from the RMC office. Samples were divided based on the population of each TAZ. After which, the samples in each TAZ were further divided according to type of house proportions, i.e. Apartments (12 per cent), Bungalows (7 per cent), Row houses (65 per cent) and Kutcha houses (16 per cent). This was done for both the RMC and RUDA areas. In total, 2,848 households were surveyed, i.e. approximately 10 per cent of all households.

Data Format: The household information and the information regarding its members were recorded in the survey form, which was later entered for analysis.

Travel behaviour

The travel characteristics study of individuals in the city were collected for transport modelling, which included trip rates, choice of travel mode, and the vehicle/passenger kilometres travelled.

Methods: To understand the travel behaviour, a travel diary was prepared for each individual in a household, detailing the travel of a person on the last working day with origins and destinations.

Data Format: The individuals' travel diaries contained information regarding their daily trips, including their destinations, purposes, modes used, etc., all of which are essential for transportation modelling.

Road infrastructure

Pedestrian infrastructure

The next level of data collection was transport infrastructure. To start with, the information on inventory for pedestrian facility was collected.

Methods: The data were recorded based on visual surveys conducted through the road networks within the city.

Data Format: This data included footpath width, length, condition, continuity, type, crosswalks, footpath furniture, segregation type, footpath obstructions, and traffic-calming tools like zebra crossings.

Infrastructure for non-motorised transport

Other road inventory information was collected regarding cycle-rickshaws and autos, which involved parking location, major routes and destinations, fleet size, authorised IPT stops, average km/day, trips per day, cost and revenues per day, occupancy, license, insurance fees and tax levied.

Table 1-2: Inventory of data collected as part of the project

Data Type	Data Collected	Data Source
Socio-demographics and travel behaviour	Household information - HH size, vehicle ownership, type of vehicle, HH income, individual information - gender, education, employment; travel diary – travel of a person on the last working day with origins and destinations.	Household surveys
Inventory for pedestrian facility	Footpath width, length, condition, continuity, type, crosswalks, footpath furniture, segregation type, footpath obstructions, traffic-calming tools (i.e. zebra crossings).	Inventory – primary surveys
Inventory for non-motorised transport facilities	Cycle lanes width, type and obstructions (provided only along the Ring Road)	Inventory – primary surveys
Inventory for cycle rickshaws and autos	Parking location, major routes and destinations, fleet size, legalised IPT stops, average km/day, trips per day, cost and revenues per day, occupancy, license, insurance fees and tax levied.	Inventory – primary surveys IPT surveys
Inventory for public transport (bus)	Bus stop locations and type of bus stop, bus stop names, routes.	Secondary data - RMC
Inventory for private motorised vehicles	Road width, length, type, condition, carriageway, parking along the street, street vending & related activities, street lights, intersection details, markings and signage type at intersections, traffic-calming measures, parking charges, speeds, vehicle restriction, signal phasing, speed and Delay survey	Inventory – Primary surveys Speed and delay Secondary data - RMC
Traffic volume count at screen line, cordon and intersection	Screen lines – 9 Intersections – 12 Outer cordon - 5	Classified volume counts
Traffic safety	Location of street lights, Major and minor accidents	Secondary data – RMC, City Police
Freight	Freight parking locations, terminal locations, operator details, type of commodities	Freight O-D – primary surveys
Others	Fuel consumption, pollution and emission data, noise levels, registered vehicles.	Petrol pump survey, Air and noise level surveys. Secondary data – RTO office, GPCB

Infrastructure for public transport

Public transport is a crucial part of assessing the transport sector in any city, and hence it was important to collect data on public transport systems.

Method: BRTS information was collected from its operator. Regarding the conventional bus transit system within the city, the data was collected from secondary sources like RMC and VTCOS.

Data Format: The inventory for public transport (bus) was recorded in the form of bus stop locations and type of bus stop, bus stop names and routes.

Infrastructure for cycle-rickshaws and autos

Private motor vehicles are a major contributor to the city's traffic, and hence an inventory survey for private motorised vehicles is crucial.

Data Format: This basically consisted of road width, length, type, condition, carriageway, parking along the street, street vending and related activities, street lights, intersection details, type of markings and signage at intersections, traffic-calming measures, parking charges, speeds, vehicle restriction, signal phasing, speed and delay survey.

Vehicular population

The number of vehicles in the city was recorded through secondary data collected from the Regional Transport Office (RTO) in the city. The data was extracted from the motor vehicle registration records with the RTO[8].

Data Format: A record of vehicles registered on each day, month and year.

Vehicular population data was also rechecked by petrol pump data (primary surveys at petrol pump) to know the actual number of vehicles on the road.

Traffic volume

The city's vehicular population does not give any picture of its traffic scenario unless and until it is considered in conjunction with the city's road networks as the number of vehicles flowing through them at a particular point of time. Traffic volume counts are the most important information required to assess the existing traffic scenario and inform future projections and system designs.

Methods: The traffic volume counts were taken at screen lines, cordon points and intersections. Outer cordon surveys are done for counting the vehicles coming in and going out. They were done at six points for 16 hours on a single day, where there is a bypass of each highway.

Data Format: The traffic volume count consists of data on the number of vehicles and the mode.

Intermediate public transit networks and infrastructure

Intermediate public transit modes like auto-rickshaws play an important role in the city's transport sector as a feeder to public transit or as a general travel mode. This type of survey is generally not

[8] The Regional Transport Office (RTO) has extensive data on registered vehicles over the years, but the vehicles that are discarded or not in use are not actually deregistered or deleted from the list of registered vehicles in the RTO.

conducted for any conventional plans, so it was conducted especially as a part of this study's context-responsive approach.

Method: Data on intermediate public transit modes is not available in any records. Hence the data required was collected through IPT surveys, basically recorded through interviews.

Data Format: The IPT survey data consisted of IPT routes within the city, origin and destination data, location of parking areas, headway counts, occupancy (peak hours and average), trips per day, fuel cost, revenue, average vehicular kilometres per day, route length, average vehicle age, etc.

Speed and delay

This survey was done to understand the average speeds on major roads in the city. This was done to also have an understanding of various causes for delays, and if they are of considerable importance.

Method: A speed and delay survey was selectively conducted, largely on arterials and sub-arterials, through direct recording made while travelling in a vehicle.

Data Format: The dataset consisted of the road name, location, length, origin and destination of the journey, start time, end time, number of delays, delay time, causes of delay, vehicles overtaken, vehicles overtaking and the speed of the vehicle.

Freight

Other than passenger movement-related information, data regarding the freight movements were also collected for the city.

Methods: This dataset included freight volume data collected through Origin-Destination (O-D) survey.

Data Format: Information about freight vehicle count, trip origin and trip destination, freight parking locations, terminal locations, operator details and types of commodities.

Traffic safety

Traffic safety information was collected regarding the street-lighting levels and accident frequencies on the roads of Rajkot. The level of street-lighting was analysed on the basis of planning, spacing and perceived lighting levels for the carriageway as well as pedestrians.

Methods: The information regarding major and minor accidents that occurred in the city in recent years along with the location details were collected from Police departments of various divisions within the city.

Data Format: The traffic safety data included information on accidents with details on the severity of human impact (fatal, with injury and without injury), and information on the accident-prone areas within the city.

Environmental data

Since this study is looking into a Comprehensive Mobility Plan with low-carbon impact, other information was also collected to support the environmental-related studies for the plan. This was mainly concerned with the quality of the urban environment and its relationship with the city's transport sector.

Methods: The data were collected through petrol pump surveys, air and noise level surveys, and other secondary data collected from departments like the RTO office, GPCB, etc. Emissions were calculated by running the Sim-Air model,[9] which is explained in detail in Chapter 5.

The petrol pump surveys were conducted at various petrol pumps in the city through interviews and recording odometer readings, vehicle type and model, etc. This survey also helped in cross-validating various sets of vehicle and traffic data collected from other methods, including household survey, vehicle count, etc.

Noise Level testing was conducted at 11 different locations within the city during morning and night hours.

Data Format: The collected data set had information on fuel consumption, pollution and emission data. The air pollution data were collected for hydrocarbons and carbon monoxide for various localities. Noise level surveys basically gave information about noise levels for various land uses at day and night times in decibel (dB) values (actual and standard values).

1.8. Conclusion

The LCMP's holistic approach and intricate methodology focuses on new approaches for environment and human-friendly development, and solves the drawbacks of conventional planning. To achieve the objectives of the LCMP in Rajkot city, there should be a clear understanding of the city as a whole in terms of its socio-demographics, economics, urban form, environment, present infrastructure and travel characteristics. For understanding the city in such detail and analysing the current scenario, primary and secondary studies were carried out. The method, analysis and outputs of these surveys and their analysis is explained in detail in the forthcoming chapters.

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[9] The Sim-Air model simulates the interaction between emissions, pollution dispersion, and impacts in an environmental context. It is an Excel-based simulation model developed by Mr. Sarath Guttikunda for Rajkot city, as a part of the project.

Chapter 2: City Status as of 2012

This chapter gives an overall perspective regarding the demographics, growth pattern and connectivity of the city. It also gives a brief idea of the land use pattern and, most importantly, the economic and employment conditions of the city. It basically gives an overall picture of the existing built form of the city.

2.1. Introduction to the City

Rajkot is the fourth largest city in the state of Gujarat after Ahmadabad, Vadodara and Surat. It is the 23rd-largest urban agglomeration in India, with a population over 1.4 million as of 2011, and is ranked 22nd in the world's fastest growing cities and urban areas from 2006 to 2020. Rajkot was the capital of the erstwhile Saurashtra State, and was merged into Gujarat State from Bombay State on May 1, 1960.

In about 400 years, it has developed from a small hamlet[10] into the prosperous city of today. It was founded by the then ruler of Sardhar in 1608 AD on the west bank of the river Aji as a small fortified town. The old town and Sardhar area, which is part of the city today, developed simultaneously. More recently, these areas were separated by the North-South Railway track, but this was subsequently removed. The areas merged with each other resulting in a coordinated development of the town. About 60 industrial units came into existence between 1900 and 1920, which induced development of the city to a great extent. Bhaktinagar Industrial Estate and Aji Industrial Estate were established. Trade and industry developed rapidly in the city, which also attracted foreign investment during these periods. With increasing industrial, trade and commercial activity, there has been tremendous growth in the population of the town. The city has grown from 150 hectares in 1901 to 10,404 hectares in 1998 (approximately 70 times its initial size).

The climate of the city is hot and dry. The average maximum and minimum temperatures recorded over the last 40 years are 43.5°C and 24.2°C respectively. The average annual rainfall is 500mm. However, over the last 60 years, rainfall has been below normal for 20 years. In these years, the city along with the Rajkot Urban Development Area (RUDA) has faced an acute water shortage.

2.1.1. Location

Rajkot is located 245km from Gandhinagar, the state capital, at the centre of Saurashtra peninsula in the central plains of Gujarat State, located in western India at a height of 138m above mean sea level, and located on the banks of the Aji River and Nyari River (Figure 2-1). It lies between latitude 20.18 N and longitude 70.51 E. Rajkot is the biggest city in terms of population in the Saurashtra-Kutch region, bustling with commercial activity, spurred by new global economic and industrial policies.

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[10] 'Hamlet' refers to a small settlement in a rural area.

2.1.2. Connectivity

By Air: Rajkot has a domestic airport which is just 2.5km from the core of the city, and 2km from the Railway station. The two airlines that operate daily connect Rajkot directly with Mumbai, Ahmedabad and Bhavnagar.

By Rail: The city is also connected by broad gauge railway lines to Delhi and Mumbai, the national and commercial capital cities of India.

By Road: It is well connected with the whole of the Saurashtra-Kutch region and other parts of the State through national and state highways, rail and by air. It has one national highway (NH-8) connecting to Ahmedabad and Gondal, and three state highways (SH-23, SH-24 and SH-25) connecting to Jamnagar, Porbandar and Morbi.

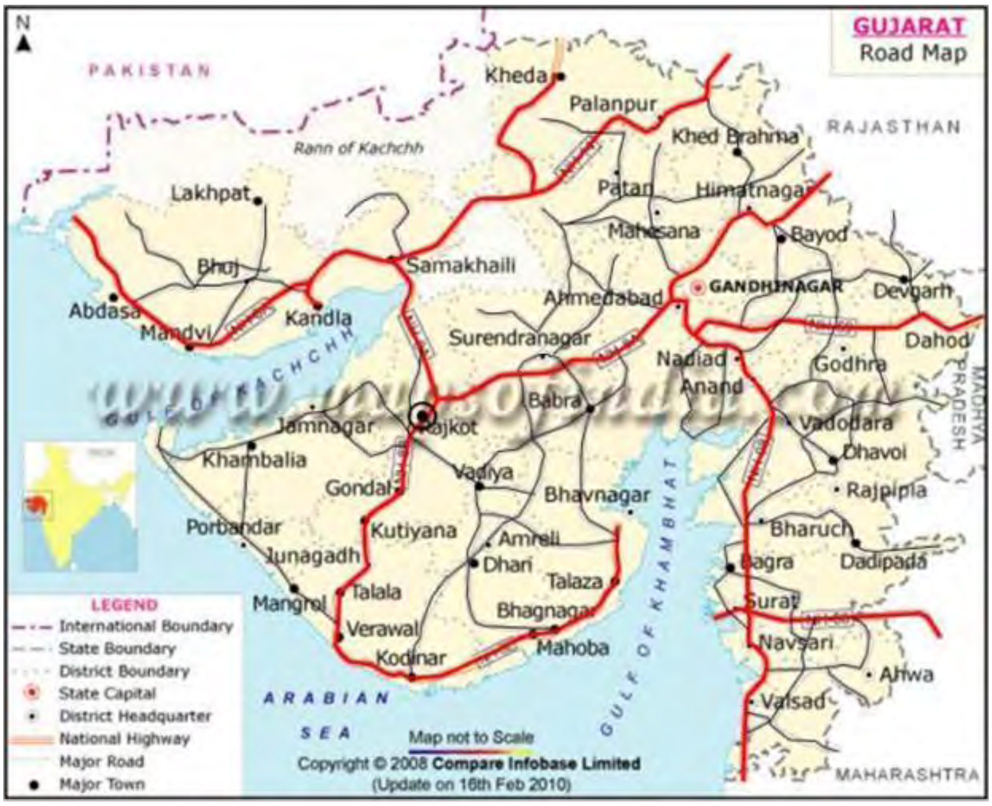

Figure 2-1: **Location of Rajkot in Gujarat**
Source: Maps of India, 2010

2.1.3. Growth of Rajkot

Initially, the city started growing on the western side of Aji River, but later growth extended to the eastern side of the river. By the end of 19th century, Rajkot emerged as a premier town having a population of 36,000. The city had started spreading in other directions, but the fastest growth was seen on the western bank of the river. Figure 2-2 shows the evolution of Rajkot from its early formation as a small trade centre in the early 19th century to the city of the present era.

Figure 2-2: Growth of Rajkot on the banks of Aji River
Source: (Rajkot Urban Development Authority, 2011)

2.1.4. Demographic trends

The population of Rajkot city is 1,288,599 (Registrar General of India, 2011). It has grown from 1,002,000 in 2001 with a decadal growth rate of 28.31 per cent. During the time of India's Independence, Rajkot city experienced the highest growth rate of 99.04 per cent from 1941 to 1951 because of a large number of immigrant refugees from Pakistan. Also, from 1991 to 2001, the city registered a growth rate of 79.12 per cent, attributed to the increase of the Corporation limit by merging three surrounding villages in June, 1998. The RMC area was extended from 38km^2 to 69km^2. Again, in June 1998, the RMC area was extended by another 34.865km^2. This has largely influenced the growth rate of the previous decade. The city is currently divided into 23 wards with an average density of 12,735 people/km^2. Rajkot city has 84 notified slum areas spread amongst almost all wards and containing within them a population of about 202,371. Table 2-1 shows the decadal growth of population in Rajkot city.

Table 2-1: Decadal growth of population in Rajkot city

Year	Population	Growth Rate
1901	36,151	-
1911	34,191	-5.42
1921	45,845	+34.08
1931	59,122	+28.96
1941	66,353	+12.23
1951	132,069	+99.04
1961	194,145	+47.00
1971	300,112	+54.58
1981	445,076	+48.30
1991	559,407	+25.69
2001	1,002,000	+79.12
2011	1,286,995	+28.31

Source: (Registrar General of India, 2011)

2.2. City Structure

2.2.1. Population density

Figure 2-3 shows the spatial expansion in all directions in a radial form along the major arterials or highways. RUDA area has population densities ranging from 0 to 870 persons per hectare with an average density of 52 persons per hectare. Areas outside the RMC have much lower densities and villages have developed in a scattered manner along the roads and river. The inner city has densities ranging from 55 persons per hectare to 870 persons per hectare with an average density of 127 persons per hectare. The walled city has the maximum population density, reaching levels of saturation. A phased expansion in the Municipal Corporation jurisdiction is expected over three distinct time periods: 2007-12, 2013-17, and 2018-21. Physical barriers as well as the potential of land and government policies have affected the city's growth pattern. The southern part has experienced significant industrial development with industries growing along the national highway towards Gondal, which is attributed to the Government's policy of providing subsidy to industries in Kotadasanghani, Jardan and Lodhika. The growth is limited in the east due to the Aji River, and in the north due to the presence of large areas under the railways and other institutions. Recent developments are along Kalawad Road and Raiya Road to the west.

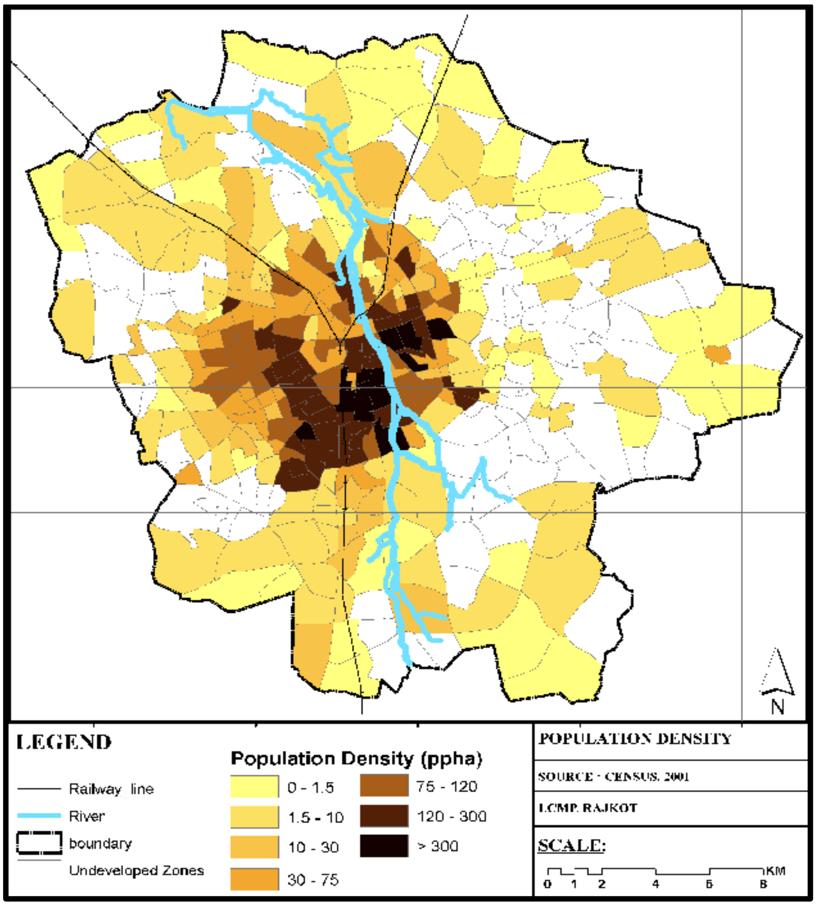

Figure 2-3: Map showing population density in Rajkot, 2011
Source: (Registrar General of India, 2011)

2.2.2. Land use pattern

The way land use is distributed in a city determines its mobility pattern. It is also important to study the pattern changes in the city's development over the years to plan for the future needs of transport infrastructure. The settlement pattern of the greater region of the city (i.e. the RUDA area) is quite different from the inner city core under the RMC. Figure 2-4 shows the existing land use map of Rajkot in 2011.

Land use in RUDA area

According to the existing land use of the RUDA area, around 67 per cent of land is either vacant or in agricultural use, compared to 81 per cent ten years ago (Table 2-2). There has been a lot of residential development in these years in all directions as well as a continuous growth in industrial development in and around the city, mainly along the Gondal Road. There is very little commercial development outside the RMC boundary, whereas recreational spaces have increased from 0.5 per cent to 3.5 per cent.

Table 2-2: Land use in RUDA area (2001 and 2011)

Land use	2001		2011	
	Area (Ha)	Per cent	Area (Ha)	Per cent
Residential	5,744	8.41	12,528	18.25
Commercial	543	0.80	827	1.20
Industrial	3,388	4.96	5,205	7.58
Traffic & transportation	1,697	2.48	2,453	3.57
Public & semi-public	633	0.93	591	0.86
Recreational space	379	0.55	1,053	1.55
Vacant, agriculture & others	55,926	81.87	45,974	66.99
Total	68,310	100.00	68,631	100.00

Source: RUDA

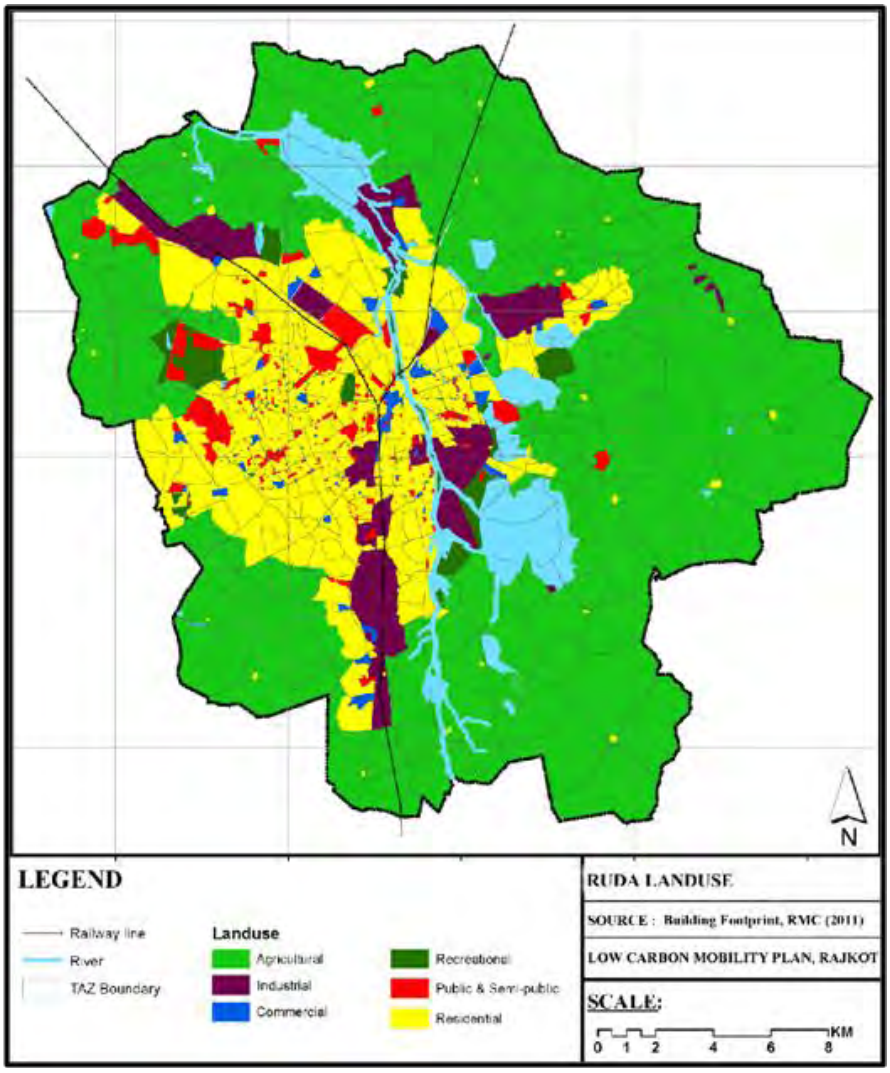

Figure 2-4: Existing land use map of Rajkot, 2011

Source: RUDA

Land use in RMC area

The existing land use plan (2011) shows an increase in residential area from 40.5 per cent in 2001 to 52.47 per cent in 2011 (Table 2-3). Approximately, 2Ha of land under agricultural use has been converted into built-up land in the last decade. There is not much change observed in commercial development or public use, but there is an increase in industrial development by around 1 per cent. Recreational spaces have increased around 4 per cent, which is still insufficient for the city.

Table 2-3: Land use in RMC area (2001 and 2011)

Land use	2001		2011	
	Area (Ha)	Per cent	Area (Ha)	Per cent
Residential	4,247	40.50	5,502	52.47
Commercial	209	2.00	279	2.66
Industrial	628	5.99	738	7.04
Traffic & transportation	1,400	13.35	1,650	15.74
Public & semi-public	149	1.42	249	2.38
Recreational space	123	1.17	523	4.99
Agriculture	995	9.49	800	7.63
Water Bodies	236	2.25	236	2.25
Others	988	9.42	508	4.84
Total	10,485	100.00	10,485	100.00

Source: RMC

Land use development and growth

Rajkot's growth has been the highest in the last decade in terms of residential, commercial and industrial development. The spatial locations and therefore directions of growth of these developments are shown in the map above. The residential areas are the return trip origins of people's daily travel, whereas the commercial and industrial areas are the destinations. This development overview also gives an idea of the mixed land use zones, which is the new trend in land use and transport research projects.

Residential development: Most residential development happens in the central area, covering the old city and the PTC Chowk, Bhavnagar Road to the east of river. There is a medium intensity of development around Kalawad Road, University Road and Raiya Road. There is very little development on the southern side of the RMC due to industrial development there. The residential development is spread over an area of 55km^2, and is 52 per cent of the total area and 60.23 per cent of the total developed area. Residential density also varies across the city. Residential typology consists of row house developments and low-rise apartments, closely packed in a fine-grain urban fabric, particularly in the older parts of the city. There are many new residential developments that differ significantly from this trend, i.e. high-rise apartments that are loosely packed alongside wider roads. Figure 2-5 shows various housing typologies found in Rajkot.

Figure 2-5: Low income family housing

Figure 2-6: Low-rise housing

Figure 2-7: High-rise housing in western Rajkot

Commercial development: The main commercial area remains the old city from where trade was conducted in the old days. Some of the commercial areas that developed in the later stage are Dhebar Road, Yagnik Road and Jagnath area, whereas the new developing commercial areas are Kalawad Road, Amin Road, University Road, Raiya Road, St. Kabir Road, etc. These areas cover grocery markets, cloth markets, jewellery markets and retail areas. These commercial activities are spread over 2.68km^2, occupying 2.66 per cent of the total area.

Figure 2-8: Commercial activities on Raiya Road

Industrial development: Two industrial estates were developed by the Gujarat Industrial Development Corporation. They are Bhaktinagar Industrial Estate and Aji Industrial Estate. Sorathiawadi plot area has also been developed as an industrial area in the later stage. Also, the National Textile mill, (which is closed) occupies very prime land and is spread across a vast area. Industrial area measuring 7.38km^2 accounts for 20 per cent and 22.28 per cent of the total area and total developed area respectively.

Mixed development: Rajkot city has developed as an industrial city. Hence, industries and residences of industrial employees developed simultaneously, which resulted in a mixed land use pattern. Thus the area near Gondal Road has emerged as a mixed development. The old city area had residential, commercial and industrial development from the very beginning, which makes for a small city in itself. But moving away from the centre, the zoning becomes less mixed use and more independent.

Figure 2-9 onwards shows the intensity of various land uses in the planning area of LCMP.

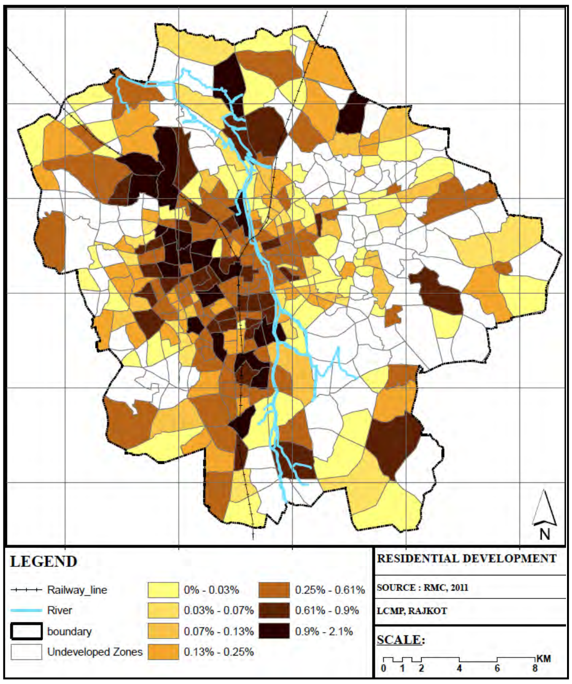

Figure 2-9: Intensity of residential development
Source: (Rajkot Municipal Corporation, 2011)

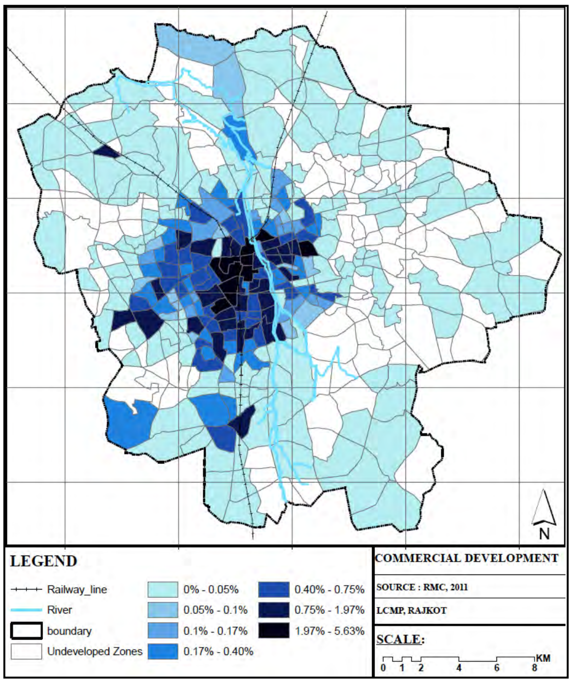

Figure 2-10: Intensity of commercial development
Source: (Rajkot Municipal Corporation, 2011)

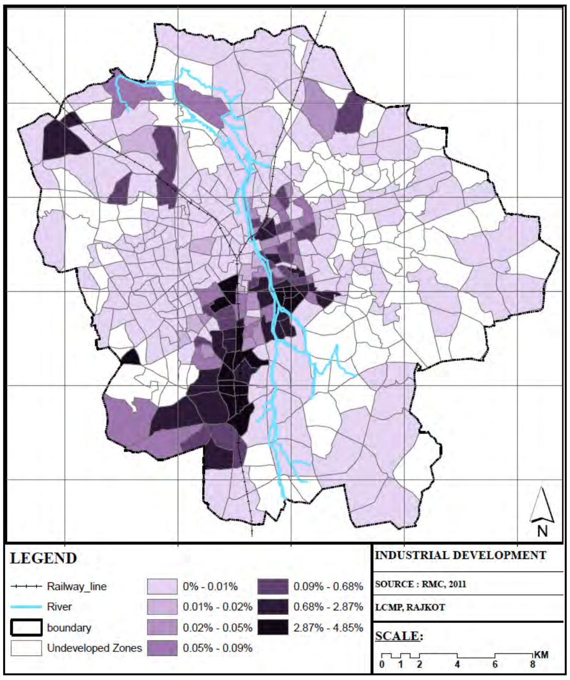

Figure 2-11: Intensity of industrial development
Source: (Rajkot Municipal Corporation, 2011)

2.2.3. Economic activities

Rajkot contributes substantially to the State's economic development, and is the main contributor to the exponential growth in the engineering sector. The fact that the State Government has positioned the city as a key node on the proposed "Economic Corridor" along the Surendranagar-Rajkot-Morbi-Kandla link is testimony to Rajkot's growing economic importance. Metoda in the Lodhika taluka of Rajkot has been proposed as an industrial park, providing a significant opportunity for industrial development along the southern part of the city. Rajkot's regional setting also makes it an important industrial centre and market for agricultural produce, both being forces for urbanisation and population growth. Urbanisation and urban population growth are pointers towards the change in the occupational pattern of the community, from agriculture and allied livelihoods to industrial and other non-agriculture occupations. This transition is apparent in Rajkot's workforce, with 76 per cent of its population involved in the manufacturing, trade and commerce, and services sectors.

Figure 2-12: A street in Rajkot with high concentration of retail activities on its edge

Employment density

Employment density for the city has been calculated from the total area of the footprint, TAZ-wise area of the commercial footprint and total workers (Figure 2-13).

Employment Density = $\frac{W_i/F_i}{f_i/a_j}$

Where Wi = Total workers in 'i' employment sector
Fi = Total floor area in the city employing workers in 'i' sector
fi = Total floor area in the ward employing workers in 'i' sector
aj = Area of ward 'j'

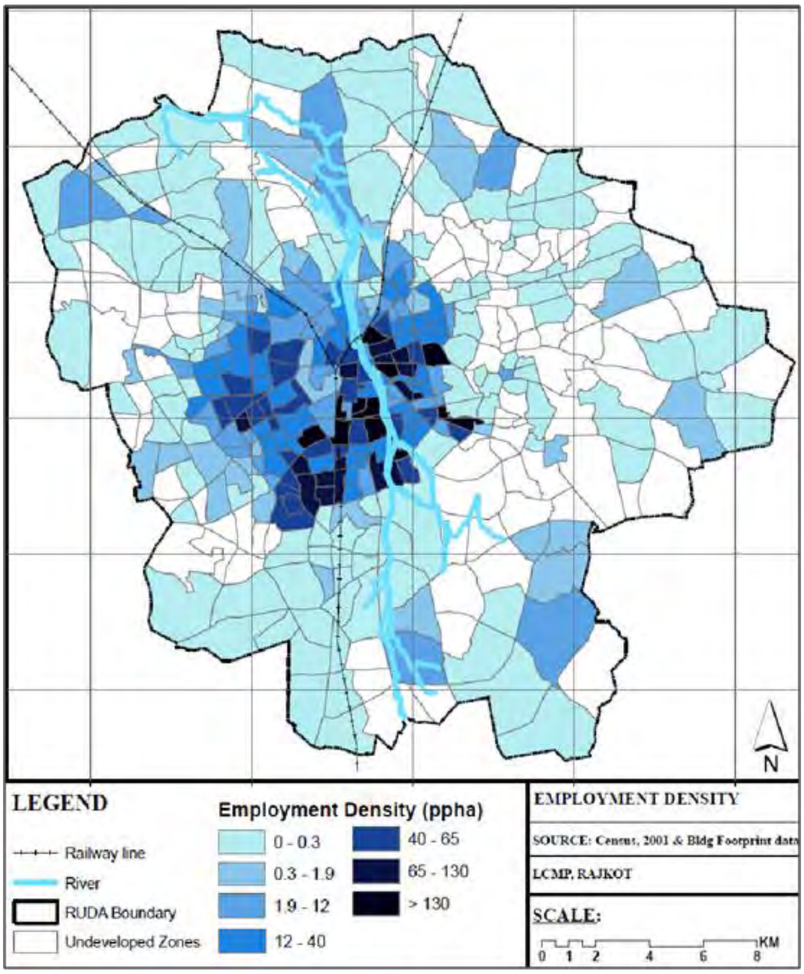

Figure 2-13: Map showing employment density in Rajkot, 2012

Source: RMC building footprint data

Rajkot's major employment zones are based in two industrial estates named Aji and Bhaktinagar industrial estates. There is a vibrant trading centre in the old city since historic times, whereas Kalawad Road, Yagnik Road, Race Course Road to the west and Bhavnagar Road to the east are developing as commercial centres.

Income distribution

In the past, Rajkot's economic activity concentrated on cloth mills. The current trend of industrial growth is towards the engineering and auto ancillary sector. The occupational pattern in Rajkot is primarily based on the manufacturing and service sectors. About 42 per cent of workers are engaged in service activities, and 34 per cent in manufacturing. Manufacturing activities are concentrated in two main industrial estates: Aji and Bhaktinagar. There are around 73 medium to large-scale industrial units in Rajkot, and over 30,463 small-scale units.

Figure 2-14 shows that most of the higher income population stays in western part of the city, which is newly developed.

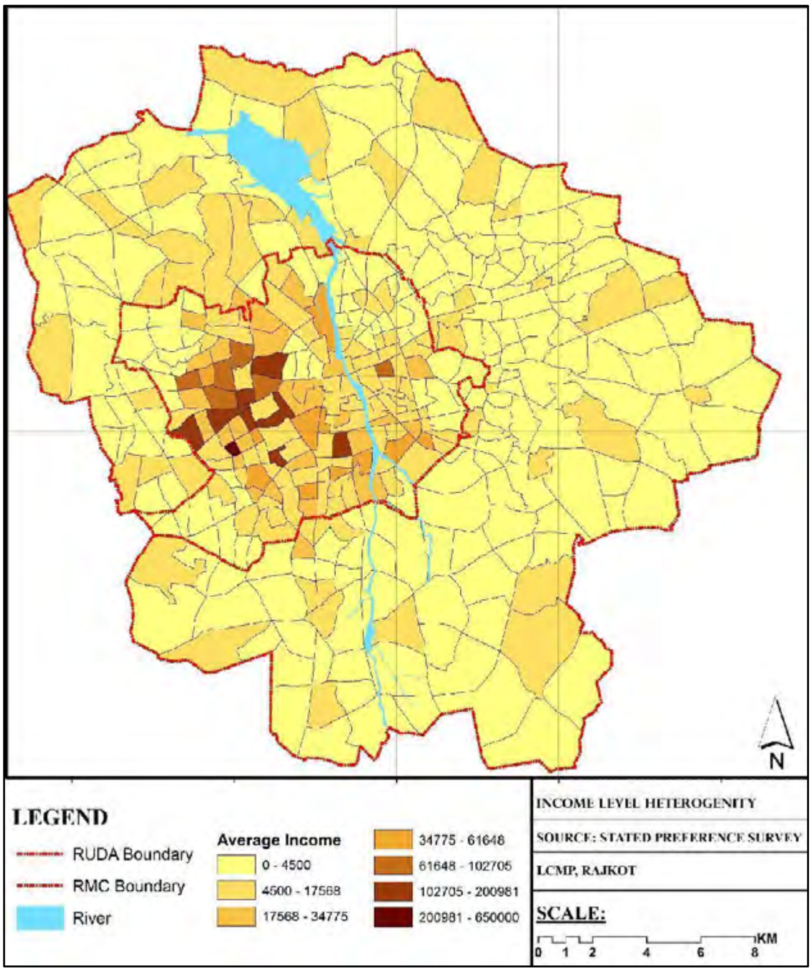

Figure 2-14: Map showing heterogeneity of income level, 2012
Source: Property tax data, RMC

2.3. Conclusion

Rajkot is the fourth largest city in the State, with a population of 12 lakhs[11]. The Rajkot Urban Development Authority has a population of 14.78 lakhs according to Census 2011. Total employment in the RUDA area is 3.04 lakh according to the 2001 census, of which 79.19 per cent is in the Municipal corporation area. The city is relatively compact with a dense road network, but is gradually growing in all directions through sprawl with sparser forms of development. It is growing in all directions along highways, but major growth is occurring on the western side. The presence of natural geographical barriers such as the river and water bodies has restricted the growth of the city on the eastern and some portion of the northern side. The major industrial growth of the city is along the southern part towards Gondal. The city has a mixed land use pattern, especially in the old city area. While the old core boasts the most jobs, it is on the verge of degeneration due to gradual shift of commercial establishments and centres to other nodes of the city.

[11] A lakh is equal to a hundred thousand. Ten lakhs make a million.

Chapter 3: Transport Infrastructure

This chapter covers the condition of transport in the city, including the infrastructure for pedestrians, cyclists, public transit, BRT, auto-rickshaw and private motorised vehicles. Infrastructure for these modes is assessed in terms of its capacity, quality, safety, security and emissions.

Rajkot, being a business hub of Gujarat, has a huge floating population travelling to and from the city every day. Aside from national and state highways, Rajkot also has an extensive and dense road network that connects it to interstate destinations and far beyond. Rajkot is connected to all major cities of India by road, rail and air. The intercity bus service is operated by Gujarat State Road Transport Corporation (GSRTC). Buses, cars, trucks and other means of transport use these well-maintained roads to connect with other regions. The intra-city transportation consists mainly of non-motorised modes like walking and cycling (as in many cities of India), due to the compact structure of the city and private modes, i.e. four-wheelers and two-wheelers, and para-transit modes, i.e. auto-rickshaw and chhakdas.[12]

The study area consists of both the Municipal area (RMC) and the Urban Development Area (RUDA). Since the characteristics of the road network would be different for both these areas, it was important to look at transportation characteristics at both these levels. It is very important to assess the existing transport supply in the city so as to understand its effectiveness in catering to the needs of the people. From the supply side, it is also essential to consider the demands of the people by examining the existing travel trends and understanding their needs. The gaps and issues identified would help in understanding the improvements required in the city. In order to appreciate the traffic and transport system characteristics, a number of field traffic surveys were conducted in the study area.

Figure 3-1: Trikon Baug: An important node in Rajkot

[12] The chhakda is a three-wheeled multi-utility vehicle manufactured locally that runs on diesel. It is rudimentary and therefore cheaper than other alternatives available in the market. Overloaded chakdas can often be seen on Rajkot roads as in several other cities in the northern parts of India (Mahurkar, 2003).

Figure 3-2: Hospital Chowk: An important node in Rajkot

Figure 3-3: Mahila College: An important node in Rajkot

3.1. Non-Motorised Transport

Non-motorised transport, including pedestrians and cyclists, are the most sustainable means of transport for people who do not own vehicles, i.e. the poor, and is also the best mode for shorter trips with almost no carbon emissions or air pollution. The infrastructure facilities available for NMT modes are as below.

3.1.1. Pedestrian facilities

Pedestrian facilities consist of the basic infrastructure required for the pedestrian to walk safely and comfortably on streets and footpaths, such as streetlights along the footpath, street furniture and traffic-calming measures like zebra crossings, and pedestrian-accentuated signals. Rajkot does not have pedestrian-accentuated signals or traffic-calming measures at intersections, but it does have footpaths and streetlights. Footpaths are present along most arterial and sub-arterial roads, but these footpaths are either discontinuous, encroached (by trees, parked vehicles and hawkers), or very narrow (Figure 3-5). This forces the pedestrian to walk on the carriageway, thus reducing the capacity for vehicular movement and exposing pedestrians to greater risk. The streetlights are mainly present on the median of the carriageway, whereas the footpaths are poorly lit and therefore unsafe. The major reason for the poor level of lighting is the large spacing between the lamps, which creates shadow areas. The size and location of footpaths is shown in Figure 3-6. Of all the roads having footpaths, only 27 per cent have a footpath width equal to or more than 2m, which is a comfortable space for two people to walk side-by-side. Footpaths are predominantly present along the 150 ft Ring Road towards Gondal Chowk, and in some parts of the old city. Most of the areas have lower footpath densities, even though the fabric of the city network is preferable for walking.

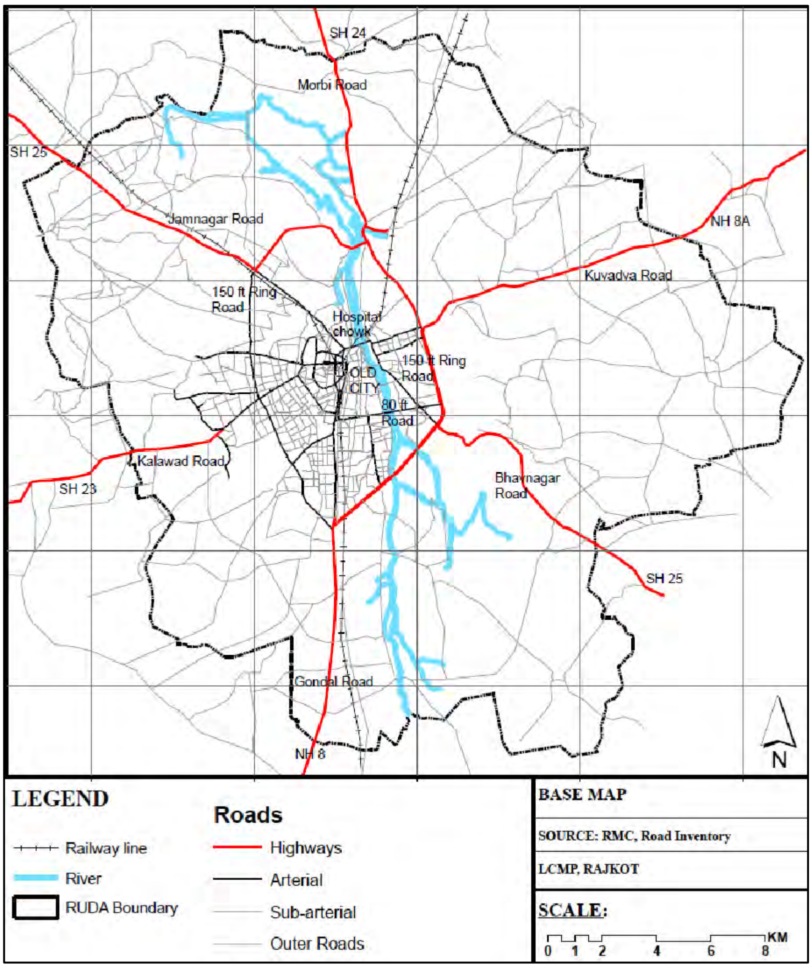

Figure 3-4: Road network in Rajkot

Source: RMC, Road Inventory, 2011

Figure 3-5: Pedestrian infrastructure in Rajkot

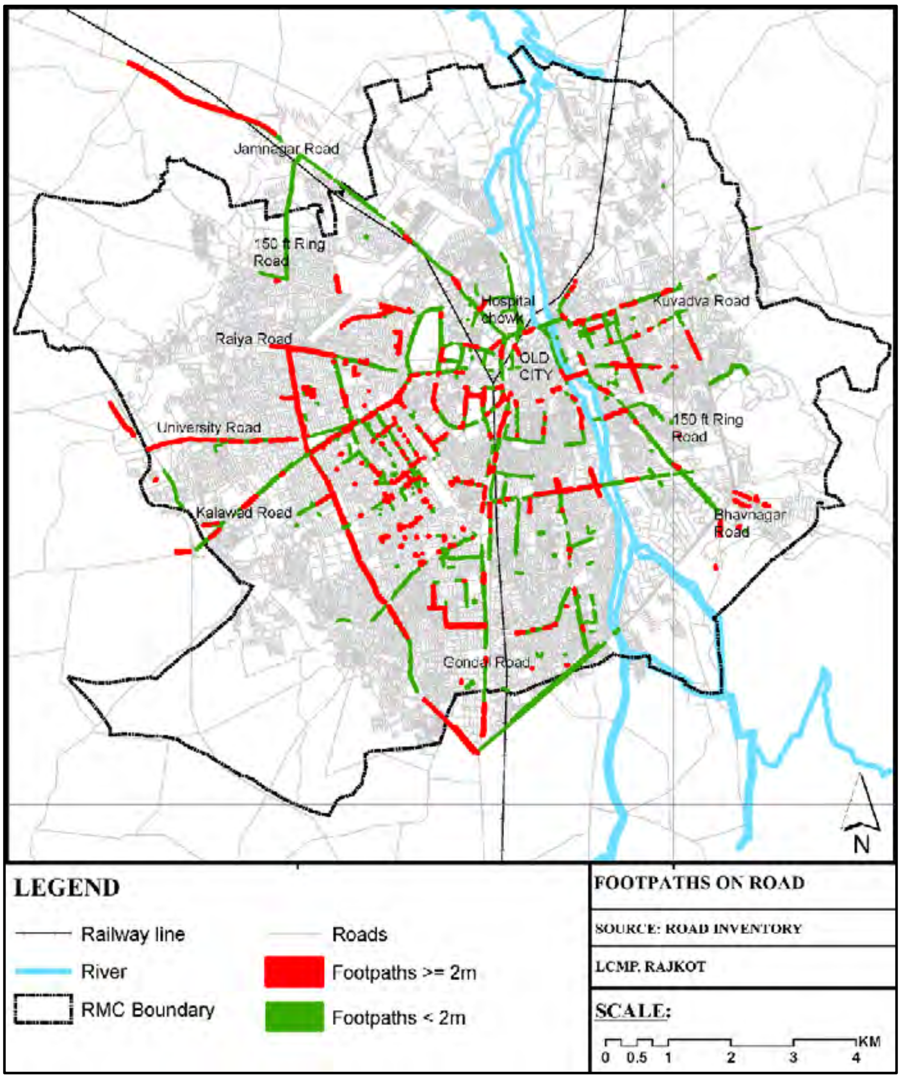

Figure 3-6: Footpaths along roads in Rajkot
Source: RMC, Road Inventory, 2011

3.1.2. Cycling facilities

The bicycle is an important mode of transport in developing countries, particularly for poor people who do not own vehicles and who want to make trips that are too long to walk. In Rajkot, bicycles are used largely by labourers working in manufacturing, and also by students going to schools. Presently, cyclists share the roads with motorised vehicles. Bicycle users feel unsafe and are slower due to the increasing number of motorised vehicles on the roads. Although cycle tracks were built along the BRT corridor in 2010, they are not the major routes of demand. Cycling facilities can be improved by providing cycle tracks and by implementing bicycle-accentuated signals, bicycle sharing and bicycle parking. Like the road network, there should be a bicycle network connecting all the possible origins and destinations of existing and probable bicycle users, based on demand. Cycle route planning with all the facilities needs to be stressed in Rajkot's City Mobility Plan. NMT infrastructure is an identified need in sustainable transport policy documents, and in low-carbon policies at the national level. It needs to be implemented at the city level, maintaining the historic share of bicycles and pedestrians in the future.

3.2. Public Transport System

Public transport is an important system for a city's internal transportation, as it mobilises groups of people simultaneously. City public transport includes city buses, BRT buses, metro, light rail transit, etc. for internal transportation. In the Indian context, auto-rickshaws are also included in the public transport system, as they work as feeders for public transport services and add an option for groups of people to commute from one place to another. The PT routes are shown in Figure 3-7 below.

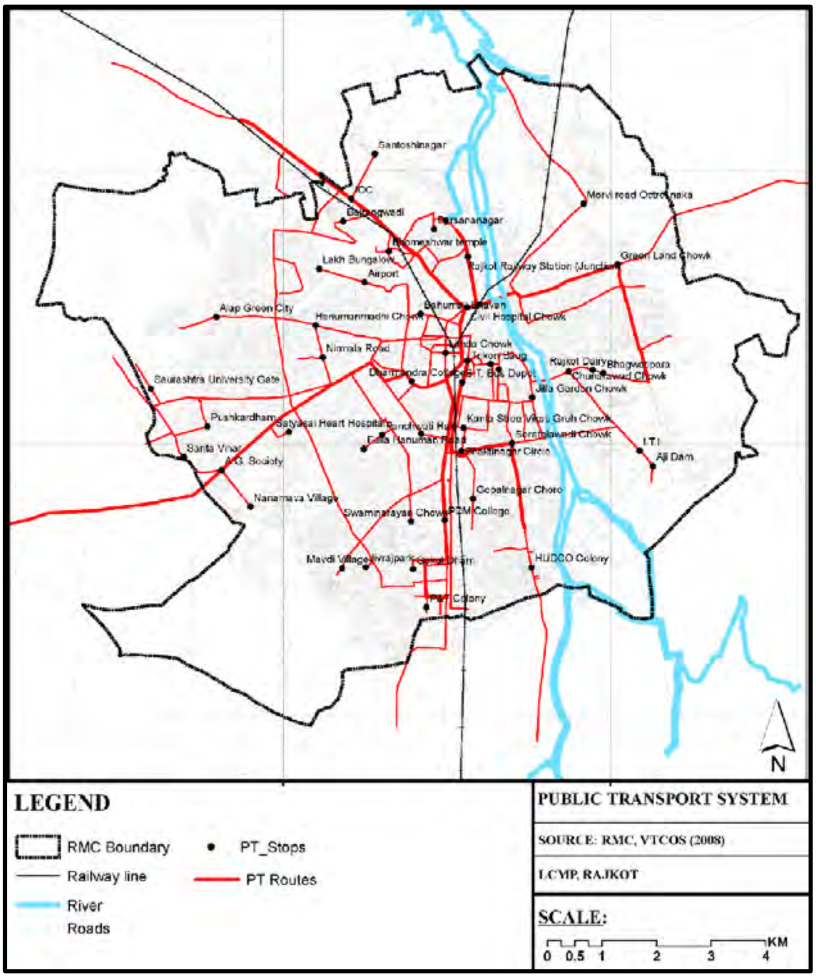

Figure 3-7: Map showing public transport routes and stops
Source: (Rajkot Municipal Corporation, 2007)

3.2.1. City transport

Public transport can be the backbone of Rajkot's transportation system. Like many medium-sized cities, it too has problems pertaining to intra-city transportation. The Municipal Corporation operated the city bus services for a while, but was unable to continue. The insufficient scale of operations made it uneconomical for private enterprise; for example VTCOS began operating city buses, but soon stopped in 2010. Since then, city buses have not operated on the roads of Rajkot[13]. At present, the majority of public transport requirements are met through autos.

3.2.2. Bus Rapid Transit (BRT)

In 2008, the RMC decided to enhance the public transport service by providing a Bus Rapid Transit system. The project was estimated to cost 110 crores[14]. The total network length of 63.5km was planned with three corridors, namely blue (29km), green (16.5km) and red (18km) to be developed phase-wise (Rajkot Municipal Corporation, 2007). About 10.7km of the first phase (29km) of the Blue corridor has been completed in the west, connecting Madhapar Chowk in the northwest to Gondal Chowk in southwest, connecting new developments in the western part of the city to the BRTS. These routes are shown in Figure 3-8.

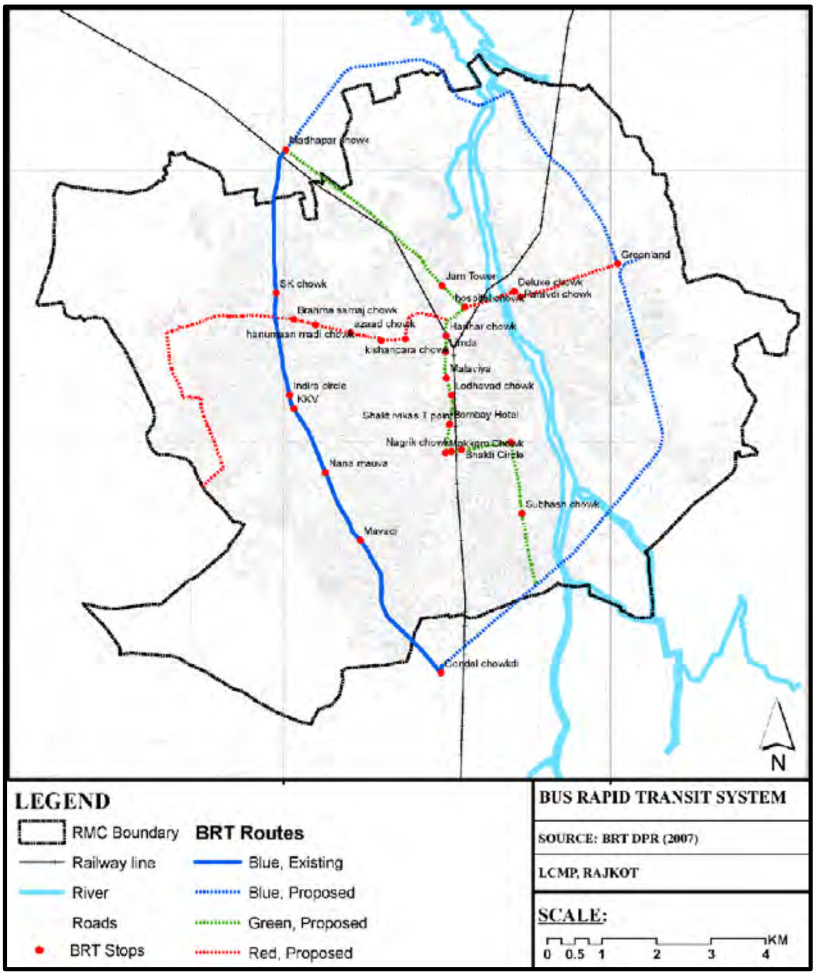

Figure 3-8: Map showing BRTS routes in Rajkot
Source: (Rajkot Municipal Corporation, 2007)

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[13] By December 2013, RMC had recommenced city bus operations through Rajkot Mass Transport Service (RMTS). Since these are initial days, its effect on the mode share in the city is hard to tell.
[14] A crore is equal to 10 million. 100 crores make a billion.

Figure 3-9: BRTS stop at Raiya Chowk

Figure 3-10: Image showing a BRTS bus negotiating the rotary at a station

Figure 3-11: Image showing activities along BRTS corridor

3.2.3. Intermediate Public Transit (IPT)

Intermediate Public Transit Systems (IPTs) are indispensable means of transport in medium-sized Indian cities for various reasons. The size, pattern, structure, socio-economic conditions and network characteristics of these cities and the service flexibility of the IPT make it a vital transport system. The popularity of the system is evident from the fact that in some medium-sized cities, IPT serves nearly 80 to 90 per cent of the total passenger trips catered by public transport (Luthra, 2006). Chhakdas and auto rickshaws are the transport modes offering para-transit services in Rajkot, and these typically offer six to eight person capacity (often packed with more people). Both these modes have supplemented the role of public transport in the city. In the context of growing travel demand, with the multi-dimensionality of trips and constraints on public resources, it is important to recognise the role of para-transit systems and incorporate them into the planning and development process. IPT surveys and road inventory surveys gave an estimate of the origins and destinations of the trips made by chhakdas, which run as a shuttle service. On average, autos operate 16 trips daily, while chhakdas operate 10 trips daily. There are about seven major points from which shuttle services start: the Bus Terminal, Hospital Chowk, Trikon Baug, Greenland Chowk, Gondal Chowk, Kothariya Road Chowk and the Rail Terminal. Dispersal is mainly through the Intermediate Public Transit System (IPTS). Chhakdas from these main stands move largely on the arterials in east, west and south, connecting Gondal Chowk, KKV Circle, Madhapar Chowk, Greenland Chowk and Aji Industrial area. Other than chhakdas, there are many auto-rickshaw stands where two to six auto rickshaws are available for the public at any time, making trips to any part of the city. Figure 3-12 shows the routes mapped for shuttle rickshaws.

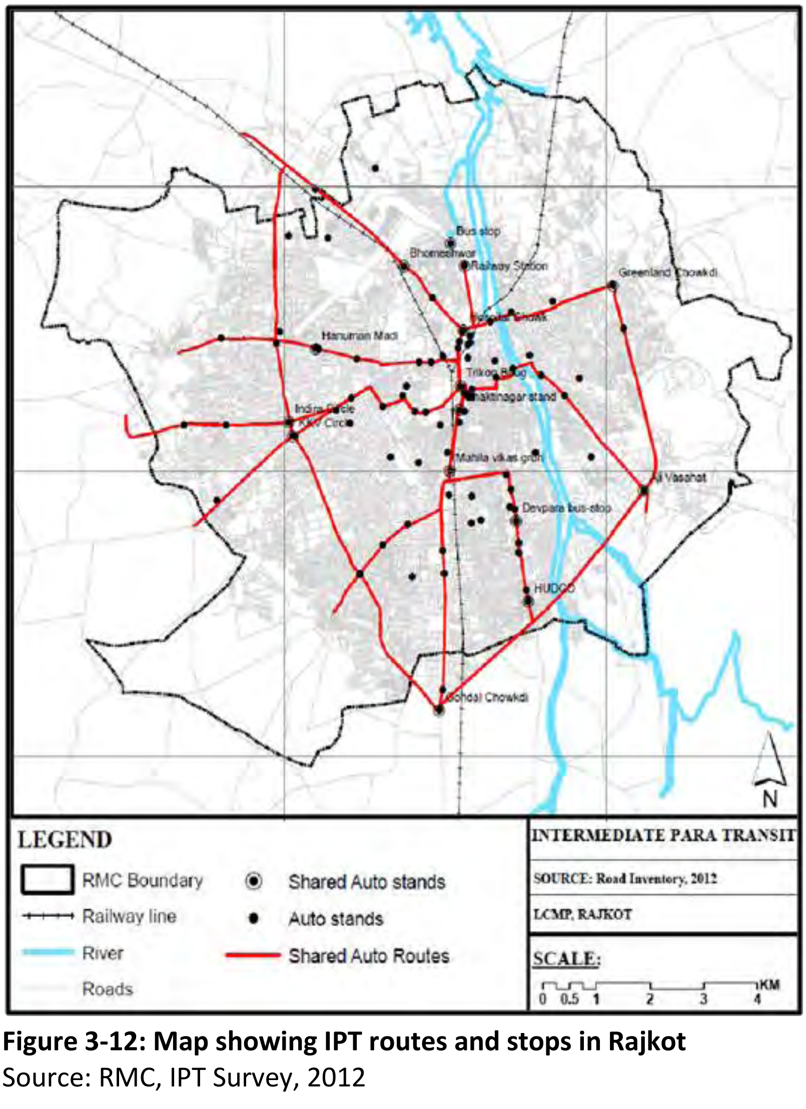

Figure 3-12: Map showing IPT routes and stops in Rajkot
Source: RMC, IPT Survey, 2012

3.3. Infrastructure for Private Motorised Vehicles

Private Motorised Vehicles include two-wheelers and four-wheelers. In this section, the infrastructure for motorised two-wheelers and four-wheelers is analysed on the basis of characteristics like carriage width, number of lanes, quality of pavement, speeds, parking and other activities on the road.

3.3.1. Network characteristics

Network characteristics are intrinsic properties related to the performance and reliability of a network. An appreciation of road network characteristics is important to assess the existing capacity, to identify the constraints and assess the potential for improvement, and up-gradation of the road network, as well as to cater to the existing and projected demand of traffic. The total road network length of the study area is approximately 2291km, out of which the RMC area includes 1,799km and RUDA has 492km of road length (79 and 21 per cent respectively). Both the agencies, RMC and RUDA, are responsible for providing infrastructure in their respective boundaries. There is very little development outside the RMC boundary, so the roads are still not 'pukka' (tarred), except for the highways. The road network inside the RMC boundary is very dense at many places, particularly in the old city area, where the network does not follow any particular pattern like the regular grid networks in the newer developments. The city roads form a ring-radial pattern. There are six radials and one major ring that form the ring-radial pattern for Rajkot. These roads facilitate the regional external-internal and internal-external traffic movement. These are Morbi Road, Ahmedabad Road, Bhavnagar Road, Gondal Road, Kalawad Road, Jamnagar Road and the Ring Road. The river Aji in the city flows from north to south, dividing the city into east and west. Another barrier to traffic movement within the city is the rail network along the river in the north-south direction. Most of the city roads have an intense ribbon development of commercial activities, forming mixed use development along the arterials and some sub-arterials.

Road hierarchy

Roads are broadly classified as highways, arterials, sub-arterials, collector & local, and outer RMC roads[15]. Passing through the study area is a national highway that connects Rajkot with Ahmedabad (NH8A), and three state highways going towards Kalawad (SH23), Morbi (SH24), Jamnagar and Bhavnagar (SH25). The ring road and major roads connect the highway with the arterials of the city. These arterials further branch out into sub-arterials leading to inner land parcels by collector and local streets. The collector and local roads also form a grid-like pattern. The national and state highways form 4.51 per cent of the road network. The arterial and sub-arterial roads account for 11.34 per cent, whereas the collector and local roads account for 63.30 per cent. The roads outside the RMC area constitute 21 per cent of the total network in the study area. The road hierarchy is not only formed by the width of the road, but also by the function of the road in terms of its connectivity in the city. The road characteristics are summarised in Table 3-1.

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[15] As per IRC 86:1983 Geometric Design Standards for Urban Roads in Plains (The Indian Roads Congress, 1983)

Table 3-1: Road hierarchy in Rajkot

Road type	Average ROW (m)	Length (km)	Per cent of length (%)	Avg. Lanes	Per cent of Metal roads (%)	Avg. Speeds (km/hr)
Highways	22.0	121	4.51	3	18%	40
Arterial	18.0	68	2.53	3	70%	18
Sub-arterial	12.5	237	8.81	2	73%	14
Collector & Local	7.5	1,704	63.30	1	60%	10
Outer roads	10.0	560	20.80	1	27%	16
Total		2,690	100.00		62%	-

Source: Speed and delay survey, 2012

Assessing the road network requires defining each of the characteristics individually, and analysing them spatially in the city. The road hierarchy for the study area is shown in Figure 3-13.

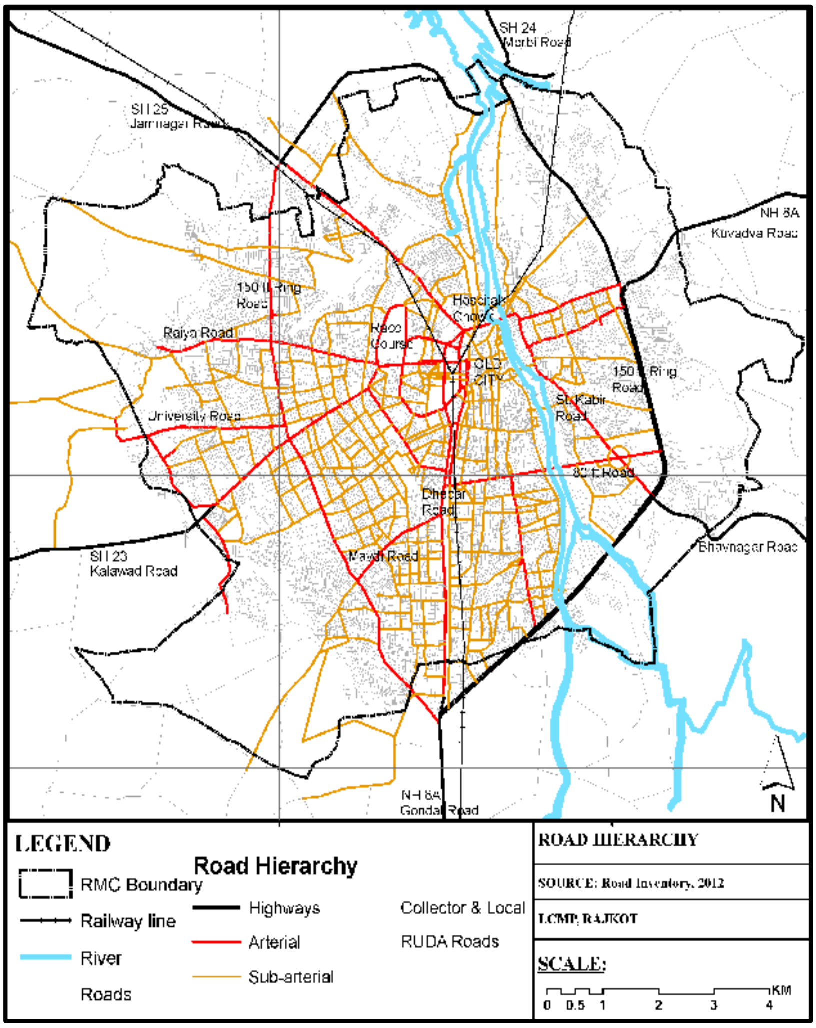

Figure 3-13: Map showing road hierarchy in Rajkot

Source: Road inventory, 2012

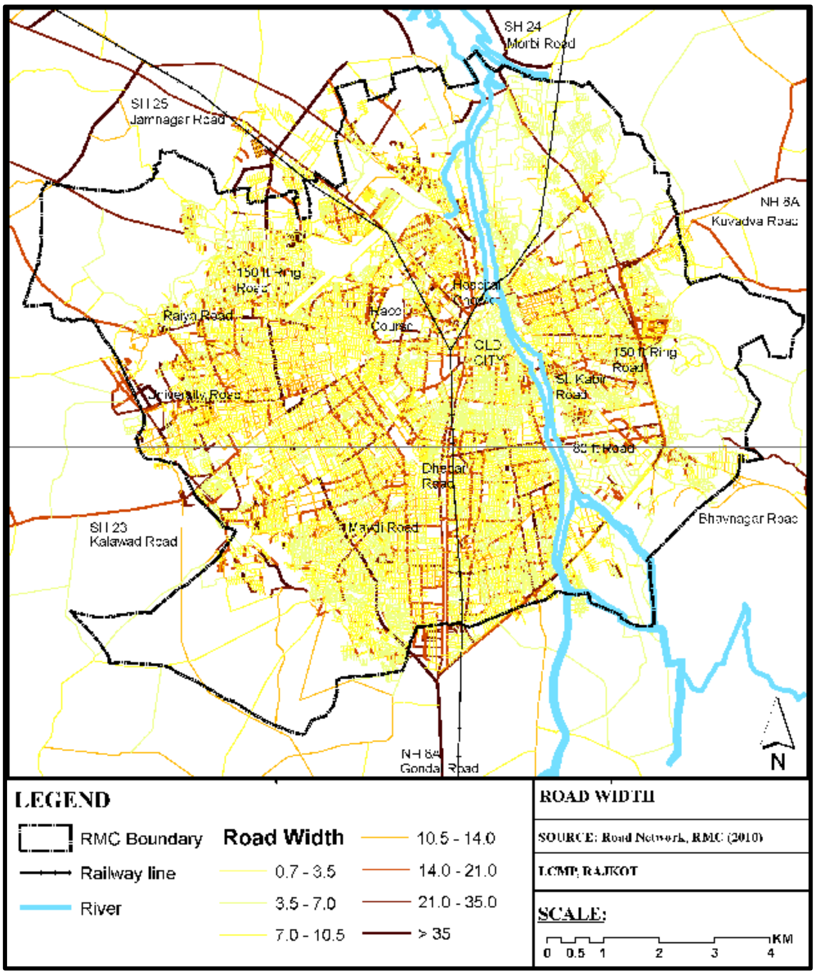

Figure 3-14: Map showing road widths in Rajkot
Source: RMC Road Network, 2010

Right-of-Way (ROW)

The distribution of road length by right-of-way (ROW) reveals that 97 per cent of the city's roads have ROW up to 30m (Figure 3-14).[16] Only 3 per cent of roads have ROW of 30 m and broader. This length of road network has the potential for being developed into corridors with a four-lane (or above) carriageway. Out of all Rajkot's major roads with the heaviest external-internal traffic, Ahmedabad Road, Jamnagar Road and the Ring Road have the broadest ROW, ranging between 30 to 40m. In the central city, most of the roads have ROW narrower than 10m. This is a high density commercial zone with intensive activities like shops, hawkers, etc., as well as high vehicular movement. Therefore, during peak hours and off-peak hours, these roads are congested with vehicles and pedestrians. Conversely, the newer developments in the west are broader but are gradually becoming commercial streets with high congestion[17] during peak hours. Road widths are

[16] Right of Way (ROW) is the width of road between property lines on both sides, whereas carriageway is the road width left for the vehicles to drive without any physical separations, laterally.

[17] Congestion occurs when the volume of traffic exceeds the capacity of the road. The road capacity differs by the number of lanes and division of the carriageway.

not homogenous, and there are bottlenecks along many major and internal roads, causing traffic congestion and delays at many points in the city. Though most roads are complete, there are some exceptions due to physical barriers like creeks or railway lines, breaking continuity and creating congestion in some pockets.

Number of lanes

A lane is part of a carriageway that is designated for use by vehicles to control and guide drivers and reduce traffic controls. The Indian Road Congress (IRC) has specified the dimensions of a typical lane and its capacity. A single lane is 3.5m and it multiplies for two, three and four lane roads. It has been observed that almost 81 per cent of roads are very narrow and have a single lane, i.e. the two-way carriage width is 7m or narrower. Further, it can be seen that only 12 per cent of roads (mainly arterial or sub-arterials) are two or three-lane roads in the city. Highways have four or more lanes, accounting for the remaining 7 per cent.

Pavement type

Road surfaces are marked to guide vehicular and pedestrian traffic. Indian surfaces are mostly made of asphalt and concrete. In Rajkot, about 57 per cent of the road network has asphalted pavement. Concrete surface roads account for 0.5 per cent of total road length, while 43 per cent roads are un-metalled. Footpaths have bituminous surfaces but are broken and chipped at many locations, making it difficult to walk. Only 8 per cent of the total roads in the study area have dividers.

Speeds

Travel speed is an important characteristic of traffic. Its measurement is frequently required in transport planning, particularly to evaluate the road network system. It provides vital input to the transport demand modelling process, and assists in the economic analysis of improvement plans. For the purpose of this study, speed and delay surveys for private vehicles were conducted, i.e. for cars, two-wheelers and auto-rickshaws, measuring the time taken by the vehicle to cross a stretch, along with the reasons for any delay. The overtaking and overtaken vehicles were also noted to learn the speed of other moving vehicles, which is known as the moving-vehicle method. Speeds were checked twice on a single stretch in peak and off-peak hours. The average speed of all these modes in the city is 16km/hr. Speeds in the city are much lower in the old city area due to delays from the narrow streets and people walking on the streets. It also shows that most arterial roads have average speeds over 20km/hr. Unlike other cities, the local streets in Rajkot have an average speed of 10km/hr due to a number of intersections after every kilometre which makes them more pedestrian and bicycle-friendly. Figure 3-15 and Table 3-2 show experienced speeds on various roads in Rajkot.

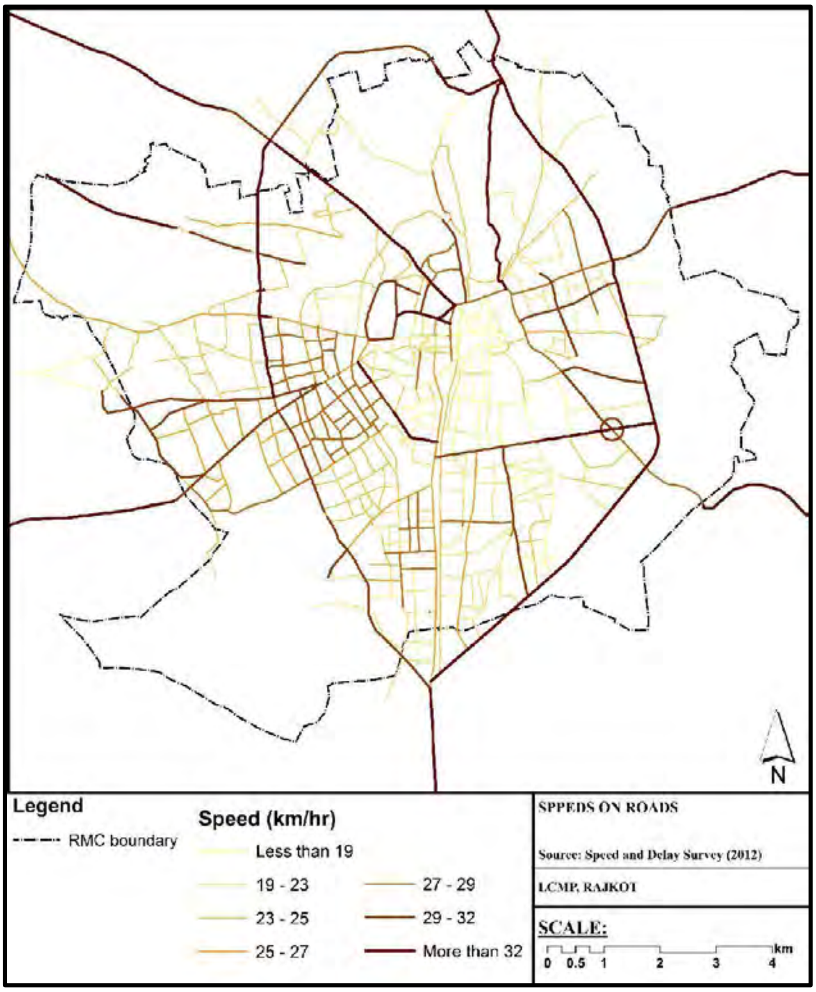

Figure 3-15: Map showing speeds experienced along various roads in Rajkot
Source: Speed and delay survey, 2012

Table 3-2: Comparison of major roads and their speeds

Road name	RoW	Lanes	Length	Type	Pavement	Divided	Speed (kmph)
NH 8	40.0	3.0	66.7	Highway	Metalled	Divided	28
Jamnagar Road (SH 25)	18.0	3.0	14.7	Arterial	Metalled	Divided	32
Morbi Road (SH 24)	24.0	3.0	5.3	Arterial	Metalled	-	35
Bhavnagar Road (SH 25)	12.4	2.0	7.2	Arterial	Metalled	Divided	25
Kalavad Road (SH 23)	20.0	3.0	5.2	Arterial	Metalled	Divided	24
Gondal Road	17.4	3.5	7.0	Arterial	Metalled	Divided	18
Dhebar Road	15.0	2.5	8.4	Arterial	Metalled	Undivided	15
Kuvadva Road	25.2	2.5	3.1	Arterial	Metalled	Divided	25
150 ft. Ring Road	40.0	3.0	29.0	Arterial	Metalled	Divided	28
80 ft. Road	23.3	2.0	3.4	Arterial	Metalled	Divided	14
Raiya Road	12.0	1.5	24.0	Arterial	Metalled	Divided	15
Mavdi Road	14.8	1.5	7.2	Arterial	Metalled	Divided	14
University Road	24.2	2.0	13.7	Arterial	Metalled	Undivided	18
St. Kabir Road	24.6	3.0	1.8	Sub-arterial	Metalled	Divided	14
Kothariya Road	18.3	2.5	16.5	Sub-arterial	Metalled	Divided	18
Yagnik Road	19.2	2.0	4.0	Sub-arterial	Metalled	Undivided	16
Canal Road	14.8	2.5	0.75	Sub-arterial	Metalled	Undivided	14
Jawahar Road	26.1	3.0	0.4	Sub-arterial	Metalled	Divided	16
Amin Marg	16.6	2.0	1.4	Sub-arterial	Metalled	Undivided	18

Source: Speed and delay survey, 2012

To provide easier and safer road infrastructure for motorised vehicles, there have been some above-grade and below-grade infrastructure facilities to assist in crossing the physical barriers in the city. Bridges across the river were built many years ago, assisting development across the river, whereas flyovers and underpasses have improved the movement of people and speeds of vehicles in recent years.

3.3.2. Flyovers, underpasses and bridges

Bridges and underpasses mainly connect the eastern and western parts, which have been divided by the river and railway track passing through the north and south of the city (Figure 3-18). The Kaiser-e-Hind and Indira Bridge are the major bridges used by motorised vehicles to travel from west to east or vice-versa. The Vora Bridge in the centre is narrow and is mainly used by pedestrians. There are presently two underpasses at Mahila College and Mavdi Chowk. There is only one flyover in the city at KKV Circle along the Ring Road, but two more are under construction. There are currently four major bridges, two flyovers and five underpasses in the city.

Figure 3-16: Image showing flyover at KKV Circle

Figure 3-17: Image showing Kaiser-e-Hind Bridge

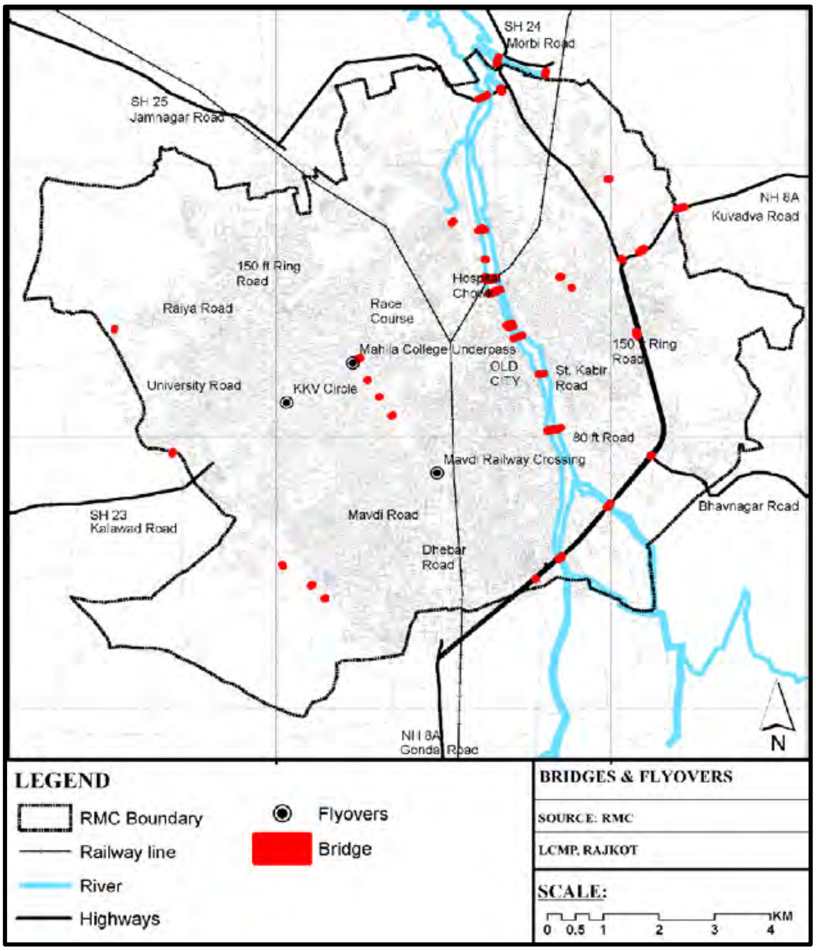

Figure 3-18: Map showing bridges and flyovers in Rajkot
Source: RMC, 2012

3.4. Infrastructure for Freight Movement

Apart from the movement of people, road infrastructure is also used for the movement of goods. Rajkot, being the hub of many small and medium-scale industries, sees considerable movement of goods to and from different parts of India. This has resulted in an increase of freight movement on the highways and arterial roads of Rajkot (Table 3-3). It becomes difficult to manage the traffic when heavy and small vehicles operate in the same space. Therefore, Rajkot Municipal Corporation and the traffic police are taking many steps to control heavy traffic movement in the city. Heavy vehicle movements inside the city are restricted between 8am and 1pm and again between 4pm and 9pm to ease traffic during peak hours. To assess freight movement in the city, freight O-D surveys were conducted at six different locations in the outer cordons. These surveys were conducted for 16 hours to identify the routes that are mainly used inside the city and the destinations of the freight. The freight terminals located in the study area were Marketing Yard near Greenland Chowk, Atika Industrial Area near Gondal Road, Bhaktinagar Railway Yard on Mavdi Road and IOC near Madhapar Chowk. It was also observed that many of the transporters are located in the city. Therefore, chhakdas or 'tempos' function as intermediate transport vehicles for the movement of goods in the city. The routes of these small vehicles for freight movement were also mapped from the OD survey shown in Figure 3-19. The loading and unloading of these small vehicles also create congestion on these routes and are illegally parked in many locations in the city.

Table 3-3: Traffic volume counts for various types of vehicles

	Chhakda	LCV	Tempo	Tractor	Truck	Truck-trailer	Grand Total
Aji Chawkdi	33	47	29	10	33	-	152
Gondal Chawkdi	39	35	17	6	40	1	138
Jamnagar Road	13	17	12	2	109	-	153
Kalavad Road	49	46	12	3	40	-	150
Kuvadva Jakat Naka	16	17	13	4	36	1	87
Morbi Road	26	14	13	3	39	-	95
Grand Total	176	176	96	28	297	2	775

Source: Freight OD survey, 2012

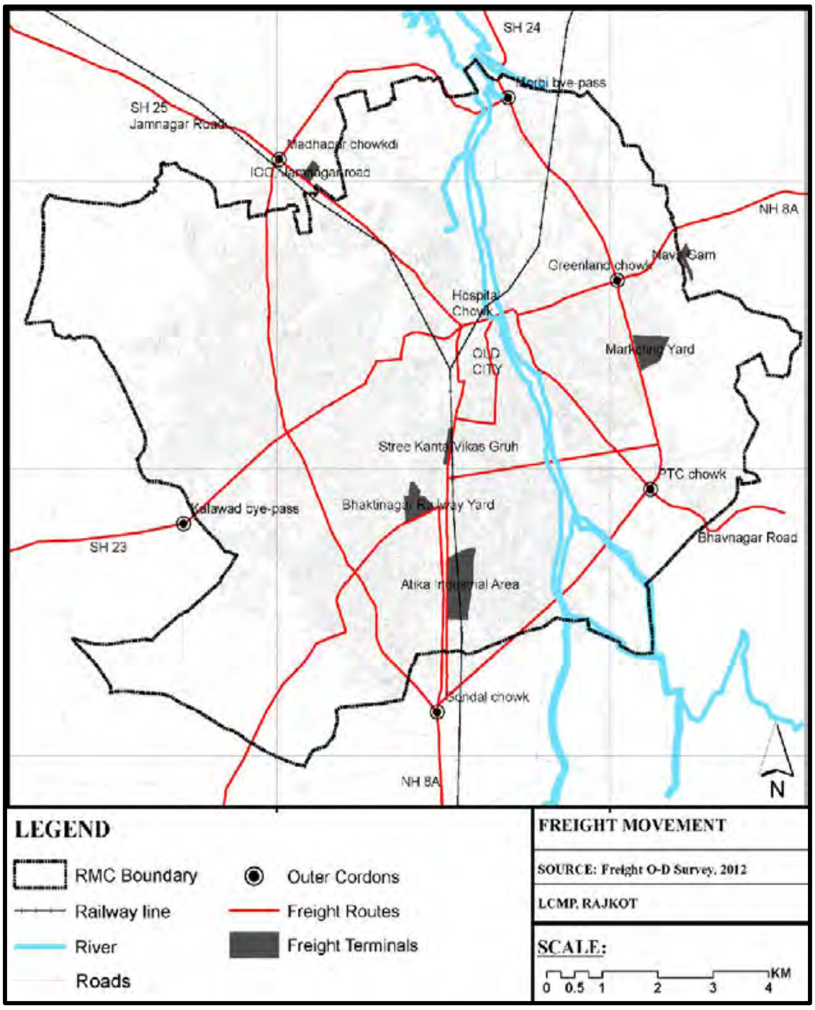

Figure 3-19: Map showing freight movement in Rajkot
Source: Freight O-D survey, 2012

The major freight routes used by light commercial vehicles (LCVs) and chhakdas are arterial roads like 150ft Ring Road, Bhavnagar Road, Gondal Road, Kalawad Road, the national highway leading to Ahmedabad, 80ft Road and Jamnagar Road.

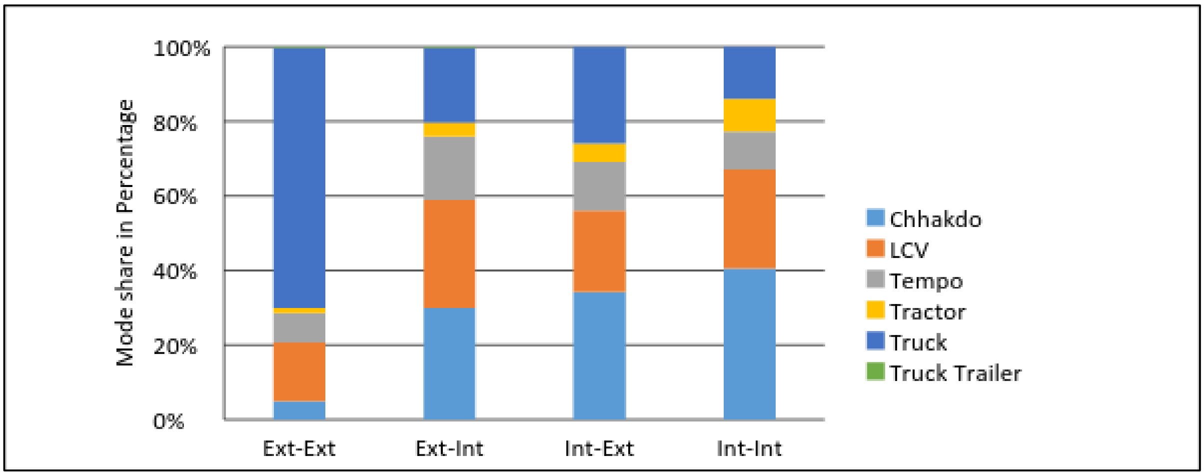

Figure 3-20: Mode-wise freight trips, origins and destinations
Source: Freight O-D survey, 2012

Most of the freight movement inside the city is made by chhakdas, LCVs and tempos. External-external freight is transported largely by trucks, whereas external-internal, internal-external or internal-internal freight movement is made largely by chhakdas, LCVs or tempos (Figure 3-20).

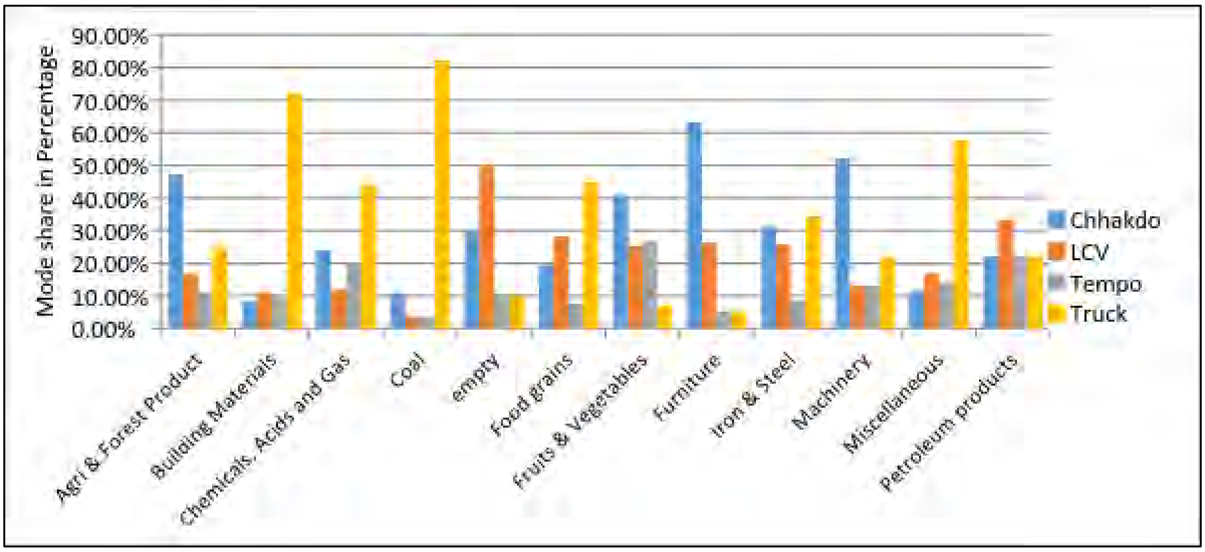

Figure 3-21: Modes used for transportation of goods
Source: Freight O-D survey, 2012

The commodities brought inside the city by chhakdas or LCVs are mostly perishable goods like vegetables, food grains, agricultural products, etc., whereas non-perishable goods like building raw materials, industrial goods, etc., are transported by trucks at night or early morning when heavy vehicle restrictions are not in effect (Figure 3-21).

3.5. Parking and Other Activities on Roads

Parking and the other activities on roads are generally not noted or mapped by the Municipal Corporation, and are disregarded in the studies and planning activities. Therefore, it was necessary to conduct a road inventory survey and mark the space used by parking and other activities in peak and off-peak hours. An intense inventory survey marking the type of activity, space usage of road and the type of vehicle parked was conducted on each road of the city. These surveys were intended to provide information on the parking demand, extent of the usage of parking and other facilities, and availability of parking space and space for other activities. These activities are largely found on arterial and sub-arterials roads that have commercial activities. Table 3-4 shows the activities across major road categories as observed during the road inventory survey.

Table 3-4: Activities along major road categories

Road type	Parking	Road-side shops	Shop spill out	Public utility	Religious	Other	Total
Highways	3%	0%	0%	0%	0%	0%	3%
Arterial	20%	58%	65%	23%	50%	63%	25%
Sub-arterial	53%	26%	24%	77%	40%	22%	54%
Collector & local	24%	16%	11%	0%	10%	15%	18%
Total	100%	100%	100%	100%	100%	100%	100%

Source: Road inventory, 2012

3.5.1. Parking

Parking is broadly classified into three categories: legal, informal and no-parking zones. Legal parking refers to parking in those spaces specifically demarcated for parking in the right-of-way with or without a parking fee. Informal parking is present along the streets with commercial or residential spaces that do not have enough parking inside. The industrial areas see trucks parked on the roads. The Municipal Corporation has prohibited parking along many segments of central city roads where the road width is narrower and parking disrupts vehicular movement. There are also some roads along which the RMC has provided legal parallel parking spaces, but no parking fee is charged, which has led to haphazard parking at many places (Figure 3-23). The spatial locations of parking on the streets are shown in the map below. Most parking is present along the Dhebar Road, Gondal Road and 80ft Road. There are trucks that are parked along some of the stretches of these roads due to the location of industries in these areas. Many roads in the old city area are crowded due to parked vehicles, making pedestrian movement difficult as the roads are too narrow. Raiya Road and Kalawad Road have parking due to commercial activities along on the whole stretch, whereas Greenland Chowk in the east has many buses in the vicinity. Hospital Chowk, which is one of the centres of the city, has many parked auto-rickshaws, which go to all parts of the city. Many internal roads have cars and two-wheelers parked on the whole stretch due to few parking spaces provided in residential areas. Figure 3-23 shows various types of parking on Rajkot roads.

Figure 3-22: Image showing roadside parking in Rajkot

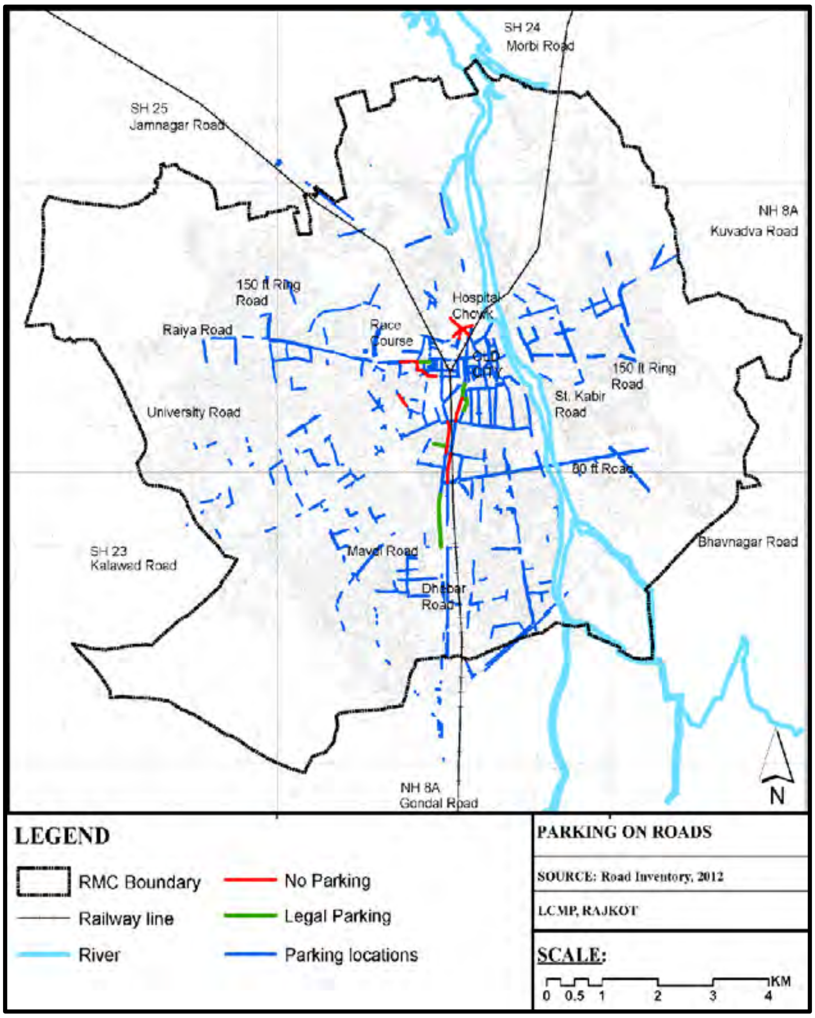

Figure 3-23: Map showing parking on roads in Rajkot
Source: Inventory survey, 2012

3.5.2. Other activities

In the Indian context, understanding the carriageway is not enough for analysing network characteristics. There are lot of activities on the streets, like parking and informal activities like vegetable markets, food stalls and laris,[18] shopping markets, etc. These activities have become part of the road and part of people's daily lifestyle. Thus, understanding its character and presence on Indian roads is very important. Other activities include hawkers, food vendors, shop spillovers, religious shrines, and public utilities or plants along the roads and footpaths. These activities are found predominantly along arterial and sub-arterial roads in commercial areas. These activities have come up on the roads without any regulations or laws, but they have become an integral part of street life. They form attractive markets for pedestrians in which to shop and walk without realizing the effort spent in walking. Table 3-5 shows parking and other activities on the major roads at a disaggregated level.

[18] Lari: Two-wheeled cart pulled by a person to sell vegetables/fruits, etc.

Table 3-5: Parking and other activities on roads

Road name	Parking	Road shops	Shop spillout	Public utility	Religious	Plants	Total
NH 8	3.83%	5.32%	0.00%	0.00%	0.00%	0.00%	3.77%
Jamnagar Road	0.77%	2.84%	0.00%	4.17%	2.33%	0.00%	1.24%
Morbi Road	0.27%	0.71%	0.78%	0.00%	2.33%	0.00%	0.41%
Bhavnagar Road	1.04%	2.13%	0.00%	6.25%	0.00%	0.00%	1.28%
Kalavad Road	0.55%	0.00%	1.55%	2.08%	0.00%	60.00%	0.60%
Gondal Road	5.46%	3.01%	3.10%	0.00%	2.33%	0.00%	4.60%
Dhebar Road	0.00%	0.35%	0.00%	0.00%	0.00%	0.00%	0.08%
Kuvadva Road	2.62%	3.19%	0.78%	0.00%	0.00%	17.39%	2.67%
150 ft. Ring Road	0.66%	0.18%	3.88%	0.00%	0.00%	0.00%	0.68%
80 ft. Road	2.90%	2.13%	6.20%	0.00%	0.00%	0.00%	2.75%
Raiya Road	0.93%	3.19%	2.33%	2.08%	0.00%	0.00%	1.47%
Mavdi Road	0.05%	0.18%	0.78%	2.08%	4.65%	0.00%	0.23%
University Road	0.87%	1.06%	4.65%	0.00%	0.00%	0.00%	1.05%
St. Kabir Road	2.57%	6.74%	6.20%	0.00%	0.00%	8.70%	3.58%
Kothariya Road	1.69%	0.35%	0.00%	0.00%	0.00%	0.00%	1.24%
Canal Road	0.22%	0.00%	0.00%	0.00%	0.00%	0.00%	0.15%
Jawahar Road	0.22%	0.00%	0.00%	0.00%	0.00%	0.00%	0.15%
Amin Marg	3.83%	5.32%	0.00%	0.00%	0.00%	0.00%	3.77%
Palace Main Road	1.97%	0.71%	0.00%	2.08%	0.00%	0.00%	1.54%

Source: Road inventory survey, 2012)

Most of the old city area has these activities on all roads. These activities are also found on arterial roads like Kalawad Road, Raiya Road, Mavdi Road in the west, and on St. Kabir Road and Pedak Road in the east. These activities are also predominantly present on the Kothariya Road. Figure 3-24 shows the major informal markets in the city.

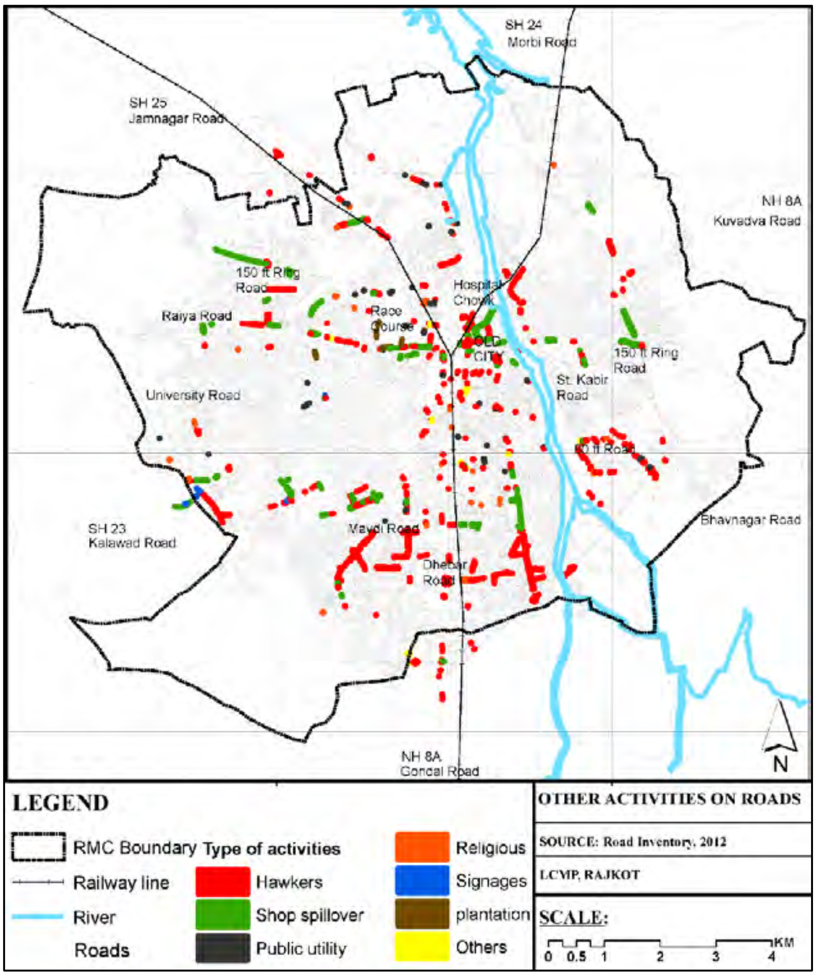

Figure 3-24: Map showing other activities on roads

Source: Inventory survey, 2012

Figure 3-25: Image showing various road-side activities on streets

3.6. Road Safety

Road safety is a major parameter in analysing road infrastructure, especially from the user perspective. The usability of roads is dependent largely on the safety of that infrastructure. When studying the safety of roads in the city, the first thing examined was the accident trend from 1988 to 2011. This data was collected from all the police stations in the city. Accidents have associated economic and social costs. With the growth of city, there is an increase in population, which causes an increase in traffic and thereby more accidents. While the data indicates a decreasing trend in the city's total accidents, fatal accidents have increased over the last year. It is also observed that males are involved in most fatal accidents in the city. Fatal accidents (as shown in Table 3-6) are almost 15 per cent of total accidents, which therefore requires attention regarding the causes, and steps to improve conditions.

Table 3-6: Percentage of accidents according to severity, 2010-11

Type of accidents	Percentage of accidents (%)
Fatal	14.66
With Injury	73.03
Without Injury	12.31

Source: Police stations, Rajkot

Figure 3-26 shows the trend line for fatal and non-fatal accidents. It can be seen that minor accidents have remained consistently high.

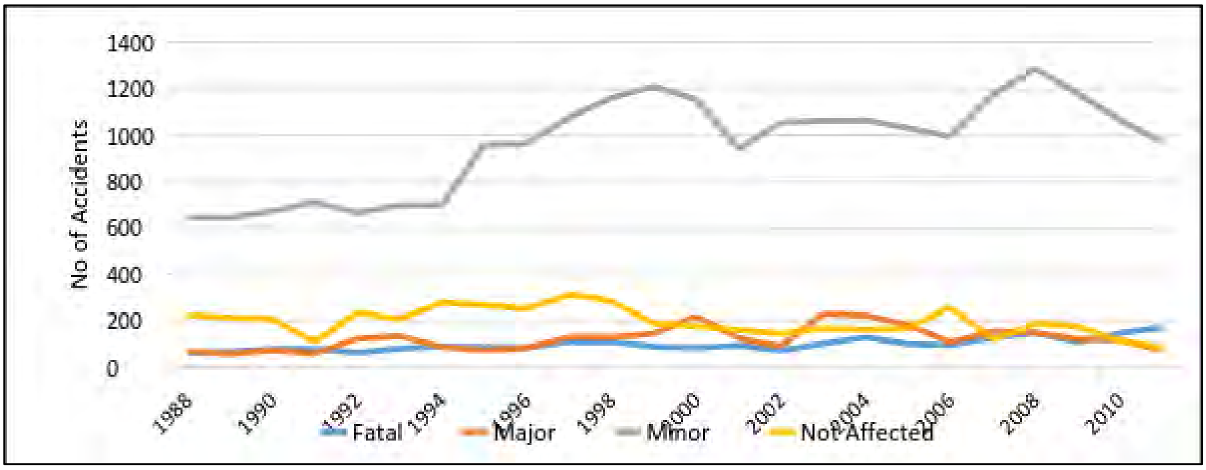

Figure 3-26: Number of accidents according to severity
Source: Police stations, Rajkot

The risk exposure of different modes refers to the number of fatal accidents per lakh of users of that mode. Mode-wise risk exposure of different vehicles shows that four-wheeler or car users are more exposed to fatal accidents than other mode users (Figure 3-27).

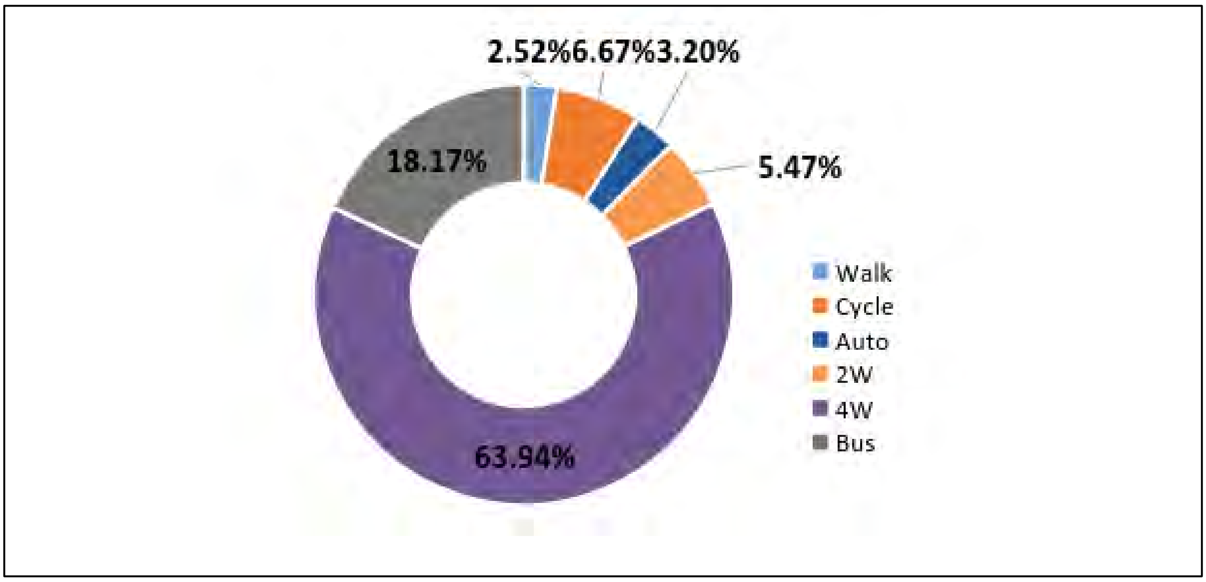

Figure 3-27: Risk exposure of different modes in Rajkot

On the other hand, the risk imposed means the number of accidents caused by the mode on other road users per lakh of all road users. Figure 3-28 shows that large trucks are the most dangerous vehicles, as they impose the most risk on other road users. Two-wheelers are the second most dangerous vehicles, which is mainly owing to their preponderance.

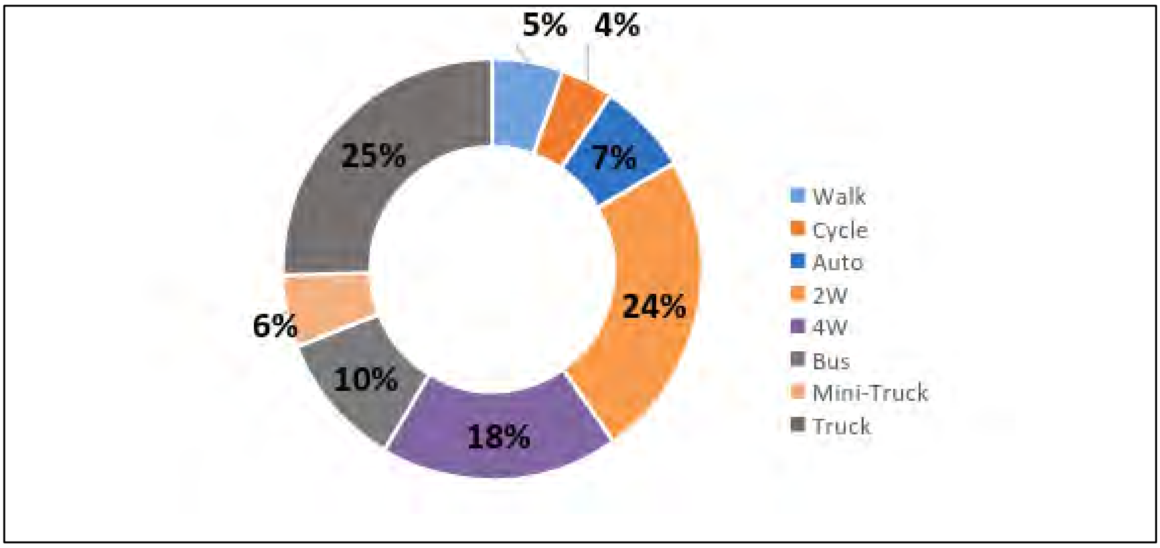

Figure 3-28: Risk imposed by different modes in Rajkot

Streets with fatal accidents

The accident rate per million people in the city is around 200, which is expected to increase over the years by 10 per cent. It is also important to examine major accident locations and then analyse the basic causes behind the accidents. Ameliorating the causes of accidents can ensure safety on the city’s road network. It is observed that 68 per cent of accidents have taken place on highways and arterial city roads where the speed of vehicles exceeds 30km/hour. The risk of accidents decreases with lower speeds on the inner roads, where there are more activities on the streets (Figure 3-29). Of the total 68 per cent of accidents that took place on highways and arterial roads, 23 per cent were fatal. These roads have high passenger and freight volumes, and very high speeds, making them more prone to fatal accidents.

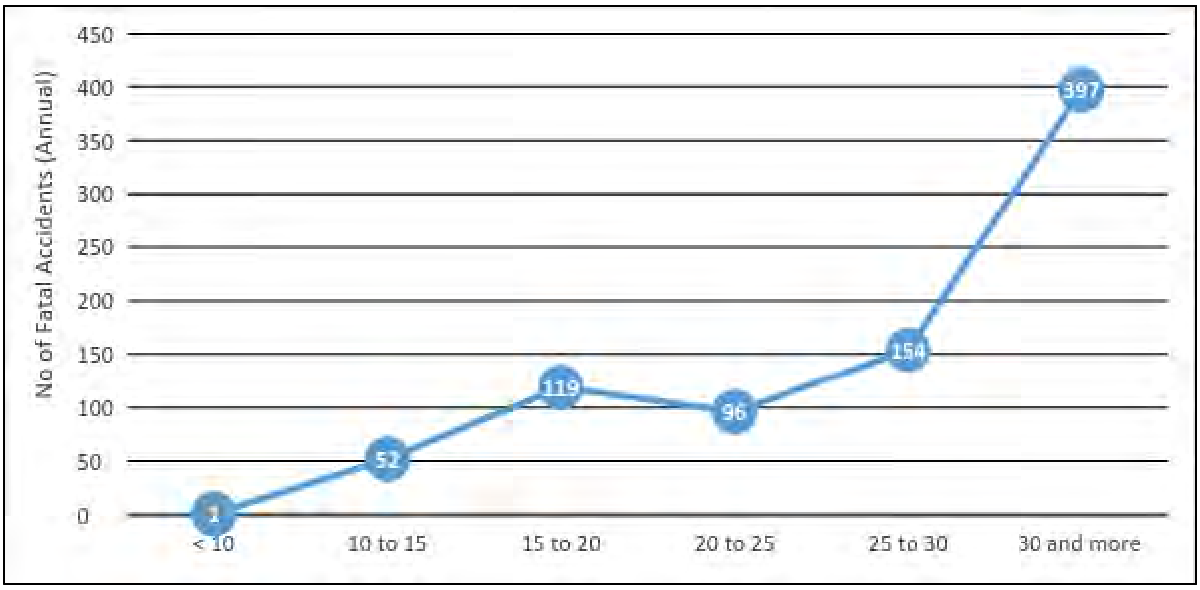

Figure 3-29: Fatal accidents and speeds

Source: Speed and Delay Survey, Study Estimates, 2012; and Police station accident data, 2011

These streets are also lit, but streetlights are present only on the road median, placed at a distance of 35m to 40m. Moreover, these streetlights are poorly maintained, and their sparse spacing and particular angles of lighting result in poor lighting levels in the streets. Poor lighting has often led to accidents on the transport network in the city. Other than the national highway, Bhavnagar Road and some state highways have frequent accidents due to high speeds and the large number of freight vehicles moving at night. Points along the internal roads that are prone to accidents are Kaiser-e-Hind bridge (peak hours) and 80ft Road where it connects to the industrial area, which has a high number of trucks parked along it. The situation is similar on Kothariya Road, which connects the Bhaktinagar Circle and has high freight traffic with 150ft Ring Road. Dhebar Road and Gondal Road also have high accident numbers as they not only connect the centre of the city to Gondal Chowk, but they also have high passenger vehicle volumes and freight traffic. Figure 3-30 shows accident spots in Rajkot.

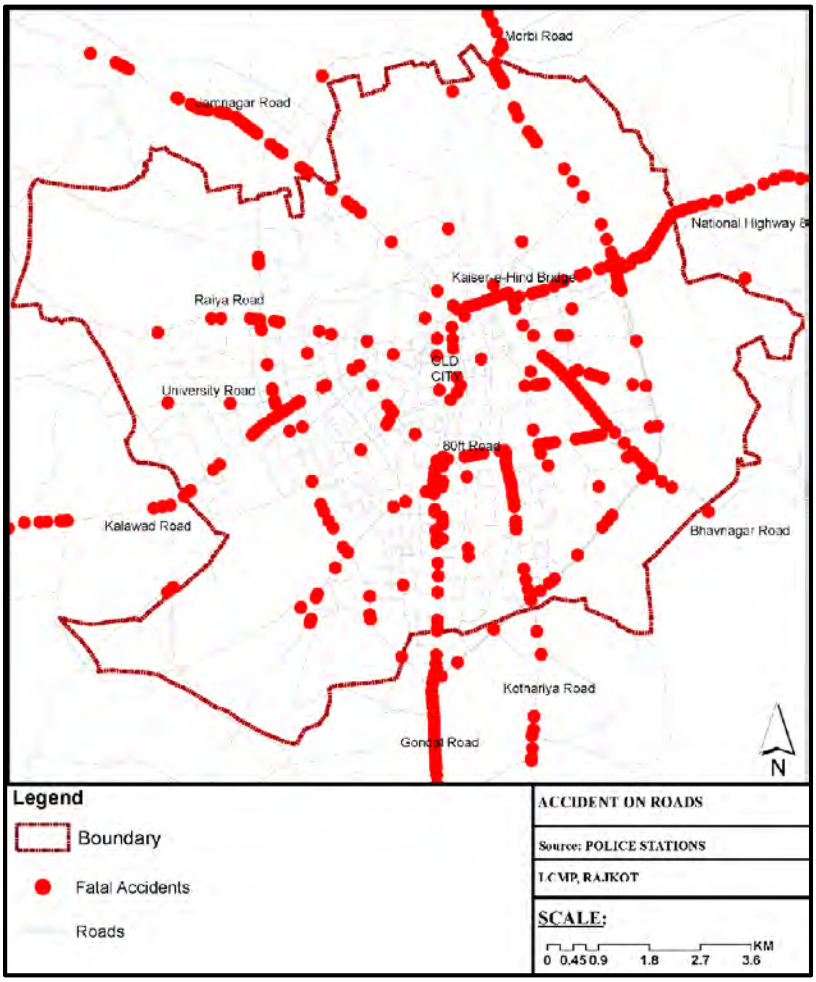

Figure 3-30: Map showing accident spots on roads
Source: Police stations, Rajkot

Studying the infrastructure for pedestrians, cyclists, public and private motorised vehicles, freight movement and parking on the roads, as well as road safety, gives an overview of public infrastructure usability. It also gives an idea about how the transport systems impact on the environment.

3.7. Vehicle and Environment Quality

Recent studies indicate that as much as 45 per cent of pollutants released are a direct consequence of vehicle emissions. The major source of energy consumption and emissions in the transport sector are public and private motorised vehicles. Currently, the transport sector is responsible for 6.7 million tonnes of carbon emissions per year in Rajkot (2011). To assess vehicular emissions, this study considers the parameters of the number of vehicles on the road, their efficiency, fuel types, and air and noise pollution.

Vehicle population

All vehicles are registered during purchase, and the Regional Transport Office maintains a database of the number and type of vehicles registered every year. The recent trend of vehicle registration is available with the RTO, which can be used to assess the vehicular population. Another way is to conduct traffic volume counts at each intersection. Thus, the daily traffic volume in the city can be extracted and projected for future years. The vehicle population for this study has been collected by both methods to cross-check and arrive at an accurate figure. Table 3-7 shows the total vehicle population category-wise for the past three decades.

Table 3-7: Mode-wise registered vehicles in last three decades

Sr. No.	Vehicle Type	1981-1991	1991-2001	2001-2011
1	Two-wheelers	145,450	370,581	530,623
2	Auto rickshaw	3,334	7,162	11,122
3	Cars & jeeps	15,665	33,280	60,734
4	Buses	1,099	2,418	1,376
5	Goods vehicles	20,364	28,382	39,507
6	Tractors	7,032	15,051	13,394
7	Others	510	813	3,139
Total		193,454	479,017	7,10,234

Source: RTO, Rajkot

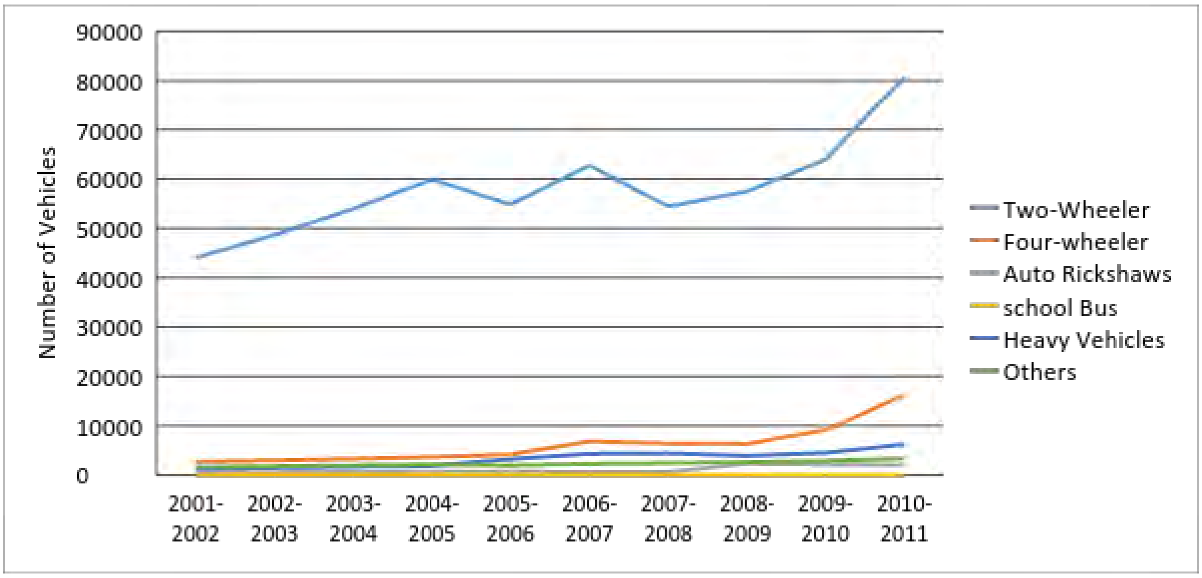

Figure 3-31: Mode-wise growth of registered vehicles
Source: RTO, Rajkot

The number of registered vehicles in the city has increased from 193,454 in 1991, through 479,017 in 2001, to 710,234 vehicles in 2011, with an average decadal growth rate of 40 per cent. On analysing the year-wise registered data, it can be observed that in the last ten years, the number of two-wheelers and cars have grown at a rate of 18 per cent and 76 per cent respectively. It was also observed that the total number of registered vehicles has increased at a rate of 31 per cent. Figure 3-31 shows the mode-wise growth of vehicles from 2001 to 2011 in the city. It can be seen that private vehicles (two-wheelers and cars) have increased considerably over the last ten years, but the number of buses or other public transport options have remained the same despite the population increasing. To disaggregate the data and understand the difference in the traffic volumes spatially in the city, surveys have been carried out such as traffic volume counts at intersections, and screen lines at physical barriers in the city and outer cordons at the bypasses of all the highways.

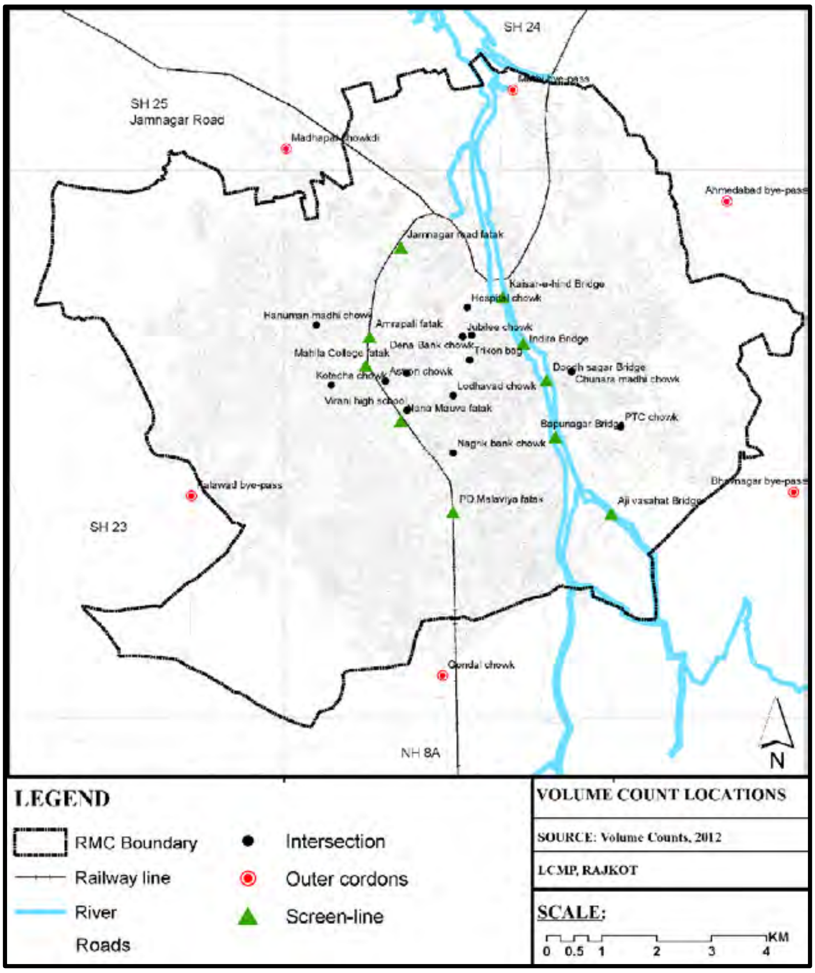

Figure 3-32: Map showing volume count locations
Source: Volume counts, 2012

Traffic volumes on roads

Traffic congestion on city roads is quite low compared to other medium-sized cities of India. However, congestion is beginning to be visible on certain stretches. There is a high traffic flow from west to south in the morning, and vice versa in the evening due to the industrial area being located in the south of the city. Traffic volume counts in different locations in the city were conducted through a manual counting method, and by putting video cameras at the junction to record the traffic conditions of the city (Figure 3-32). Turning movement counts (TMC) were recorded at twelve different junctions for 16 hours on a single day. These junctions represent the major intersections of the city as mentioned in the Comprehensive Mobility Plan by the RMC.

Outer cordon traffic

Outer cordon surveys were conducted for counting the vehicles coming in and going out of the city. As mentioned, they were conducted at six points where there is a bypass of each highway for 16 hours on a single day. At the outer cordon, on average, 282,489 vehicles leave and enter the city each day. Through a directional split, it was observed that 48 per cent of the traffic entered the city and 52 per cent exited. Goods traffic accounted for 8,200 vehicles per day, amounting to 3 per cent of the total composition. Table 3-8 encapsulates the number of vehicles at all the cordon points at peak hour and 16-hour counts. Gondal Chowkdi[19] and Ahmedabad outer cordon points had the heaviest flow of traffic.

Table 3-8: Traffic volume at outer cordon

Sr. No.	Outer cordon	Peak hr. count	16 hr. count
1	Morbi	2,417	31,755
2	Ahmedabad	3,266	69,230
3	Bhavnagar	2,442	26,164
4	Gondal	5,863	79,283
5	Kalawad	5,989	49,110
6	Jamnagar	2,051	26,947

Source: Traffic volume count, 2012

Screen line

Screen line surveys are usually conducted at points where there are physical barriers in the city. For Rajkot, the river and railway track that run north-south were chosen as the screen line. Therefore surveys have been conducted on the bridges and underpasses to examine the east-west movements in the city. On average, 726,018 vehicles cross the screen line daily. The Mahilla College and Raiya road crossings have the highest number of vehicles crossing. Table 3-9 gives the peak hour and total daily traffic at all the screen line points.

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[19] Gujarati for 'crossroads'.

Table 3-9: Traffic volume at screen lines

Sr. No.	Location	Peak hr. count	16 hr. volumes
1	Raiya	8,712	108,900
2	Indira	4,644	58,052
3	Kaiser-e-Hind	7,365	92,058
4	Bapunagar	6,265	78,318
5	Doodhsagar	3,404	42,544
6	Mahilla college	8,495	106,183
7	Malviyafatak	6,682	83,521
8	Nana-mauva	7,568	94,599
9	Ajivasavat	1,609	20,116
10	Jamnagar	3,338	41,727

Source: Traffic Volume count, 2012

Fuel consumption and emissions

The total fuel emissions of a city in terms of their quantity and contents (or composition) depend on the vehicular population and type of fuel used. Vehicle fuel consumption and emissions are two critical aspects considered in the transportation planning process. With increases in fuel consumption, the city is deviating from the national goal of reducing emissions. A survey was conducted at all petrol pumps in the city, stopping every vehicle coming to the petrol pump. Information about the vehicles running on the road including the odometer reading, fuel used, age, mileage was collected. Of all the vehicles, those running on petrol are 61 per cent, while those on diesel and CNG are 22 per cent and 16 per cent respectively. The number of vehicles running on LPG is not very high in the city. Furthermore, it was observed that vehicles on the road are typically less than eight years old, and there are very few old vehicles[20] in the city. Figure 3-33 shows the mode and fuel type-wise consumption in Rajkot city. It is difficult to discover the most consumed fuel, as different modes use different fuels, and their consumption rates are also different. In the case of large vehicles, like buses and trucks, the fuel consumption rate of diesel is higher than other fuel. In the case of small and medium-sized vehicles, the fuel consumption rate of petrol is higher than other fuels.

[20] Refers to vehicles that are more than 15 years old.

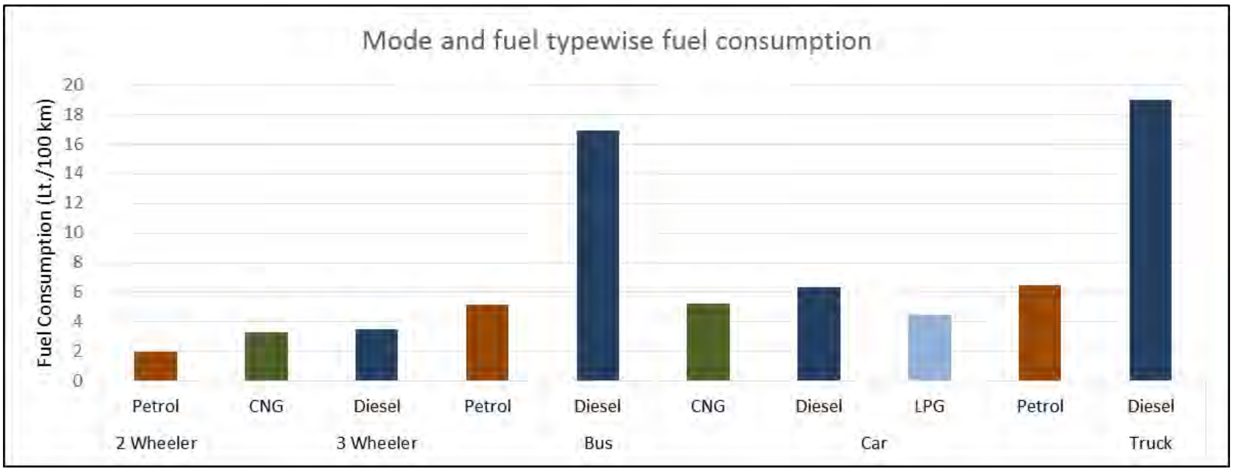

Figure 3-33: Mode and fuel type-wise fuel consumption
Source: Petrol pump survey, 2012

Fuel efficiency by modes is required to identify the technology used for motorised vehicles, and to introduce interventions to change the fuel and vehicle technology to reduce emissions. If we compare mode-wise fuel efficiency, then CNG is the most efficient fuel for three-wheelers and LPG for cars. Figure 3-34 shows mode and fuel type-wise fuel efficiency.

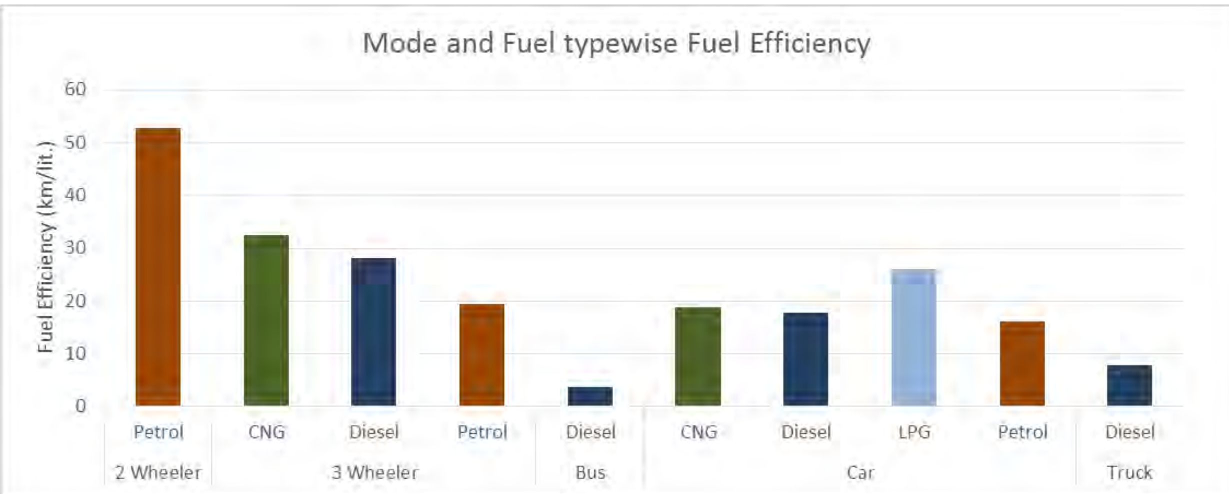

Figure 3-34: Mode and fuel type-wise fuel efficiency
Source: Petrol pump survey

Fuel efficiency reduces with vehicle age. Vehicles running on the road for more than five years will have a lower mileage and greater fuel consumption, making them less environment friendly. Figure 3-35 shows the age and mode-wise fuel efficiency in Rajkot. It clearly shows that as the age of the vehicle increases, the efficiency decreases, irrespective of mode or vehicle type and the fuel type used.

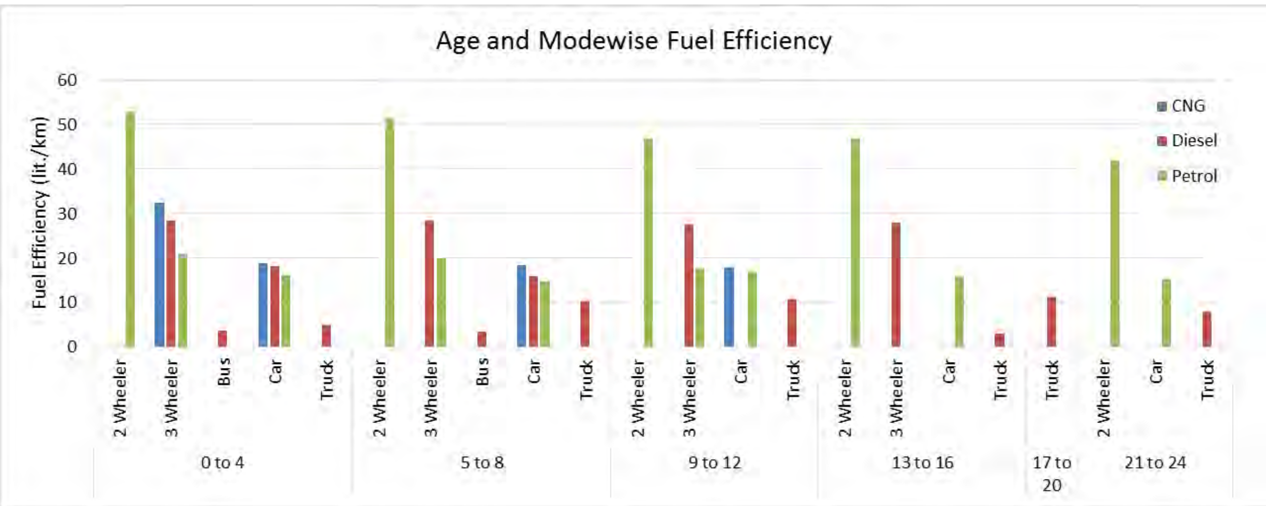

Figure 3-35: Age and mode-wise fuel efficiency
Source: Petrol pump survey

Air quality

From the data collected by surveys at petrol pumps, it was observed that trucks, buses and SUVs have high fuel consumption. Examining consumption by different fuel types, diesel vehicles like trucks and older auto-rickshaws have the highest hydrocarbon and carbon monoxide emissions. Although all diesel auto-rickshaws were to be replaced by CNG auto-rickshaws, there are still some diesel auto-rickshaws operating in the city.

The data for hydrocarbon and carbon monoxide levels were collected at ten locations around the city (Figure 3-36). Carbon monoxide levels at many places are higher than prescribed standards, which are 4000 µg/m³. No standards are available for hydrocarbons (HC), so no comparison was made. Gondal Chowk and Hospital Chowk have the highest levels of hydrocarbon and carbon monoxide levels. The levels of congestion and number of vehicles are also very high at these locations.

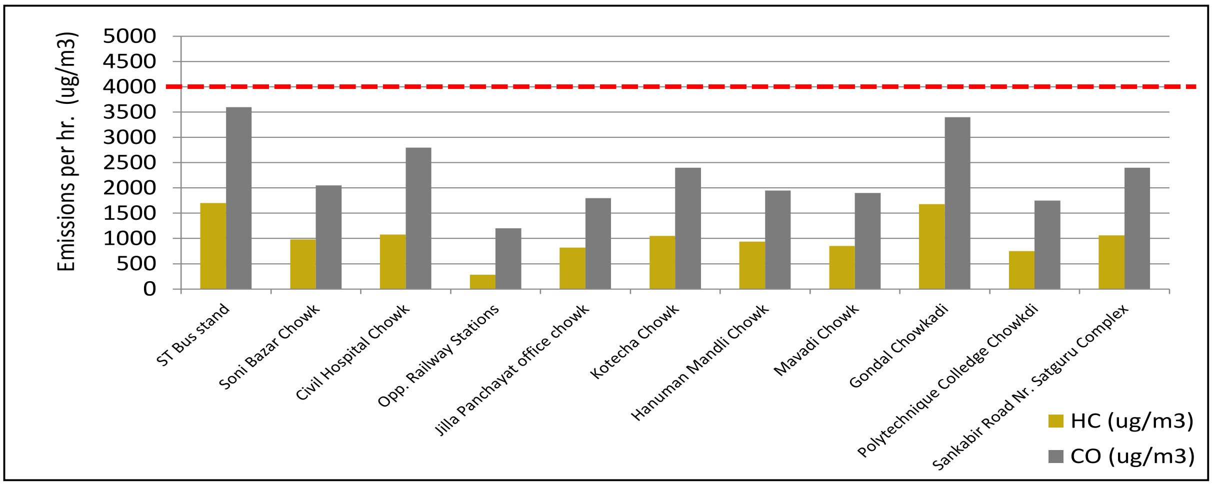

Figure 3-36: Hydrocarbon and carbon monoxide levels
Source: Primary Survey, 2012

Noise levels

Noise pollution is defined as unwanted sound released into the environment. It disturbs people and causes an adverse effect on their mental and psychological well-being. It is measured in decibel units (db). Vehicular traffic noise pollution may be an everyday pollution that is perceived as annoying but not really detrimental to our health or well-being. For this study, while looking at the pollution levels in the city, it was also very important to look into noise levels at different locations at different times of the day. It was observed that noise levels at industrial areas are within the limits, but levels are higher than the standard values for residential and commercial areas.

Table 3-10: Noise levels in various zones

Land use	Day actual (db.)	Day standard (db.)	Night actual (db.)	Night standard (db.)
Commercial	70.3	65.0	60.3	55.0
Industrial	69.9	75.0	53.9	70.0
Residential	69.3	55.0	57.4	45.0

Source: Primary Surveys, 2012

Noise level testing was conducted at eleven different locations in the city during morning and night hours (Table 3-10). Out of these eleven locations, four are commercial, five are residential and two are industrial. It shows that three out of four commercial areas have higher noise levels at both, day and night, compared to GPCB standards (Figure 3-37). Civil Hospital Chowk and ST Bus stand recorded noise levels much higher than the standards both in the morning and night. The main reason for this comparatively high noise level is because both of them are important nodes in the city with intensive activities and traffic levels.

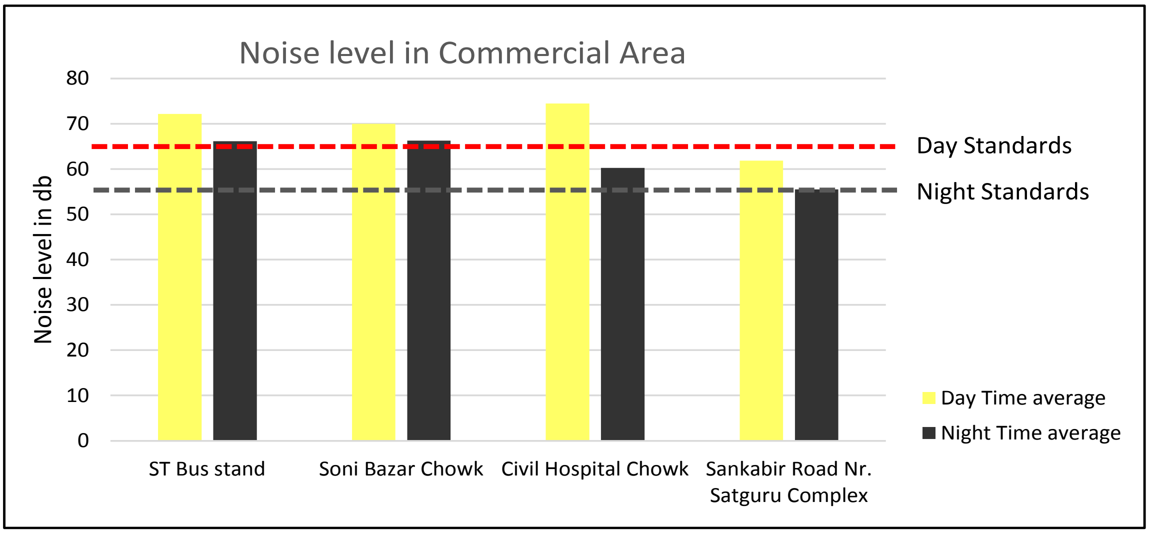

Figure 3-37: Noise levels in commercial area
Source: Primary Survey, 2012

Whereas all the residential areas have a higher noise level than national standards in both day and night, Jilla Panchayat Office Chowk and Kotecha Chowk have higher pollution levels than others in both day and night as seen in Figure 3-38.

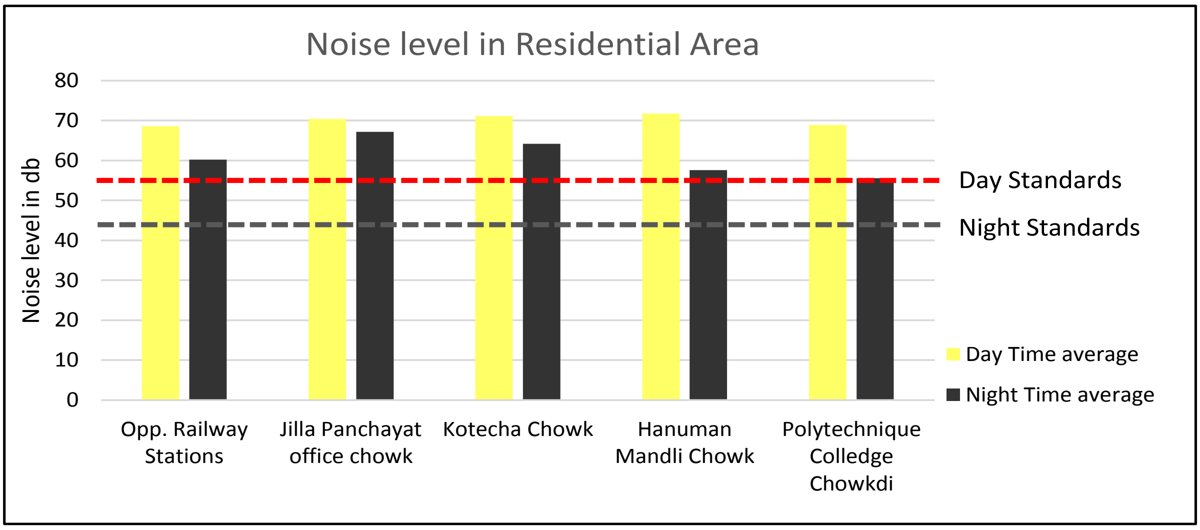

Figure 3-38: Noise levels in residential area
Source: Primary Survey, 2012

3.8. Conclusion

Rajkot is well placed in terms of its transport infrastructure, as there are proposals for road widening, footpaths and other road inventory. Rajkot has also used JnNURM funding for BRT lanes, on which it has already started operations. Since for public transport bus stands already exist, the demand-based route selection can be done to operationalise the public transport service. Rajkot has taken steps to provide infrastructure for pedestrians and cyclists, but demand analysis should be conducted to discover the potential users of the infrastructure spatially all over the city. The impact of this infrastructure and increase in vehicle volumes on the roads have increased the emissions and lowered the air quality of residential and commercial areas.

Chapter 4: Travel Patterns

This chapter explains the demand side of transport using travel patterns,[21] perceptions and preferences of individuals in the city. It also gives a descriptive analysis of trips made inside the city for various purposes, the mode used, kilometres travelled and carbon emitted per individual. The chapter concludes with inferences on the gaps between the demand and supply of transport infrastructure, explores the major issues of the city in the sector.

4.1. Introduction

The travel pattern of any city is an important factor that helps understand the transportation system and its performance from the user's perspective. Travel characteristics include trip rate, mode, purpose and travel time. These characteristics vary from person to person, depending upon his/her socio-economic background, the area he/she is living in or the surrounding land use. These are determined by studying the characteristics of different types of households in the city through a household survey.

4.1.1. Household surveys

To conduct household surveys to analyse the socio-economic and travel characteristics of city residents, the study area has been divided into Traffic Analysis Zones (TAZs). The data was collected for two spatially heterogeneous areas in the study area: the RMC area (TAZs 1-183) and the RUDA area (TAZs 184-394).

Household surveys were carried out for 2,848 samples, involving 11,100 individuals (over 16 years of age) and 14,614 trips spread over 394 Traffic Analysis Zones. The spread of the survey locations can be seen in Figure 4-1. Surveys were conducted during August-October 2012 during weekends, so that all the members of the family were mostly present. Household selection followed the sampling strategy. In each of these TAZs, a stratified random sampling procedure was followed. The stratification of samples in each zone was based on the socio-economic distribution of the zone's population, based on the type of house (apartments or individual bungalows or kachha houses), and also based on the asset ownership like an AC unit, fridge and television.[22] Samples have been taken in each zone where development is found.[23]

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[21] Travel patterns are defined differently by different studies, but the summary of measures used for exploring travel patterns are: travel distance, travel frequency, modal split, travel time and transport energy consumption (Stead & Marshall, 2001).

[22] The ownership of assets was based on the property tax data obtained from the RMC and the building land use in the GIS shape file.

[23] There are some TAZ outside RMC boundary where there is no settlement and is part of the LCMP study boundary.

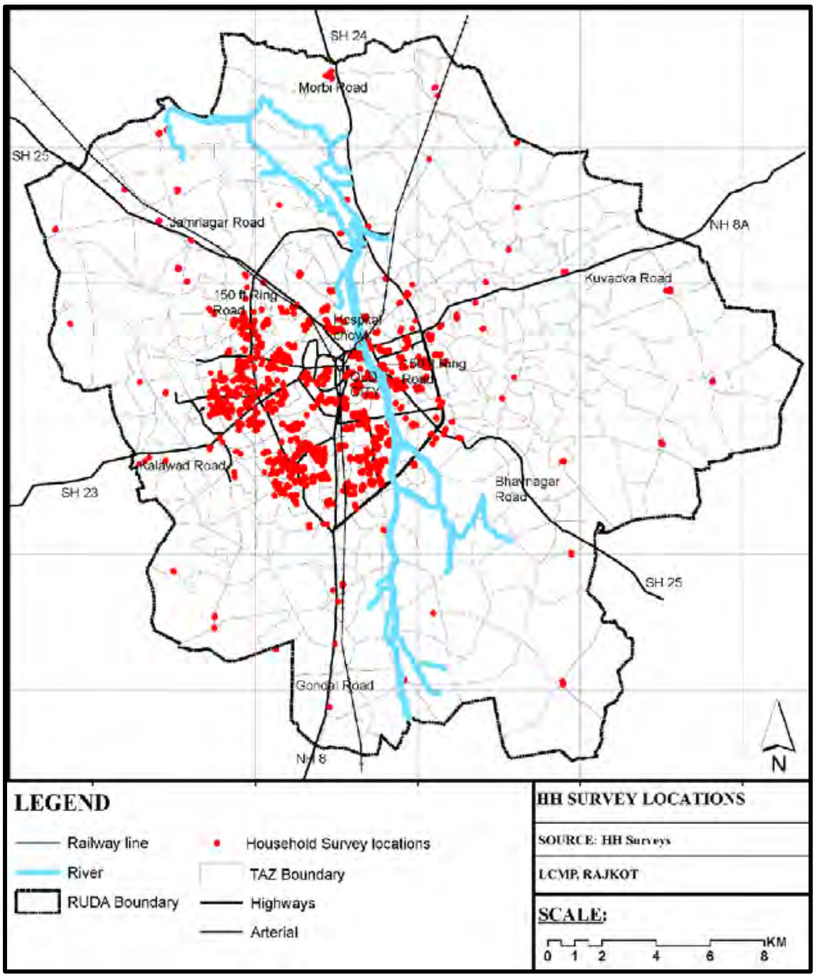

Figure 4-1: Household survey locations
Source: HH surveys, Study Estimates, 2012

It is very important to ensure questions are asked in a manner that leads to unambiguous answers in the samples. So a common questionnaire for the three cities of the LCMP was formed to ensure accurate information would be obtained from the individuals. The questionnaire format decided upon by the expert panel (involving UNEP, UNEP DTU Partnership), which prepared the toolkit for the LCMP, was refined to fit to the context of each city. The household survey questionnaire can be broadly divided into two sections: a revealed preference survey and stated preference choice. The revealed preference survey includes questions related to information about the household and its members, and their various choices under existing conditions, whereas the stated preference choice includes their choices under alternative scenarios (mode choice) or other conditions which are currently non-existent. The survey information was collected at three levels: the household, personal, and trip level (i.e. a trip diary). Household and personal level information consisted of details about members, their assets, housing and living conditions, vehicular ownership, accessibility to important destinations and mode choices, along with their opinions. The trip information was recorded in a tabular format. The trip diary consists of trip origin, trip destination, distance of travel, time taken for the trip, frequency of the trip, purpose of the trip, mode taken for the trip, trip cost, etc. The stated preference survey involves the individual mode choice in two alternative scenarios, with different conditions on travel time, efficiency, safety, comfort, etc. These household surveys were extrapolated to arrive at figures for the population and the actual number of vehicles. The surveyed households were located on a map in GIS, and property tax data of each unit (i.e. land use, type of building, property rate, etc.) was incorporated into the household survey information for checking and re-evaluating the analysed data. Thus the land use or the built form around the trip was generated, and the destination of the trip was also analysed, to examine its impact on travel.

4.2. Socio-Economic Characteristics

The socio-economic characteristics of the city have been analysed in the form of age, gender, literacy rate, household size, household income, vehicle ownership and employment distribution from the household surveys. These data were collected from the household and individual information section of the household survey.

4.2.1. Age and gender ratio

The age distribution showed that individuals in the productive age range of 22 to 59 years formed 60 per cent of the population, and students between 6 and 21 years of age formed 26 per cent of the total. The total dependents constituted 13.65 per cent, which includes children between 0 to 5 years and people above 60 years of age. The gender ratio is alarmingly low at 816 females per 1000 males. In other words, males form 55 per cent of the total population, whereas females form 45 per cent. The age-gender pyramid in Figure 4-2 shows that Rajkot has most of the population in the productive age, which is a good sign in terms of future productivity.

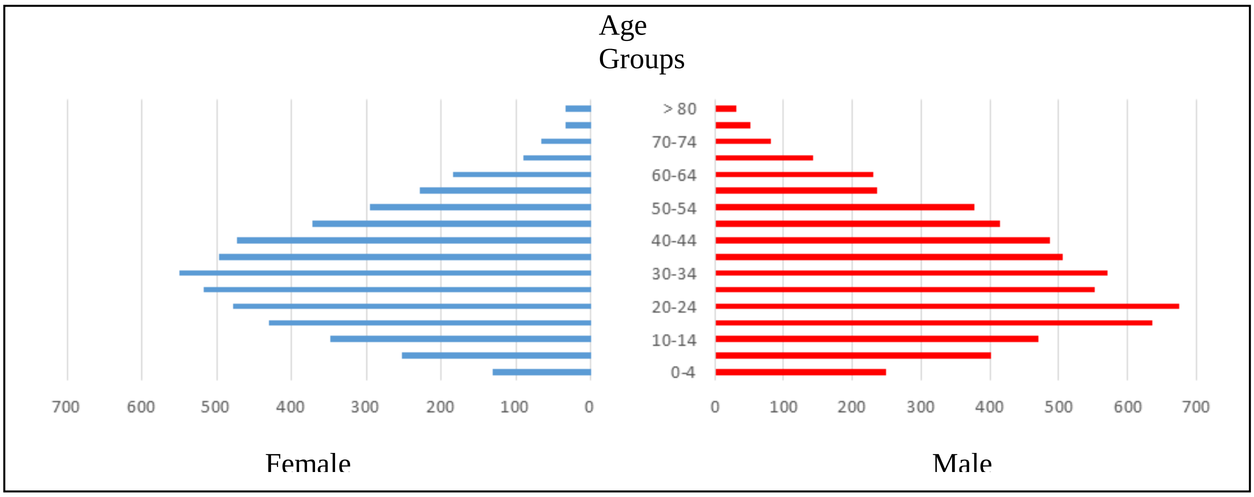

Figure 4-2: Age-gender pyramid
Source: (Registrar General of India, 2011)

4.2.2. Literacy rate

The literacy rate of the city is important in understanding the scope and type of development possibilities in the city. It is also observed that people who are literate make more trips and travel longer for work compared to illiterates. The overall literacy rate for the city is 85.63 per cent. There is a significant difference between the average literacy rates of urban and rural areas (Table 4-1). This difference between urban (91.34 per cent) and rural (84.83 per cent) males is lower as compared to that for urban (81.49 per cent) and rural (66.70 per cent) females.

Table 4-1: Literacy rates by gender, 2011

Literacy rate	Rural	Urban
Average literacy	75.97 %	86.63 %
Male literacy	84.83 %	91.34 %
Female literacy	66.70 %	81.49 %

Source: (Registrar General of India, 2011)

4.2.3. Household size and income

The household size is the number of individuals living together in a house. It is used to determine the requirement of the number of households for the growing population of the city. The household size also varies with the type of house. The average household size of Rajkot is 4.23 people. Slums and economically weaker sections (EWS) have higher household sizes, whereas other income groups have an average household size of less than 4 people. Regarding the choice of living, city residents mostly prefer living in the low-rise housing. The households in apartments and bungalows are mostly of higher income groups, and are largely located in the western part of the city, whereas the households in kachha houses are largely lower income groups located in slums in the eastern side or near the city centre (Figure 4-3). Of the total 2,848 households surveyed, 95.08 per cent were Hindu, 0.2 per cent Christians, 0.45 per cent Jains and 4.24 per cent Muslims, whereas around 28 per cent of people were of SC/ST/OBC caste. The average monthly income found in the surveyed households was INR 22,000. Households located along new roads like Kalawad Road, Race Course Road and Raiya Road had high monthly incomes ranging from INR 30,000 to INR 50,000 or higher, whereas areas near Gondal Road in the south or to the north of Hospital Chowk had households with mostly middle income levels ranging from INR 10,000 to INR 30,000. The old city areas and developments on the eastern side of the river had monthly incomes ranging between INR 1000 to 2500. Table 4-2 shows the socio-economic groups to which the sample surveyed can be attributed to.

Table 4-2: Socio-economic classification

Socio-economic categories (SEGs)	Total households	Sample size
SEG 1 (low income)	154,885	1,509
SEG 2 (middle income)	189,068	1,139
SEG 3 (high income)	32,894	200

Source: Property Tax data, 2012 and Sampling Technique, Study Estimates, 2012

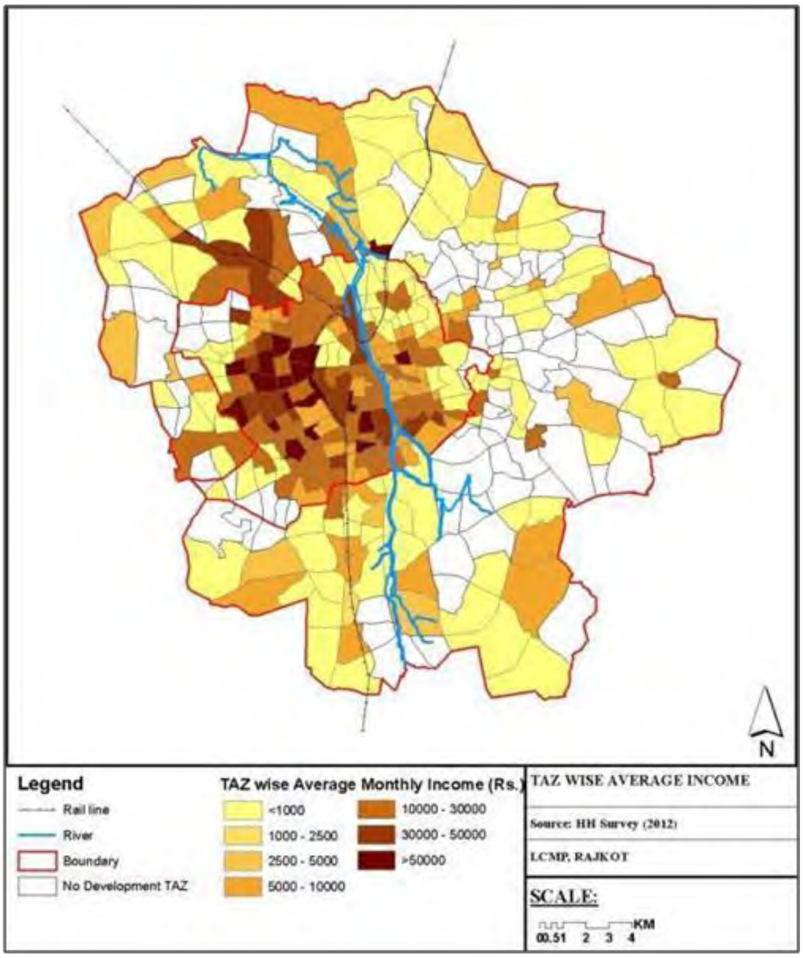

Figure 4-3: TAZ-wise average income
Source: Household survey, 2012)

4.2.4. Employment distribution

From the surveys it can be observed that employed people would make more frequent trips than those who are retired or inactive. Likewise, the type of travel also differs by the distribution of employment in the city. Of the total individuals surveyed, 35.7 per cent are main workers, including salaried employees, the self-employed, labourers and farmers. Females are mostly involved in housework (32.8 per cent). Individuals not involved in any economic activity constitute only 3.2 per cent of the population. In the RUDA area, workers are mostly labourers, farmers and a few salaried employees. Very few individuals in RUDA area are not involved in any economic activity (Table 4-3).

Table 4-3: Employment distribution (as a percentage of total employment in the study area)

Area	No Activity	Unemployed	Student	Retd.	Farmer	Labourer	House work	Salaried employee	Self-employed	Other
RMC	2.32%	0.64%	21.28%	4.19%	0.57%	8.12%	30.99%	13.01%	11.46%	1.14%
RUDA	0.00%	0.05%	01.26%	0.32%	0.03%	0.59%	01.85%	01.04%	00.96%	0.00%
Total	2.50%	0.69%	22.54%	4.52%	0.59%	8.71%	32.83%	14.04%	12.43%	1.14%

Source: RMC, RUDA

4.2.5. Vehicle ownerships

Vehicle ownerships are directly related to income ranges. High income households typically own more vehicles, and lower income households fewer vehicles (Figure 4-4). Vehicle ownerships are also directly related to the trip made by motorised vehicles. The per capita vehicle ownership, including two-wheelers, four-wheelers, auto and bicycles is 1.45, whereas the vehicle ownership rate excluding bicycles is 1.15. Vehicle ownerships are found to be high in the western part of the city with wealthier households living in tenements and apartments. Surprisingly, vehicle ownerships are also high in the old city area and some parts on the eastern side, as bicycles are also considered in the vehicle ownership data (Figure 4-5).

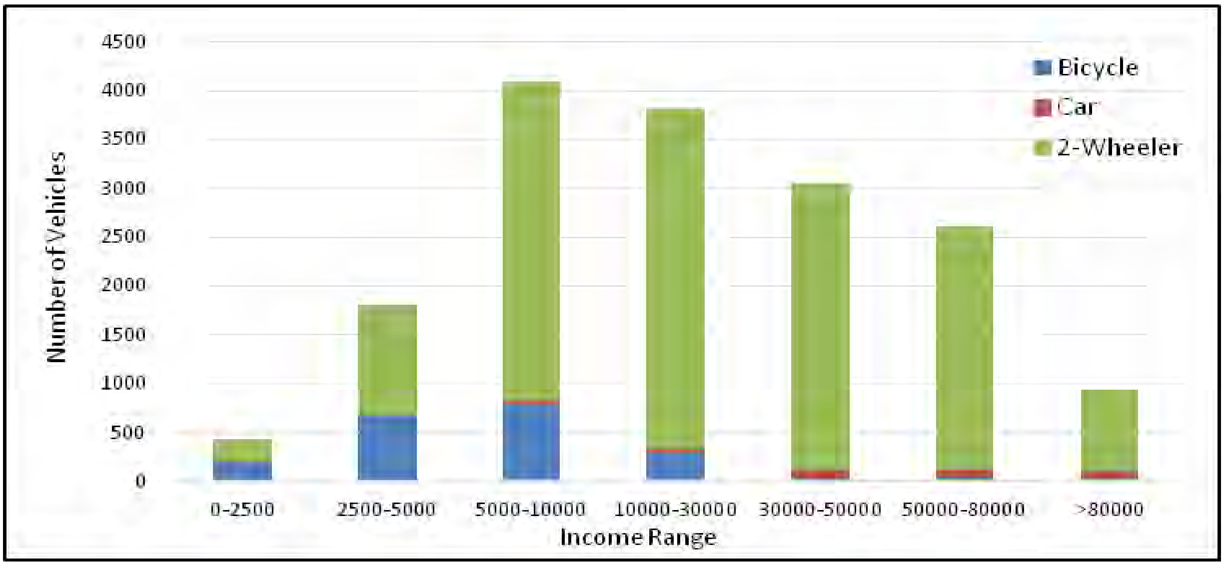

Figure 4-4: Income-wise vehicle ownership
Source: HH Survey, 2012

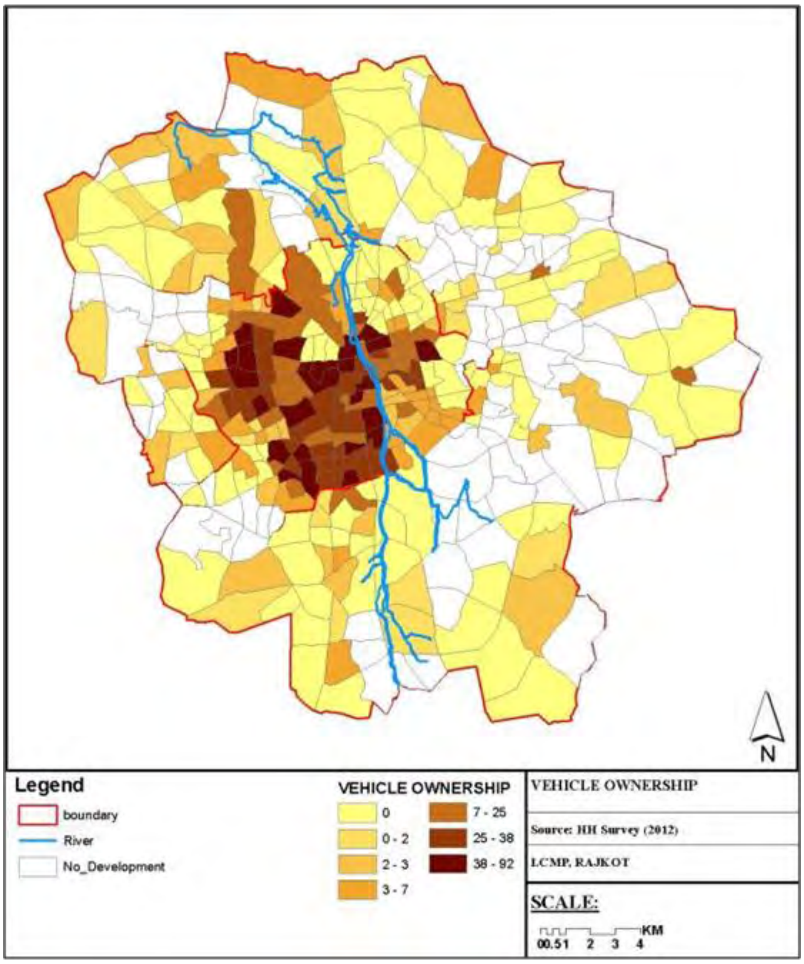

Figure 4-5: TAZ-wise vehicle ownership
Source: HH Survey, 2012

4.3. Trip Characteristics

Trip characteristics have been defined differently in the relevant literature. Summarising the literature, travel characteristics are distinguished in terms of travel distance, travel time, modal split, travel frequency and transport energy consumption (Stead & Marshall, 2001). An additional travel variable added in this study is the accessibility to infrastructure, referring to not just mobility, but also accessibility to facilities and to people. With these, even safety, comfort, reliability and affordability have been captured for travel characteristics. The data was collected for trip characteristics from the household surveys in the form of a travel diary. Each individual of the household was asked to describe their travel on the previous working day. The questions were intended to cover every aspect of a day's travel, like the number of trips, purpose, mode, time taken, origin and destination of the trips.

4.3.1. Trip rate

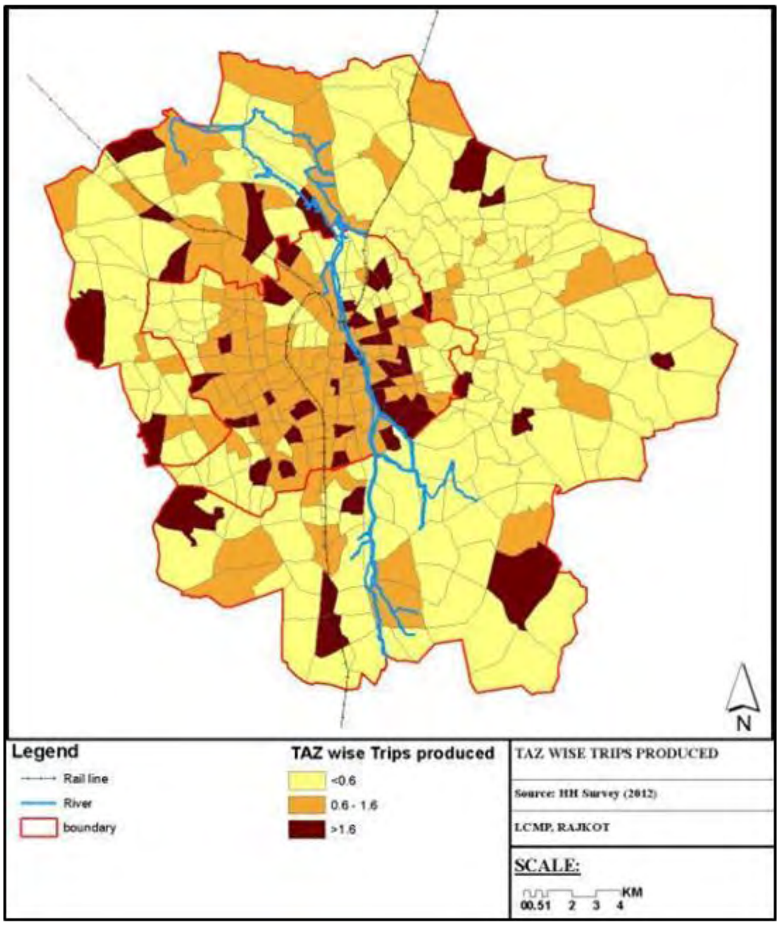

Figure 4-6: TAZ-wise trips produced
Source: Household Survey, 2012

The trip rate is defined as the number of trips made by an individual in a day. It largely depends on the type of land use at origin and destination, socio-economic background and the purpose of travel. Observations from the household survey state that an estimated 18.20 lakh trips are made daily in Rajkot. The per capita trip rate including walk trips is 1.30 trips/day, and when walk trips are excluded it is 0.81 trips/day. Trip rates are higher in the outer villages of RUDA due to fewer nearby facilities. Trip rates are also higher in the old city area where people make short trips. The trip rates for other areas of the RMC are in the same range of 0.8 to 1.3 trips. The eastern part of the city has higher trip rates, although the distances travelled are shorter as most trips are made by walking. The western part of the city has a lower trip rate as there is a greater automobile dependency. The trips in the western part are fewer, but they are chained[24] trips, completing many small trips in one long trip (Figure 4-6).

[24] Trip chaining is defined by linking trips of different purposes, made by an individual in a single day. Trip chaining can be simple or complex for different individuals. For example: rather than simply travelling from home to work or vice versa, additional trips like shopping, visiting friends, etc. are included (Halden, Jones, & Wixey, 2005).

4.3.2. Mode share

Mode share is defined as the percentage of modes used by a person for a trip. It was observed that trips in the city are made largely by walking and two-wheelers, i.e. 38 per cent and 35 per cent respectively. The share of non-motorised mode is high, which is 48 per cent including walking and cycling shares. Like most medium-sized cities of India, Rajkot also has a very high mode share of non-motorised transport and public transport, i.e. 60 per cent. In the absence of public transport, auto-rickshaws play this role with a share of 11 per cent. Figure 4-7 shows the composition of different modes used for travel in the city.

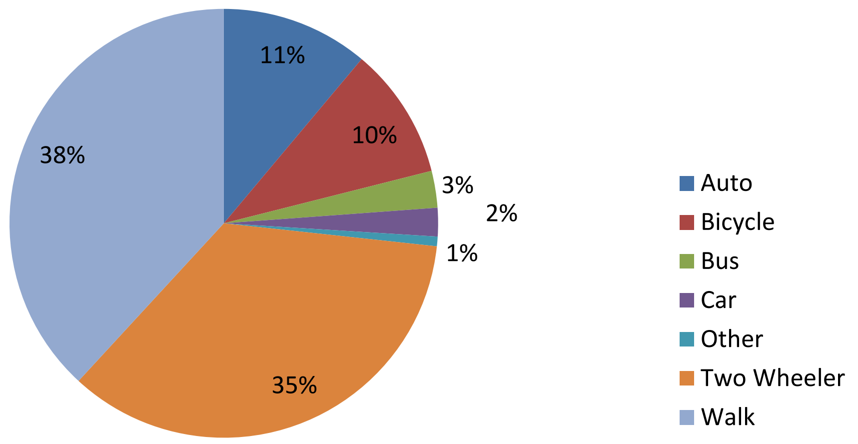

Figure 4-7: Mode share in Rajkot
Source: Household Survey, 2012

The choice of a particular mode is largely dependent on the income of an individual and their vehicle ownership. The mode share also differs by gender (Figure 4-8).

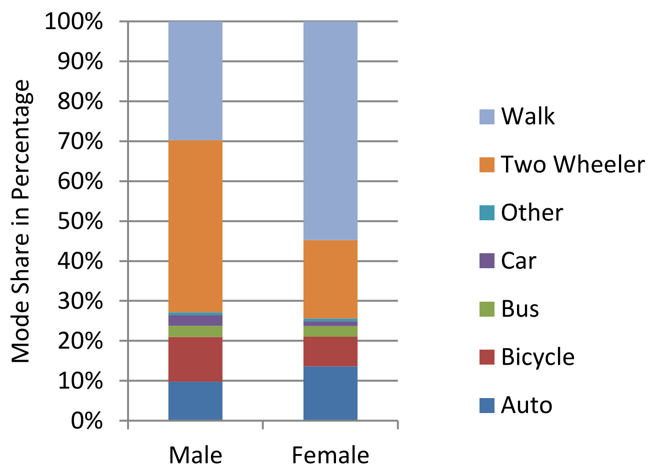

Figure 4-8: Gender-wise mode share
Source: Household Surveys, 2012

Females have a greater preference than men for walking instead of using motorised vehicles. A greater usage of private vehicles and bicycles was seen in males.

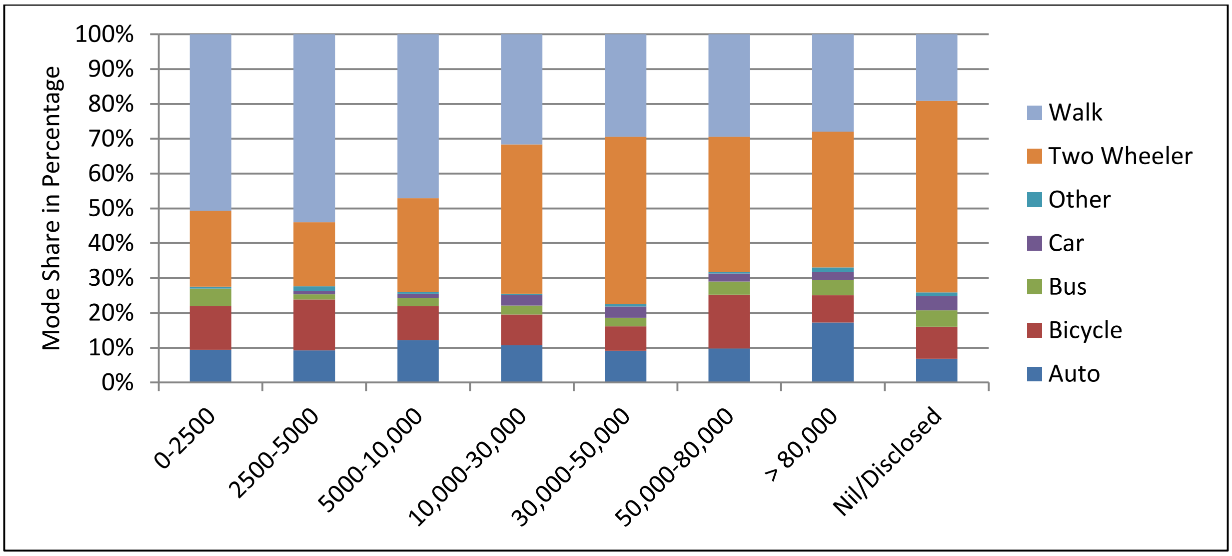

Figure 4-9: Mode share by income group
Source: Household Surveys, 2012

As household income increases, car usage increases and people walk less. It is the lower and middle-income group that uses bicycles, whereas middle and higher income groups use auto rickshaws and two-wheelers. Car ownership and the share of four-wheelers is low throughout the city, as it is only used by households with monthly incomes over INR 30,000 (Figure 4-9).

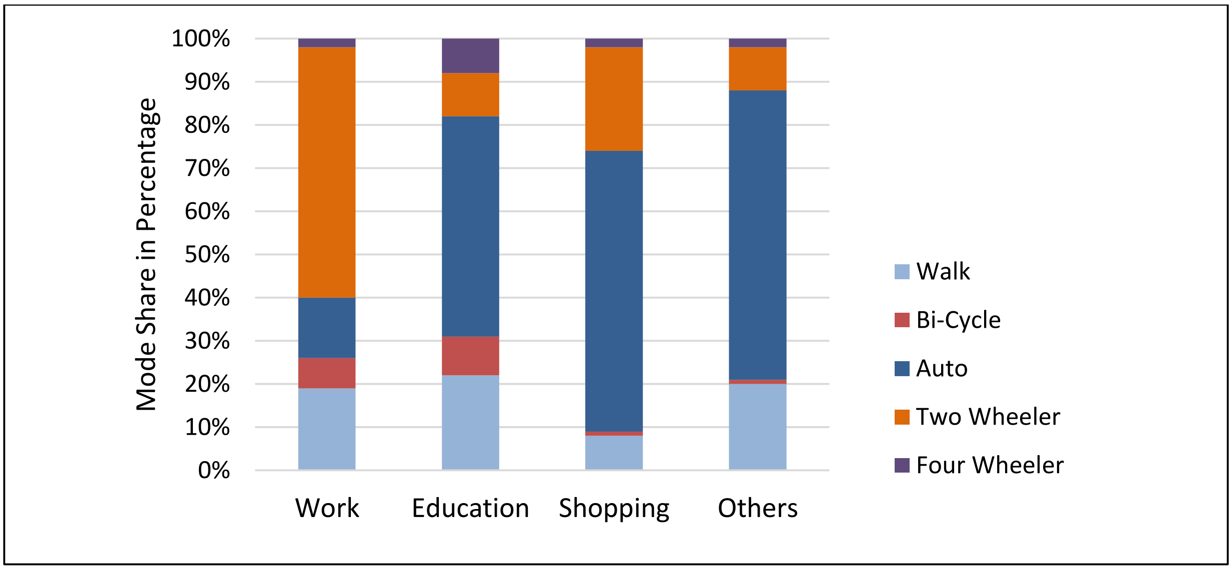

Figure 4-10: Mode share by trip purpose
Source: Household Surveys, 2012

Almost 25 to 30 per cent of people prefer non-motorised modes for work and education trips. Due to the lack of city public transport facilities, the two-wheeler is the most preferred mode for work trips (60 per cent), and for other kinds of trips, the auto-rickshaw is most predominant (50 to 70 per cent). If public transport facilities are provided, there is a possibility that half the auto users may shift to the PT system (Figure 4-10).

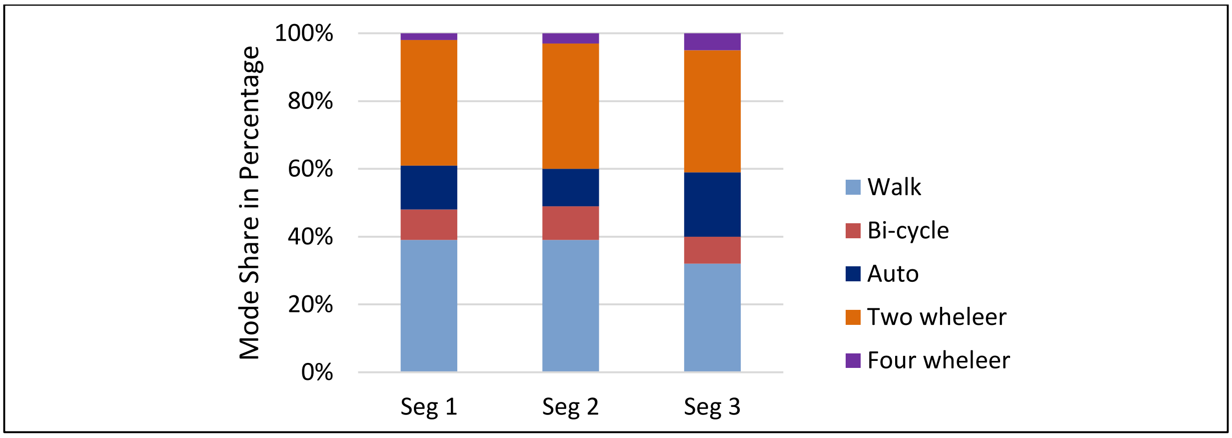

Figure 4-11: Mode share by social group
Source: Household Surveys, 2012

Almost 50 per cent of people from both SEG 1 and SEG 2 (low and medium income groups respectively) prefer to generally walk or cycle (Figure 4-11). Even 40 per cent of people from SEG 3 (the high income group) prefer to travel by walking or cycling, which indicates that the NMT infrastructure needs to be improved so that they can travel more easily. Figure 4-13, Figure 4-14, Figure 4-15, Figure 4-16 and Figure 4-17 show the per capita trips produced by different modes in the city. They illustrate that a lot of walk trips are made from the central and southern parts of the city. Conversely, two-wheeler and car trips are produced mostly from the western area (i.e. along Kalawad Road) as higher income groups reside in these areas. Bicycle trips are made along the Ring Road because of the presence of a cycling track.

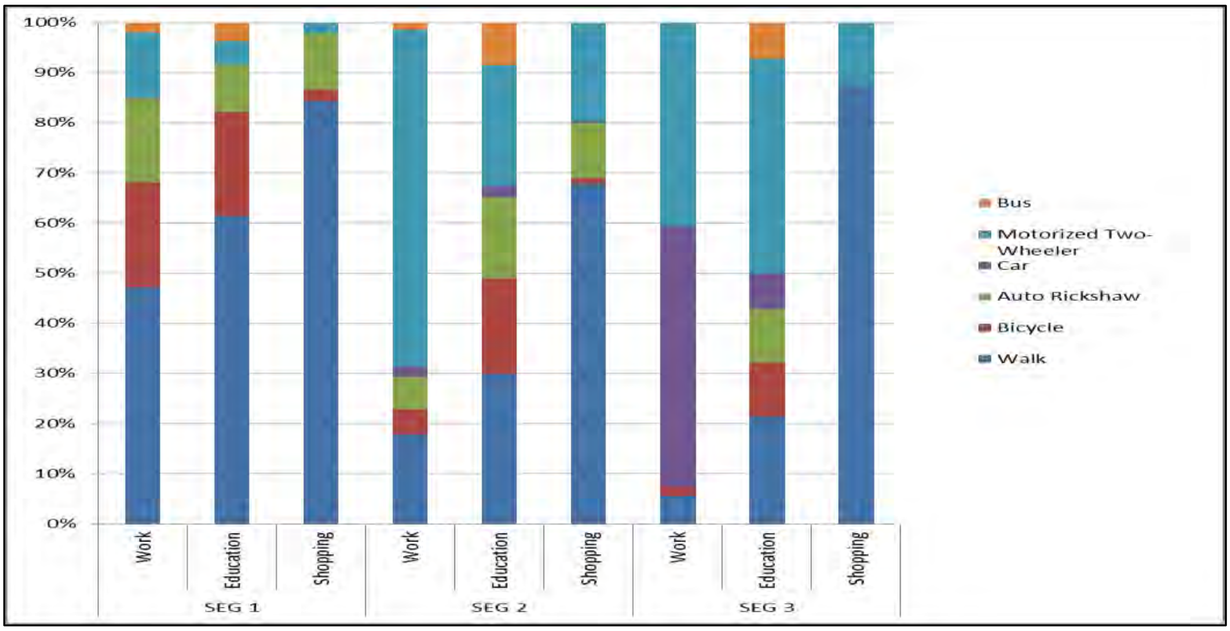

Figure 4-12: Mode share by trip purpose and social group
Source: Household Surveys, 2012

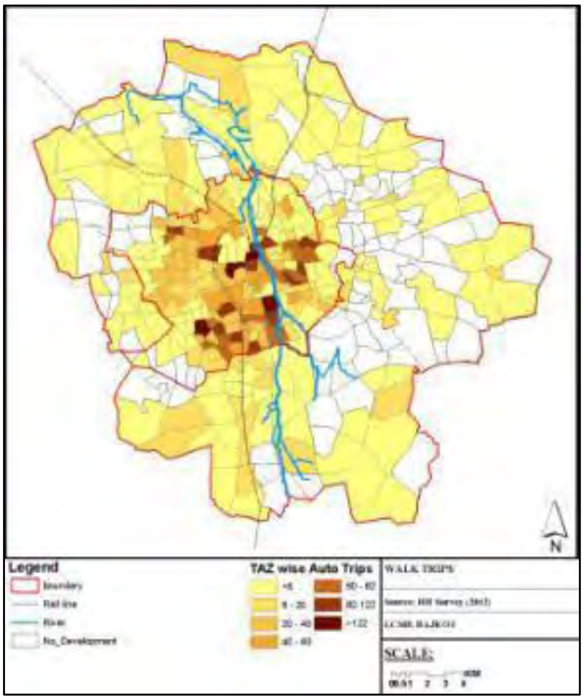

Figure 4-13: TAZ-wise produced walk trips

Source: Household Survey, Study Estimates, 2012

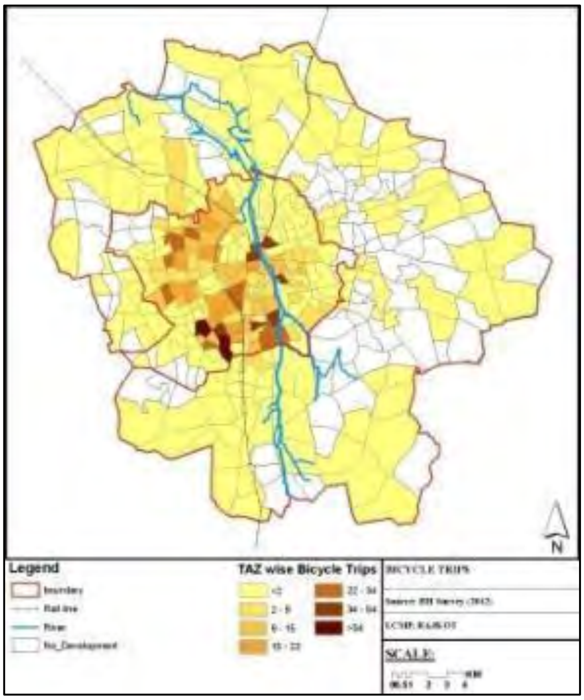

Figure 4-14: TAZ-wise produced bicycle trips

Source: Household Survey, Study Estimates, 2012

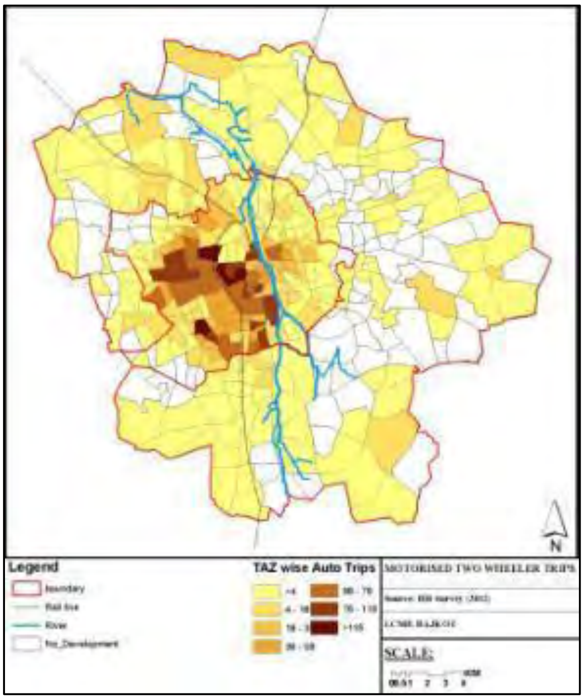

Figure 4-15: TAZ-wise produced MTW trips

Source: Household Survey, Study Estimates, 2012

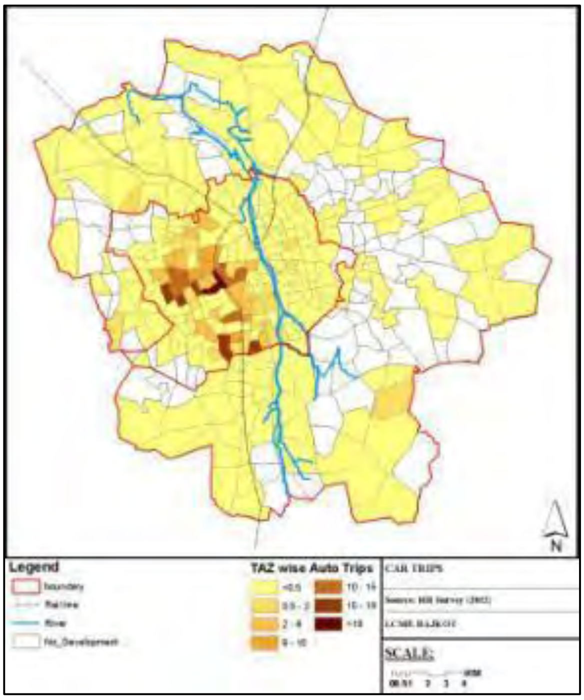

Figure 4-16: TAZ-wise produced car trips

Source: Household Survey, Study Estimates, 2012

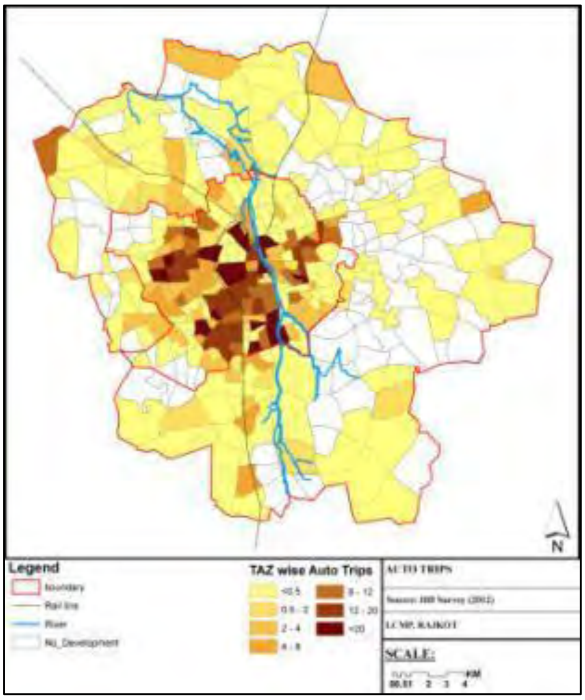

Figure 4-17: TAZ-wise produced auto trips
Source: Household Survey, Study Estimates, 2012

4.3.3. Trip purpose

Trip distribution by purpose shows that most trips are made for work and education, i.e. 53 and 26 per cent respectively. Figure 4-18 shows the composition of trips by purpose in the city.

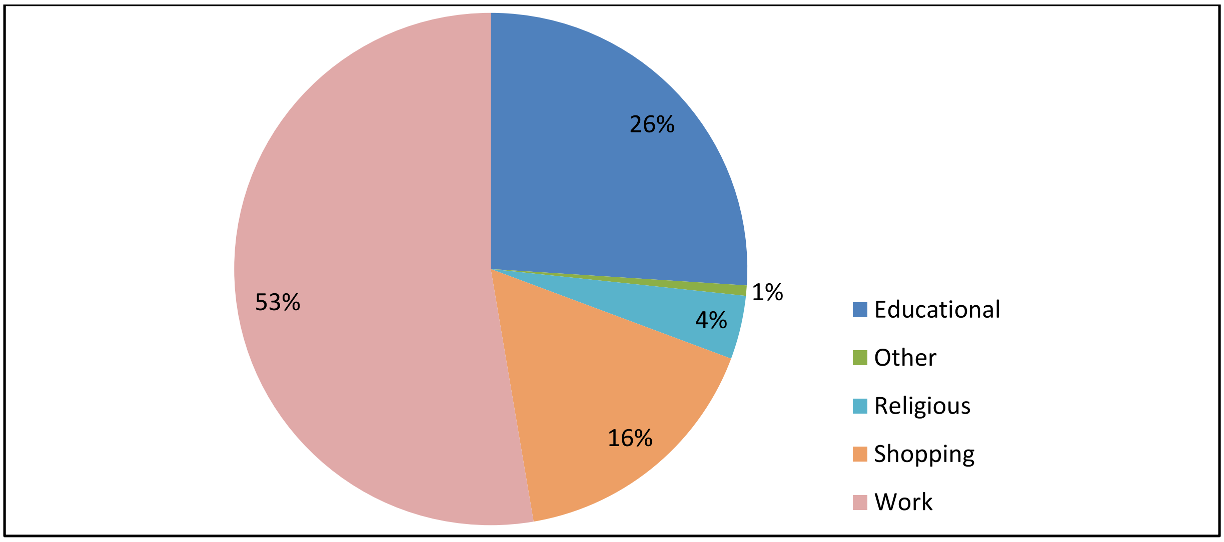

Figure 4-18: Trip distribution by purpose of travel
Source: HH Survey, 2012

The purpose of making a trip differs by gender and income range.

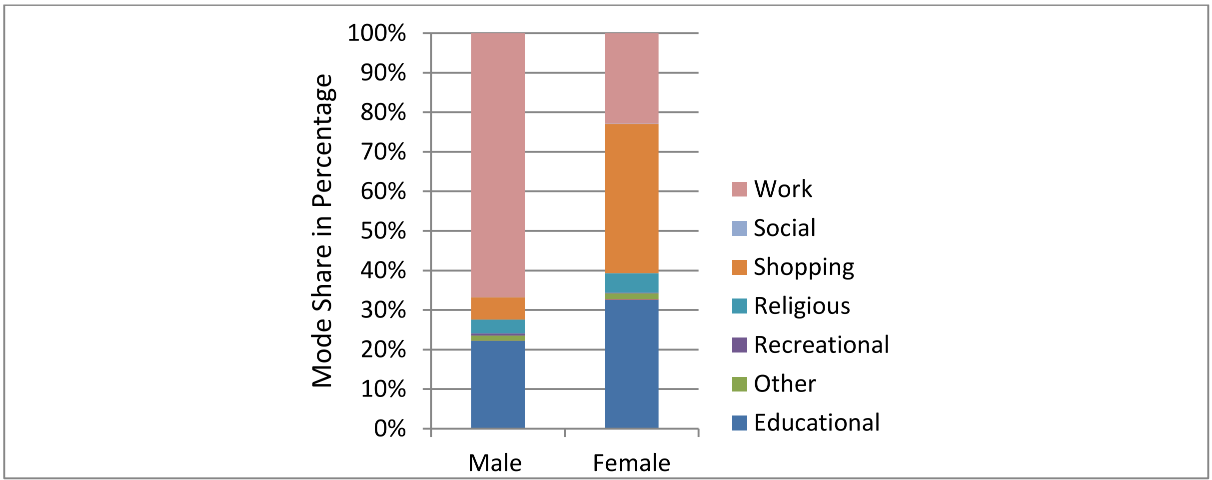

Figure 4-19: Gender-wise trip purpose
Source: Household survey, 2012

The percentage share of work trips remains high, and work trips are largely made by males in the city. The trips by females are equally split between work and educational trips (where they drop their children to their place of study). The percentage of shopping trips is high by females, whereas other trips have an equal share for males and females (Figure 4-19).

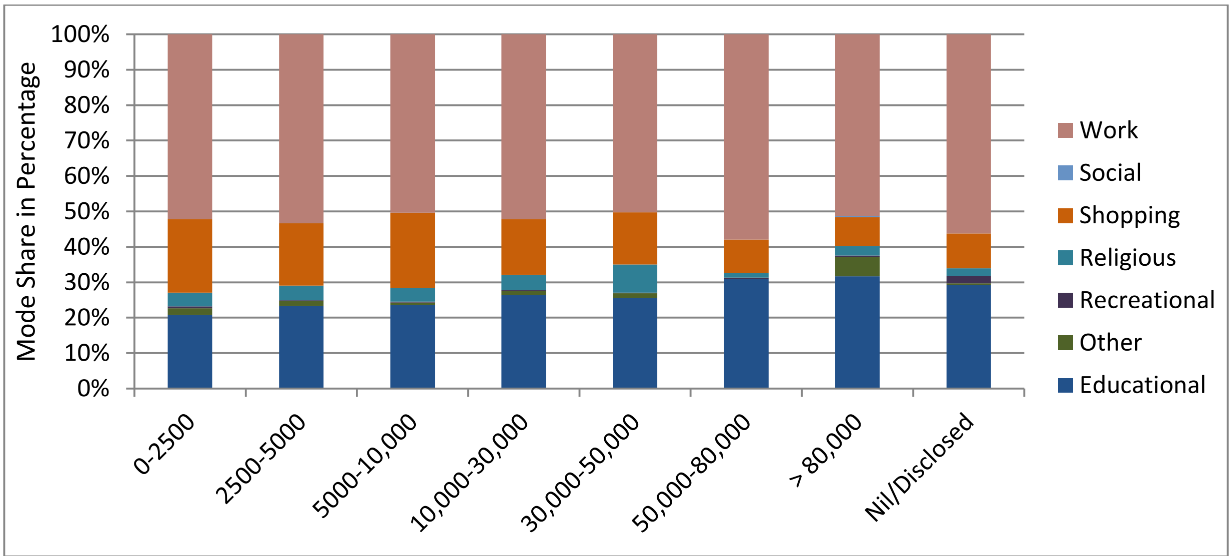

Figure 4-20: Income-wise trip purpose
Source: HH survey, 2012

The trip purpose doesn't differ much with the income range, but since middle and high income groups have females who work, the number of work trips is higher. Given that middle and high income groups are more educated, they have more frequent education trips, whereas shopping trips reduce for the high income groups as they generally purchase goods of daily needs in bulk and store them (Figure 4-20).

4.3.4. Trip length

The distance from origin to destination is defined as the trip length. The average trip length for the city, inclusive of walking trips, is approximately 3.8km. The trip distribution curve shows that generally people make more trips ranging from 1.5km to 4.2km, which is due to more walking and bicycle trips (Figure 4-21).

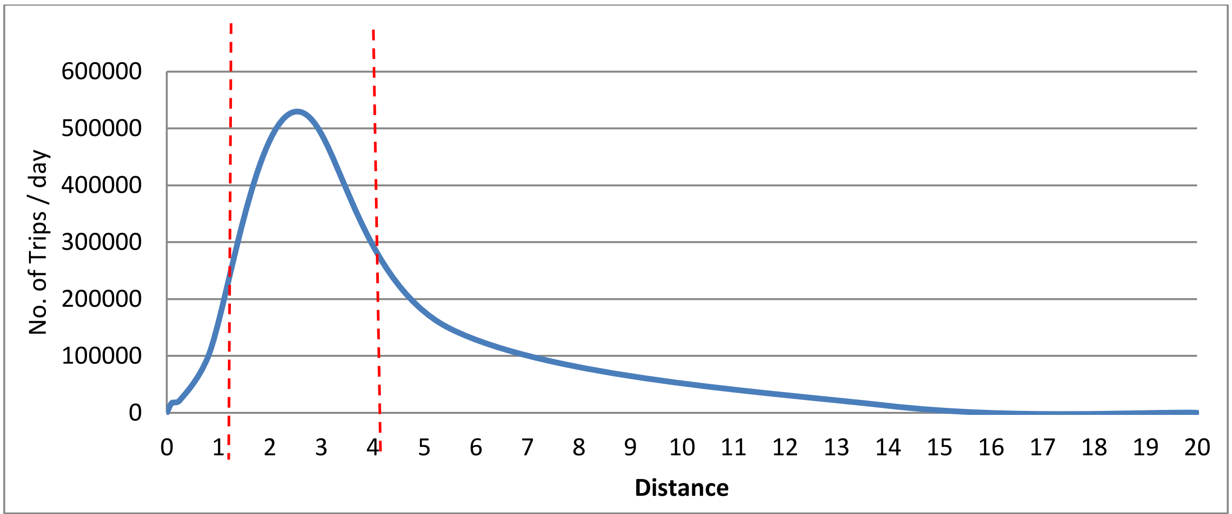

Figure 4-21: Trip length distribution curve
Source: Household survey, 2012

Analysing trip lengths by income groups shows that trip lengths vary positively with income, as higher income groups travel longer distances, while low and middle income groups travel shorter distances (Figure 4-22). This suggests that low and middle income people prefer living near work places or commercial areas.

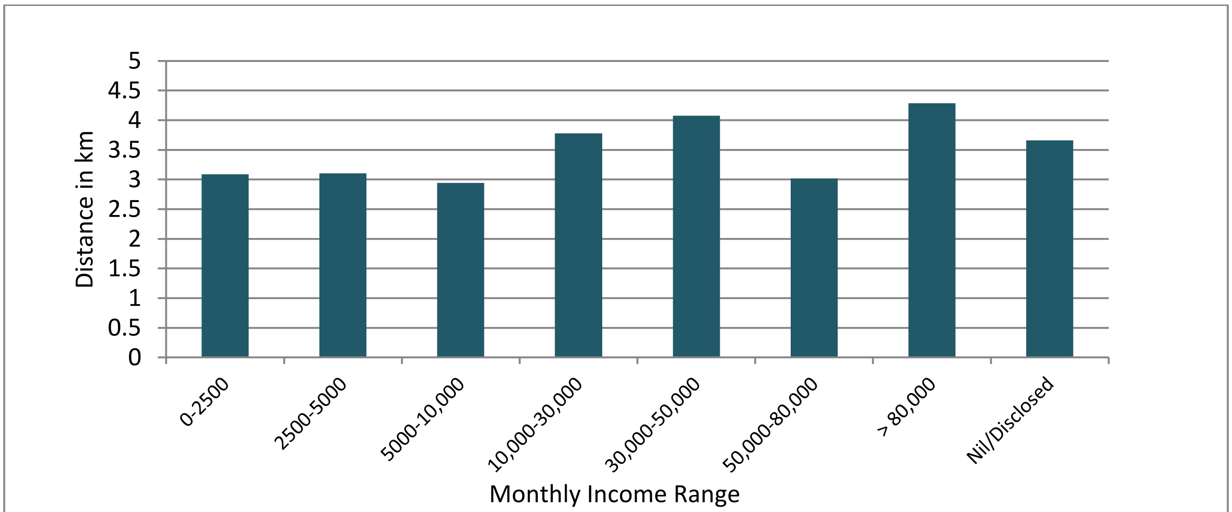

Figure 4-22: Trip length by income group
Source: Household Survey, Study Estimates, 2012

Considering trip lengths by modes used shows that people use cars and buses to travel longer distances, whereas to travel within the city they use auto rickshaws, two-wheelers and cycles, or walk. It can be seen in Table 4-4 that the trip length varies depending on the mode used.

Table 4-4: Trip distribution by trip length and mode

Mode	Distance (km)					
	Mean	Percentile 05	Percentile 25	Percentile 75	Percentile 95	Percentile 99
Auto	4.31	1.00	2.00	5.00	10.00	18.00
Bicycle	3.40	0.50	1.00	5.00	8.00	16.00
Bus	8.47	1.00	2.00	10.00	20.00	20.00
Car	11.67	1.00	2.00	10.00	30.00	30.00
Cycle rickshaw	4.00	0.50	3.00	5.00	8.00	8.00
Other	5.16	0.50	2.00	5.00	13.00	15.00
Shared Auto	3.21	0.50	1.00	4.90	10.00	10.00
Two-Wheeler	4.18	1.00	2.00	5.00	10.00	20.00
Walk	1.68	0.20	1.00	2.00	5.00	10.00

Source: Household survey, Study Estimates 2012

The non-motorised modes such as walking and cycling have mean trip lengths of 1.68km and 3.4km respectively. Buses and cars are used for trip lengths over 4km. Two-wheelers and auto rickshaws are used for trip lengths of 2 to 6km. Similarly, Table 4-5 shows that for making social trips, people take longer trips. Work and educational trips are made within 3 to 5km.

Table 4-5: Trip distribution by trip length and purpose

Distance (km)						
Purpose	**Mean**	**Percentile 05**	**Percentile 25**	**Percentile 75**	**Percentile 95**	**Percentile 99**
Educational	3.01	0.30	1.00	4.00	10.00	15.00
Health	1.69	0.30	0.50	3.00	3.50	3.50
Other	1.76	0.20	0.30	3.00	5.00	5.00
Recreational	2.76	0.20	0.60	5.00	6.70	12.00
Religious	2.12	0.20	1.00	2.00	6.00	10.00
Shopping	1.84	0.50	1.00	2.00	5.00	10.00
Social	7.67	3.00	3.00	15.00	15.00	15.00
Work	4.29	0.50	1.00	5.00	10.00	25.00

Source: Household survey, 2012

4.3.5. Travel time

The time needed to reach a destination is known as travel time.

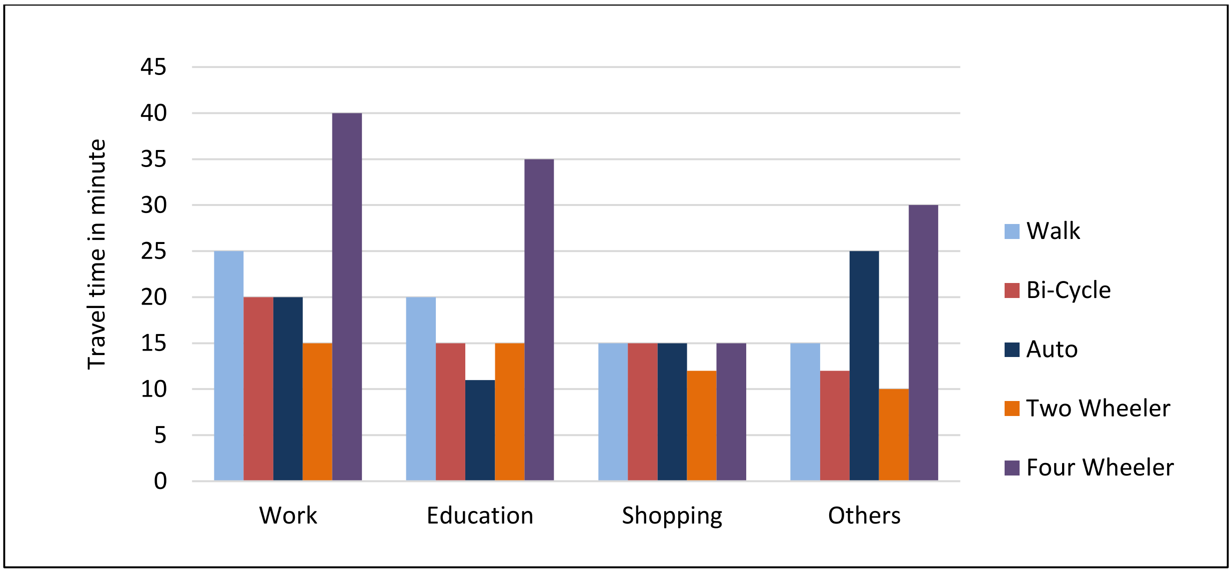

Figure 4-23: Travel time by trip purpose
Source: Household survey, 2012

Figure 4-23 indicates that people are likely to spend more time travelling to work than other kinds of trips. Cars or four-wheelers have the longest travel time, as they travel the longest distances. Also, irrespective of the different modes (except car users), people generally prefer to spend 20 minutes or less travelling, and thus they choose their modes accordingly.

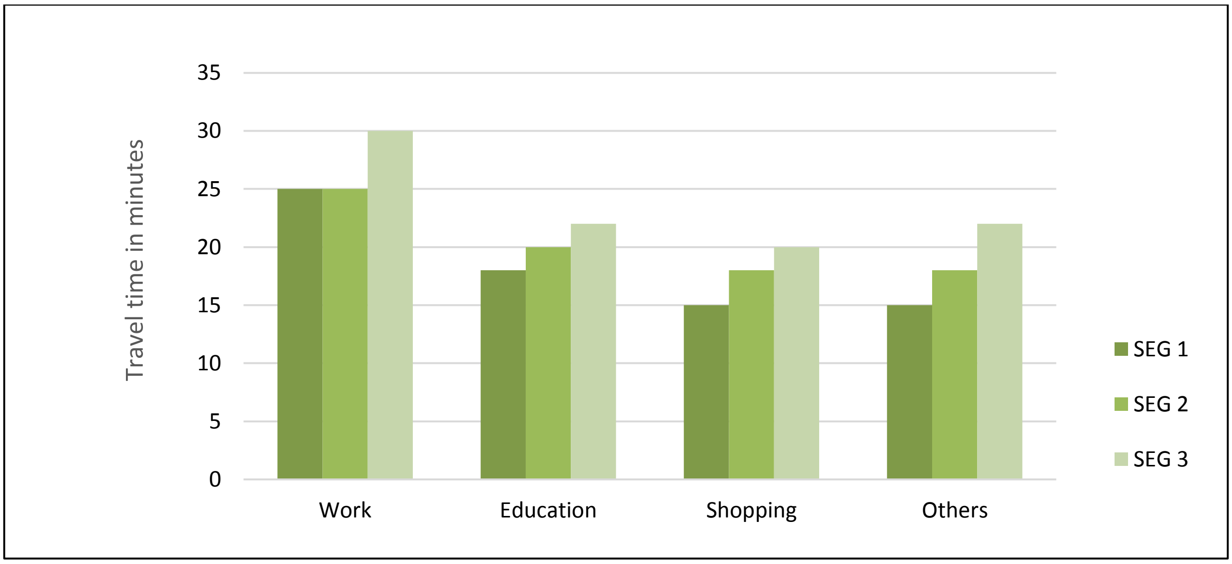

Figure 4-24: Travel time by trip purpose and social group
Source: Household survey, 2012

Figure 4-24 shows that there is not much difference in travel times, irrespective of trip purpose, between the various social groups. The travel time of SEG 3 (the high income group) is slightly higher than the other two, as they live further away from activity centres.

4.4. Accessibility to Infrastructure

Accessibility may be defined as the extent to which the land use transport system enables individuals to reach activities or destinations by means of a (or a combination of) transport mode(s) (Geurs & van Eck, 2001). It can also be seen as the ability to access infrastructure by a number of people. It is important to analyse the accessibility to transport infrastructure in addition to the presence of that infrastructure. Trips[25] made by individuals can be largely divided into work and non-work trips. Work and education trips constitute 79 per cent of the total trips, whereas social, religious, retail and recreation trips form the remaining 21 per cent of the total trips. Of the total number of trips, 11 per cent are made by auto, whereas 3 per cent are by transit. To analyse the access areas to public transit, Intermediate Para Transit (IPT) stops, and network and intersection densities, kernel densities[26] have been calculated by taking the search radius as 500 metres, which is considered as the walkable distance to the stops. The advantage of using kernel density over point density is that the influence of built environment features that are commonly found on the boundaries of TAZs will count, as they should, towards any nearby zones, rather than only the zone containing the transit stop (Tracy et al., 2011). Public transit stops were found to be inaccessible for the inner residential areas of the city, whereas para transit stops are accessible from the inner city area and from all the major arterials of the city.

To analyse the road access areas, the kernel densities of roads and intersections were calculated, which showed that almost all the roads of the RMC are highly accessible (Figure 4-25, Figure 4-26, Figure 4-27 and Figure 4-28). Intersections are also highly accessible in the central part of the city, but become less accessible as one goes outside from the city centre. Twenty-one per cent of trips, excluding those for work and education, consist mainly of retail, health, recreation, social and religious trips. These facilities are also considered part of the daily needs of individuals, and therefore access to these facilities needs to be studied. If these facilities are not nearby their residential area, individuals are pushed to travel further to access them. Figure 4-29, Figure 4-30, Figure 4-31 and Figure 4-32 show the areas where individuals have to travel longer distances to access retail, health, religious and recreation facilities, and which are therefore not within walkable distances.

[25] Trips here include trips below 500m made by walking or cycling along with the longer trips made by other modes. Thus the purpose of trips like retail, religious, social and recreation are also included with work and education trips.

[26] For calculating kernel density, each stop is assigned a kernel radius and a kernel function, whose value is highest at the source point and decreases smoothly as the distance from the point increases until it reaches zero at a distance equal to the kernel radius.

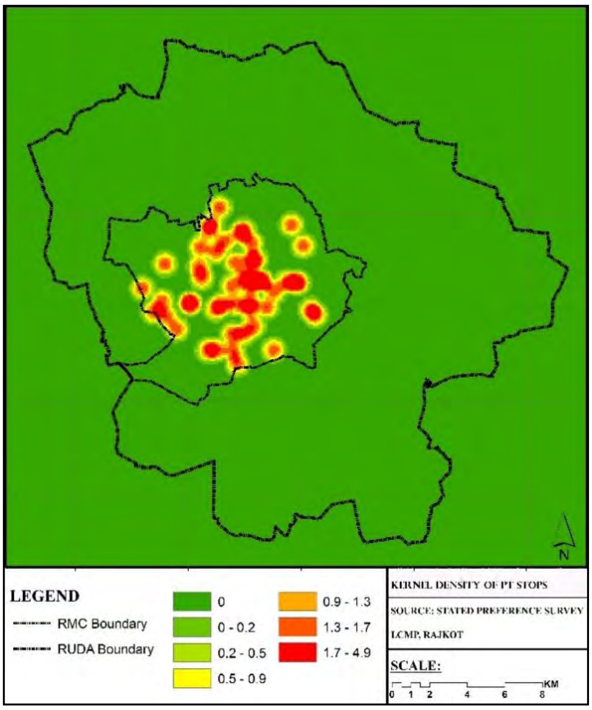

Figure 4-25: Kernel density of IPT stops
Source: RMC and Study Estimates, 2012

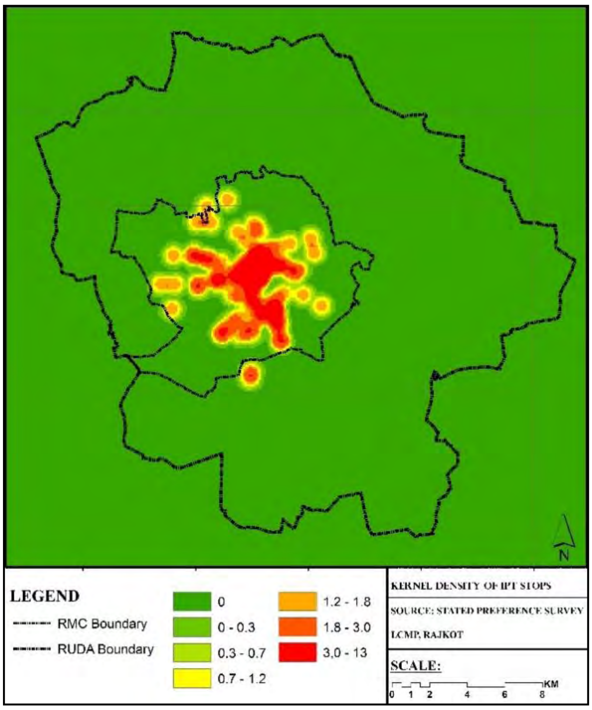

Figure 4-27: Kernel density of PT stops
Source: RMC and Study Estimates, 2012

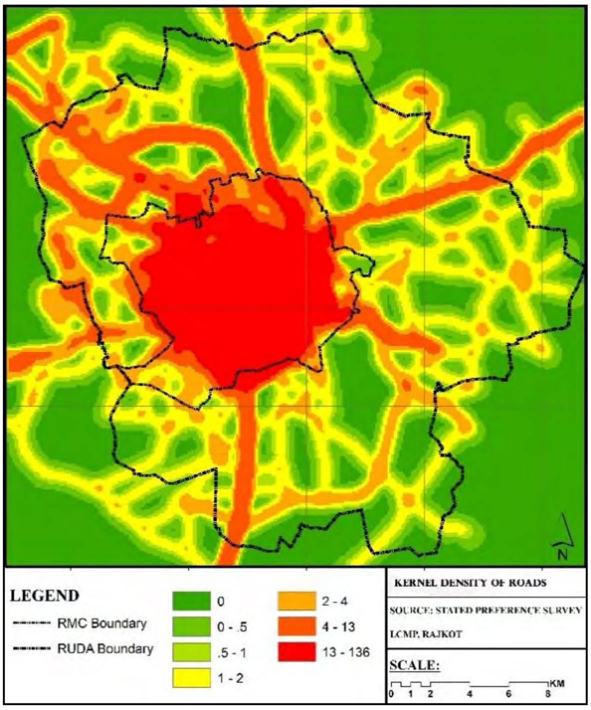

Figure 4-26: Kernel density of roads
Source: RMC and Study Estimates, 2012

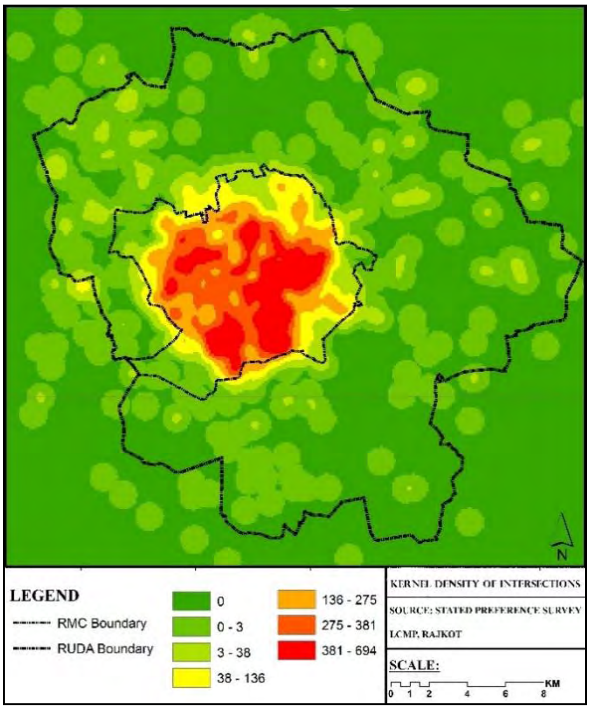

Figure 4-28: Kernel density of intersections
Source: RMC and Study Estimates, 2012

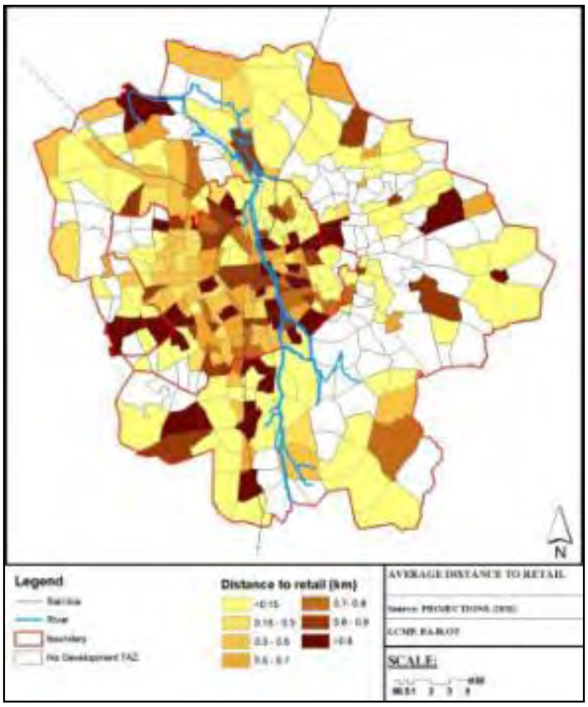

Figure 4-29: Average distance to retail
Source: RMC and Study Estimates, 2012

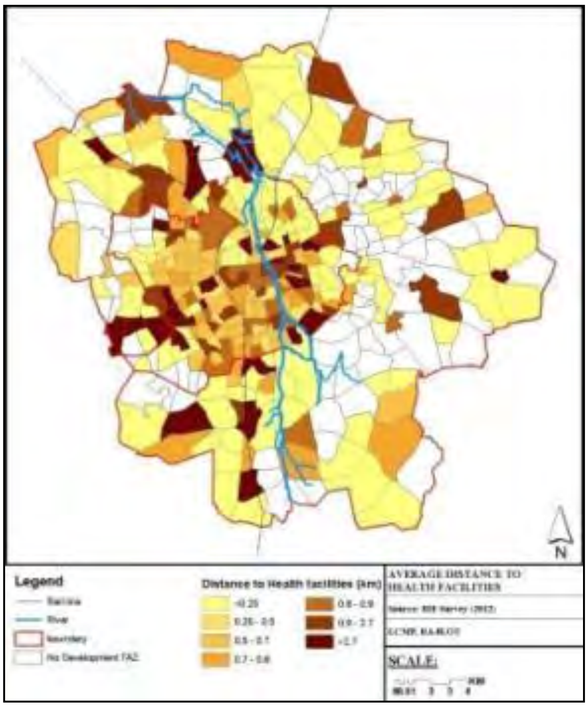

Figure 4-31: Average distance to health facilities
Source: RMC and Study Estimates, 2012

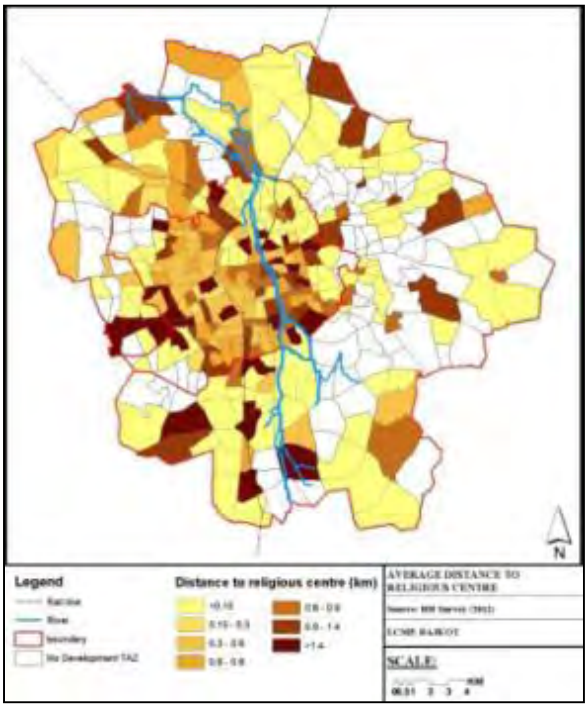

Figure 4-30: Average distance to religious centre
Source: RMC and Study Estimates, 2012

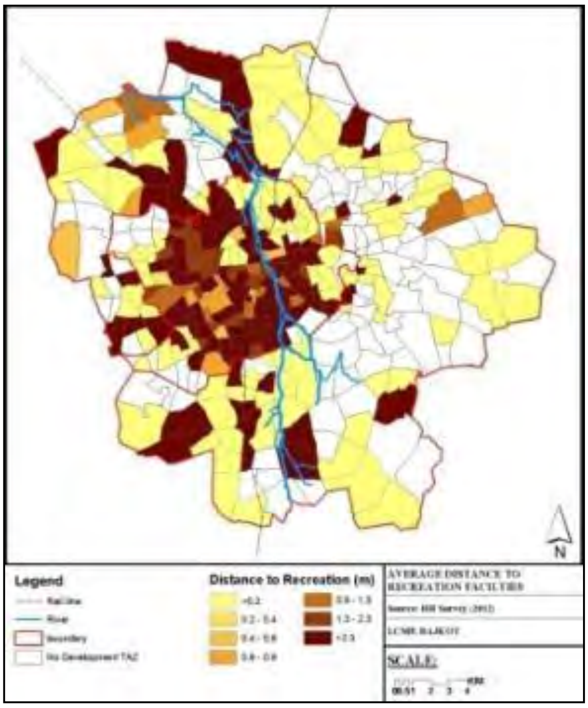

Figure 4-32: Average distance to recreation
Source: RMC and Study Estimates, 2012

4.5. Public Perception on Safety, Reliability and Affordability

The RMC and RUDA have laid down infrastructure and provided safety measures for the people. But for this study, after discovering the travel demand and the user perspective on the infrastructure, it was also very important to learn their perspective on the comfort of using the city's infrastructure. Therefore, along with a household survey, a perception survey was carried out so as to discover the opinion of the users on the quality of different modes they use in their daily routines. The majority of the population considers auto-rickshaws (hired and shared) as a reliable and safe mode, but they find it expensive in comparison to their incomes. Also, it was found from the surveys that people in Rajkot feel 'safe/ok' to walk, even though they do not have appropriate pedestrian facilities.

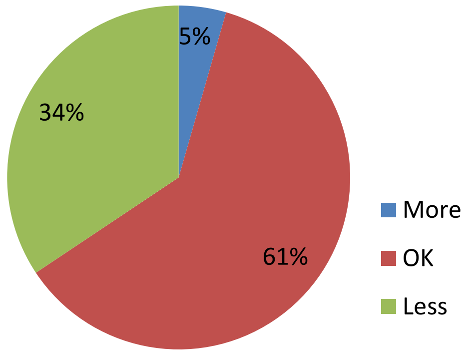

Figure 4-33: Reliability of shared-auto
Source: Household survey, 2012

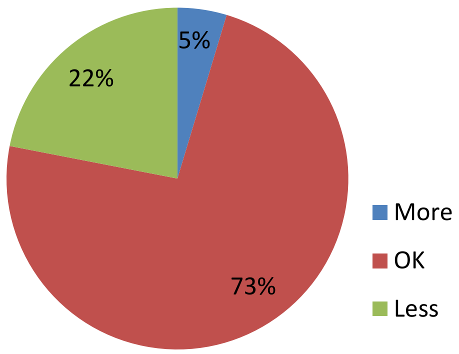

Figure 4-34: Safety in shared-auto
Source: Household survey, 2012

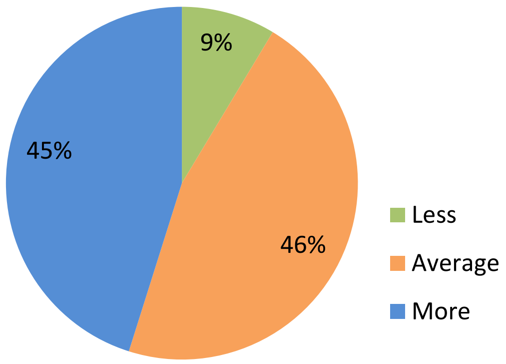

Figure 4-35: Perception of people of expenses in shared-auto
Source: Household survey, 2012

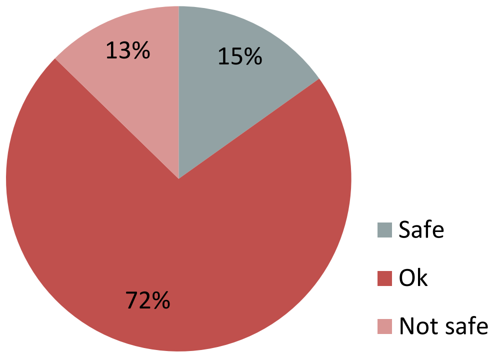

Figure 4-36: Safety perception of pedestrians
Source: Household survey, 2012

4.6. Strengths and Issues

Analysing the existing transport system, socio-economic structure and travel characteristics of Rajkot city, a few strengths and issues have been identified in Table 4-6.

Table 4-6: Major strengths and issues in Rajkot

	Strengths	Issues
City structure	Trip lengths are short, which can promote compact development of the city	The city is sprawling in all directions with inadequate transportation facilities The residential and industrial mix is seen in the southern part of the city
Facilities for pedestrians	38% of trip share is by walking Footpaths are present on all the major roads of the city	Footpath widths are less than 1.5m and are encroached all over, making it inconvenient to walk Traffic-calming measures are not prevalent on the intersections
Facilities for non-motorised vehicles	10% of trip share is by bicycles, which includes education and work trips.	Cycles lane exists only along the BRT corridor on one stretch of the Ring Road Cycle parking facilities are not present No signals present for NMVs
Facilities for public transport	BRT is being constructed on the Ring Road Bus stops are present in most parts of the city	No public transit systems exist in the city presently
Facilities for motorised vehicles	Ring radial road network Low travel time and distance	No proper parking spaces in the city, with vehicle ownership rising significantly each year Presence of bottlenecks at many roads. Local roads have direct access to arterials, which decreases speeds on major roads.
Facilities for IPT	11% of trip share is by auto It is a major public transport mode of the city	No proper parking locations for IPT Increasing share and monopoly of autos increases travel cost
Facilities for goods transport	There are many manufacturing and small and medium-scale industries in the city Well-connected to other cities	Goods movement by LCVs and chhakdas adds to high congestion and carbon levels in the city. No proper goods terminal in the city.

These issues and strengths can be applied in framing future strategic proposals, and in identifying policies and programs for the city's transportation.

Chapter 5: Business as Usual Scenario

5.1. Introduction

The 'Business as Usual' (BAU) scenario is a hypothetical sequence of events used to focus on causal processes and decision points, and is often used in analysing uncertain futures. It involves projecting urban development and growth for the transport sector based on past trends to arrive at more accurate predictions on the future scenario. The rates of change for the various parameters considered are kept constant. Further, it is assumed there will be no changes in policies and taxation regimes prior to the horizon year. It is also assumed that the ongoing implementation of projects and their studied impacts on development patterns and travel behaviour will continue as they are. Accordingly, population, vehicle ownership and transitions in city land use structure are projected for the years 2016, 2021 and 2031, with the base year taken as 2011.

5.2. Socio-Economic Transitions

To understand the future socio-economic behaviour in the city, it is important to understand the socio-economic transitions occurring across the country, and their effects upon the city. It is also necessary to understand the place that Rajkot holds in the state and centre's planning goals in terms of economic development. The socio-economic transition practically means the projection of population (local and migrants), household size, income levels and vehicle ownership. Rajkot acts as a regional centre for the Saurashtra region in Gujarat, and therefore its economic growth also depends on the growth of the region. In the near future, no large-scale investments are foreseen in the Saurashtra region, and therefore it is assumed that the economic development of Rajkot and the migration of population to the city will follow past trends in the future.

5.2.1. Population projection

The population projection for this study was conducted using the geometrical projection method. The projections were calculated by different methods, and by comparing (validating) the projection with past trends it was found that the geometric method was more realistic, and was therefore used for further analysis in this study. Figure 5-1 shows a comparison of projection methods used to estimate the population growth for Rajkot city.

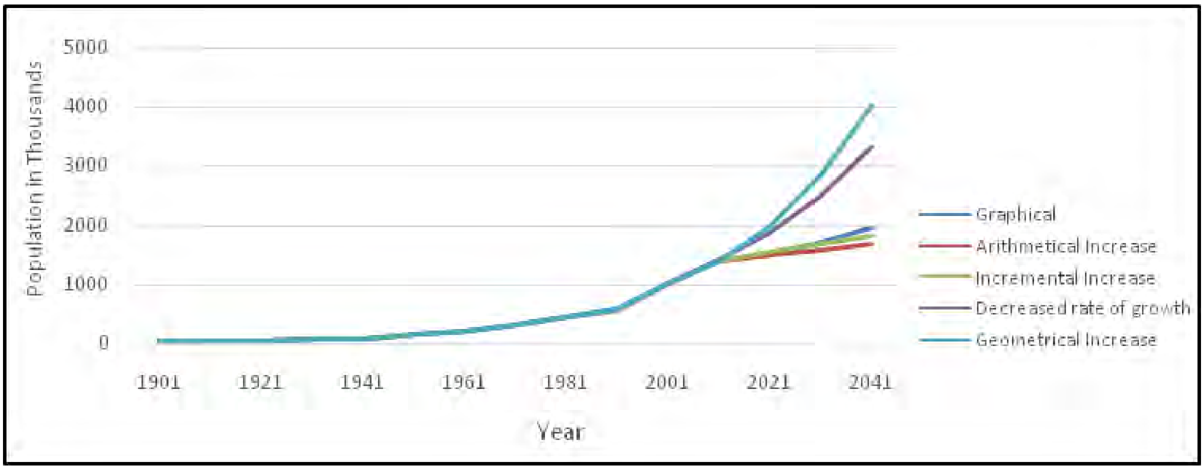

Figure 5-1: Population projections for Rajkot

Based on past population growth trends, the projected population estimated to reside in and around the RMC area in 2031 will be around 1.8 million. Thus, an increase of half a million people would be added to an existing population of 1.3 million residing in the Rajkot urban agglomeration area. But factoring in economic growth, the city's population is expected to grow at a rapid 3.99 per cent CAGR[27] to 2.2 million in 2021 and around 3 million in 2031 (Table 5-1). The United Nations projection[28] for the city for 2010, 2020 and 2025 are 1.36 million, 1.70 million and 1.90 million respectively. Thus the population projection estimates made in this study are on the higher side, but considering the high growth rates that the city has experienced in recent decades, the estimates look realistic.

Table 5-1: Population projection for horizon year

Year	Population	Households	Average Household Size*
2011	1,478,265	376,849	3.92
2016	1,795,574	486,819	3.69
2021	2,112,883	571,697	3.70
2031	3,019,942	868,995	3.48

Source: (Registrar General of India, 2011) and Study Estimates
* The average household size for 2011 was computed from the HH data. For the projected years, the reduction is based on Dhar et al. (2013).

5.2.2. Employment projection

Data on employment collected by the Census of India uses a nine-fold classification, which includes manufacturing, construction, trade and commerce, transport and communication, and other

[27] Compounded Annual Growth Rate (CAGR): The year-on-year growth rate of population over a specific period of time. It is particularly useful to compare growth rates. It is calculated by taking the nth root of the total percentage growth rate, where n is the number of years being considered.
[28] Available at http://www.unhabitat.org.jo/en/inp/Upload/1052216_Data%20tables.pdf

services. The estimates of the sectors and the related activities that will newly develop in the city until the year 2031 are conducted by developing a relationship between growths in activities in the years from 1980 to 2000 with Gujarat State's Gross Domestic Product (SGDP). Future estimates of SGDP are used to forecast the designated years' (2010, 2020 and 2030) activity space requirement. In Rajkot, enumerators at the property tax department in the municipal corporation collect the data for each residential and non-residential building. Thus, the jobs for each activity could be related with the SGDP and projected for the future.

5.2.3. Industrial growth projection

Industrial growth projections are based on the national and state policies for the region, and the trend of growth for individual industrial sectors existing and planned for the city.

5.3. Land Use Transitions

As previously stated, the transitions in residential, commercial and industrial land uses have been projected for the horizon years. The methods used for the stated transitions are described in the following section. During consultations with RMC, it was found that the old RUDA boundary, which was formerly considered as the study area, would not be adequate to accommodate the urban growth, particularly in the western part of the city. Therefore, the study area boundary for the land use projections has been extended beyond the administrative boundary on the western part of the city. Additional TAZs were added on the assumption that new developments would come up in the Kalawad Road area.

5.3.1. Methodology of land use projection and allocation

The land use projections were conducted for building floor spaces that would develop in Rajkot under residential, commercial and industrial land uses for the years 2016, 2021 and 2031. The methods used for projections and the allocation are described below. As seen in Figure 5-2, the methodology adopted for land use projections and allocation for the horizon years involves three steps. In Step 1, population and employment was projected for 2016, 2021 and 2031, according to which the floor space requirement for each land use was calculated. To derive floor space from employment projections, the ratio of present floor space to the total employment under each of these uses was used. Thus, this was a simple multiplication of the mentioned ratio with the projected employment under different sectors and residential population. Step 2 involves the allocation of non-residential activities. For this, potential locations where this development could occur were identified based on past trends, and from discussing the potential growth areas with RMC officials. Non-residential activities were allocated first, as it was assumed these would catalyse residential development. In Step 3, residential activities were allocated, for which accessibility to jobs was computed for each TAZ, and the same was used as a measure to determine the probable location of residences. This is the subsequent special step used to allocate housing stock[29]. Urban

[29] Housing stock refers to the physical number of dwellings, i.e. occupied as well as unoccupied dwellings.

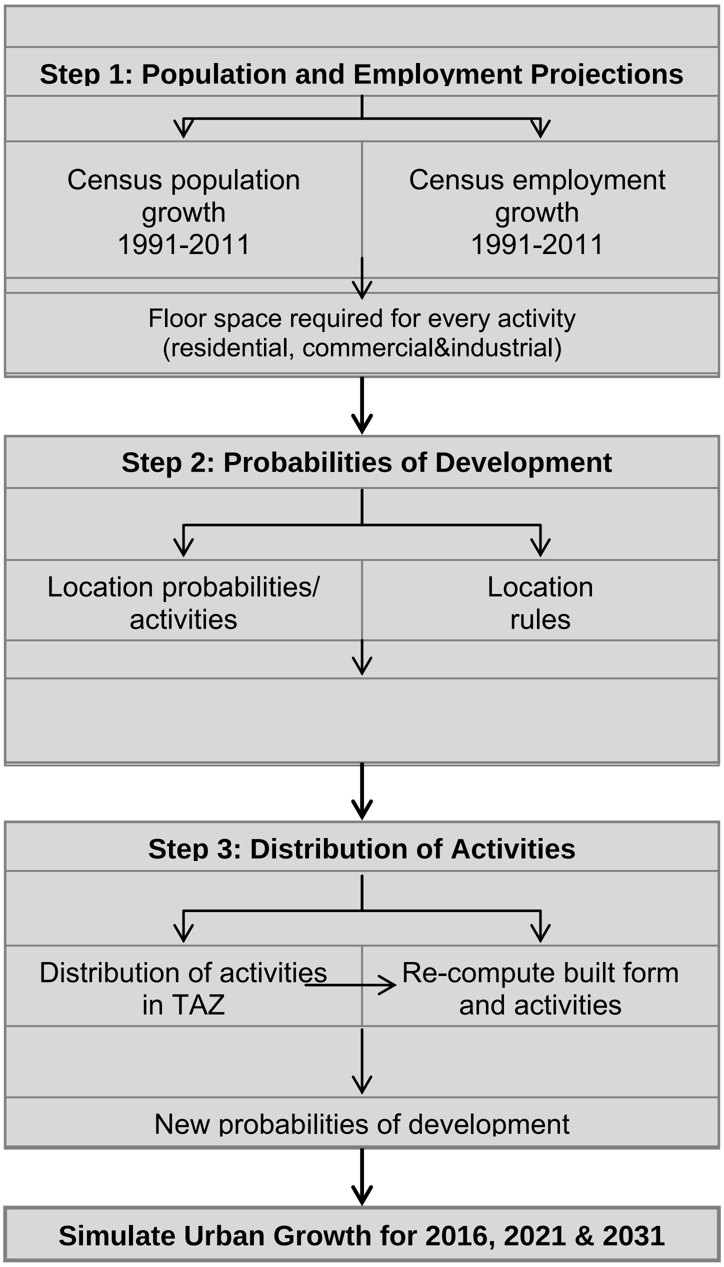

Figure 5-2: Methodology of land use projections and allocation

and land use growth will essentially depend upon the space available for development and, to an extent, on the regeneration of certain urban areas (i.e. demolition of old buildings and construction of new ones).Therefore, the objective of the simulation exercise is to make informed urban planning decisions. For example, urban growth models identify the type of land-use that will develop, when and where, and its repercussions on other developments. The General Development Control Regulations (GDCRs) define how much floor space can be developed and under which land use. This step allows us to determine the total area that can be developed per land use activity in the grid cell (D_a). The total space available for development is computed by deducting the existing development/land use activity from D_a. To ascertain D_a, the portion of area under development is found from the TAZs that are already developed. It was found that on an average a gross FSI of around 0.6 is consumed, which was used to ascertain D_a. Using the aforementioned method, the land use transition or change was modelled for the three land uses: residential, commercial and industrial. The following three sections explore the details of the various land uses and projected areas for the horizon years, along with the respective maps.

Commercial land use

According to the population projections, employment projections were also conducted for the horizon years, and the per capita use of commercial space requirements was found. For the commercial land use projections, the main corridors of development were identified based on the current pattern of development, and from consultations with RMC officials. Development of the existing road network and planned developments like the Outer Ring Road were taken into consideration in allocating development. Areas along major arterials and the Ring Road were assumed to have a potential for higher commercial development, whereas lesser commercial development was assumed to occur in internal areas, and along collector and local roads. The total commercial land use was allocated according to the assumed commercial development in each TAZ as seen in Table 5-2.

Table 5-2: Commercial area projections

Year	Floor area under commercial use (Ha)
2011	303
2016	371
2021	435
2031	619

Currently, commercial developments are concentrated largely in the city centre, but they are also located along the arterials, touching the Outer Ring Road. The city centre will remain the commercial hub for all the horizon years. In 2016, it is expected that commercial areas in the western part of the city along the 150ft Ring Road would develop on account of growth in residential developments. In 2021, commercial development will be seen along the industrial corridors as the major development will commence on those arterials. In 2031, it is assumed that the Outer Ring Road to 150ft Ring Road will come up to support the radial development of the city. It can be seen that some minor commercial development will likely occur on the Outer Ring Road, and the 150ft Ring Road will have denser commercial spaces. Figure 5-3 shows how the commercial development is expected to be in 2011, 2016, 2021 and 2031.

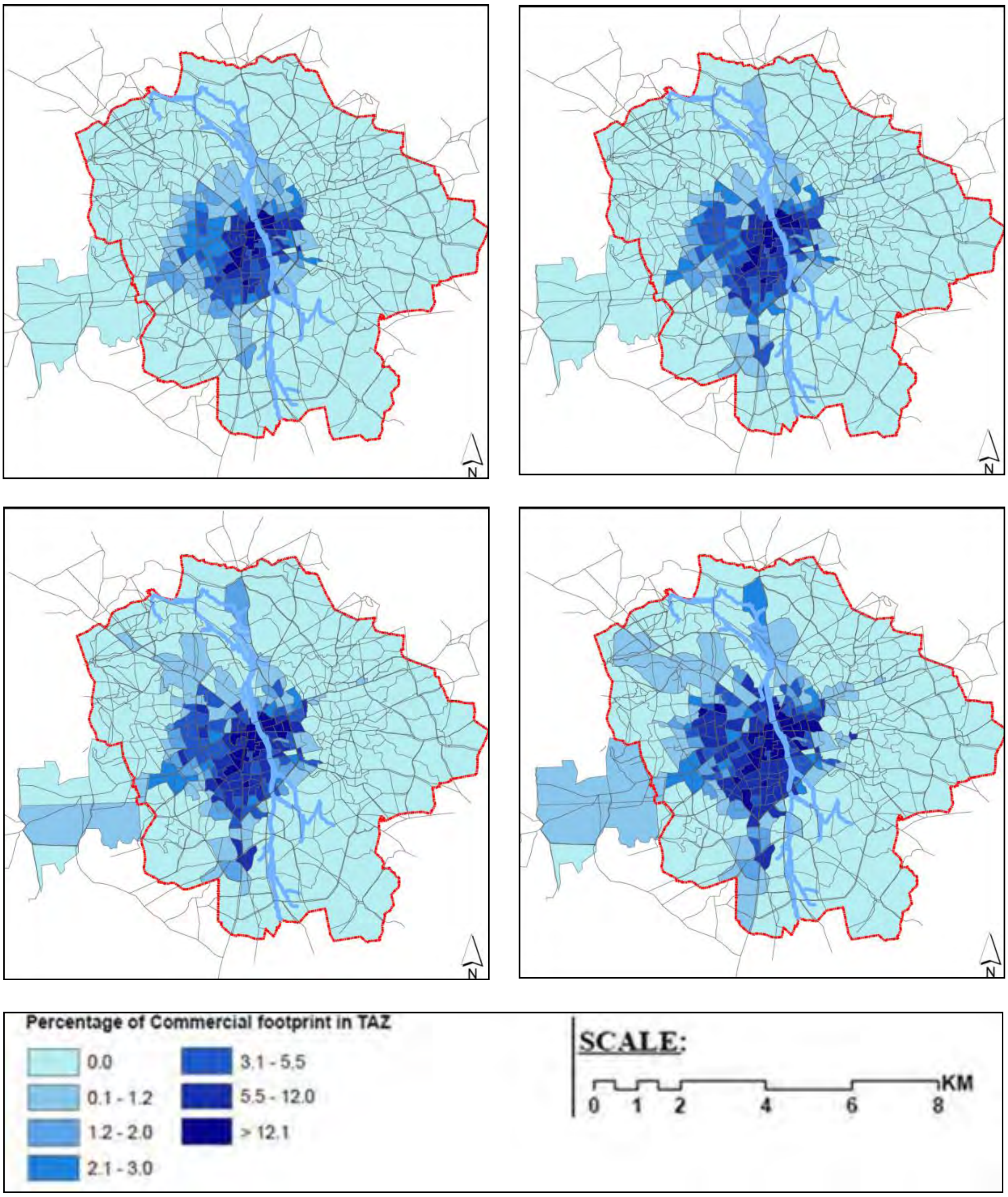

Figure 5-3: Map showing commercial development

(Start from upper left corner: 2011, 2016 and lower left corner:2021 and 2031)

Source: Land use simulation: Study Estimates, 2012

Industrial land use

For industrial land use, the iNDEXTb[30] data was used to determine the industrial area requirements. As with commercial land use, corridors were identified for industrial growth in consultation with RMC officials. Likewise, the areas with future industrial developments were assigned percentages of development, and then the total industrial growth was allocated as per the trend and distance from the city centre.

Table 5-3: Industrial area projections

Years	Industrial Area (Ha)
2011	402
2016	465
2021	561
2031	750

Source: Study Estimates

Figure 5-4 shows how the commercial development is expected to be in 2011, 2016, 2021 and 2031. Industrial development is expected along the Gondal Road in the south, but by 2021 the Jamnagar Road would also have industrial development according to the development plan. By 2031, Jamnagar Road and Ahmedabad Road would also have increased industrial development. After determining the land use projections for the three horizon years, travel demand has to be found keeping the base year as 2010.

[30] The Industrial Extension Bureau, popularly known as iNDEXTb, is a Government of Gujarat organisation established with the objective of accelerating industrial development in the state. The Bureau acts as a single point of contact for entrepreneurs establishing industrial ventures.

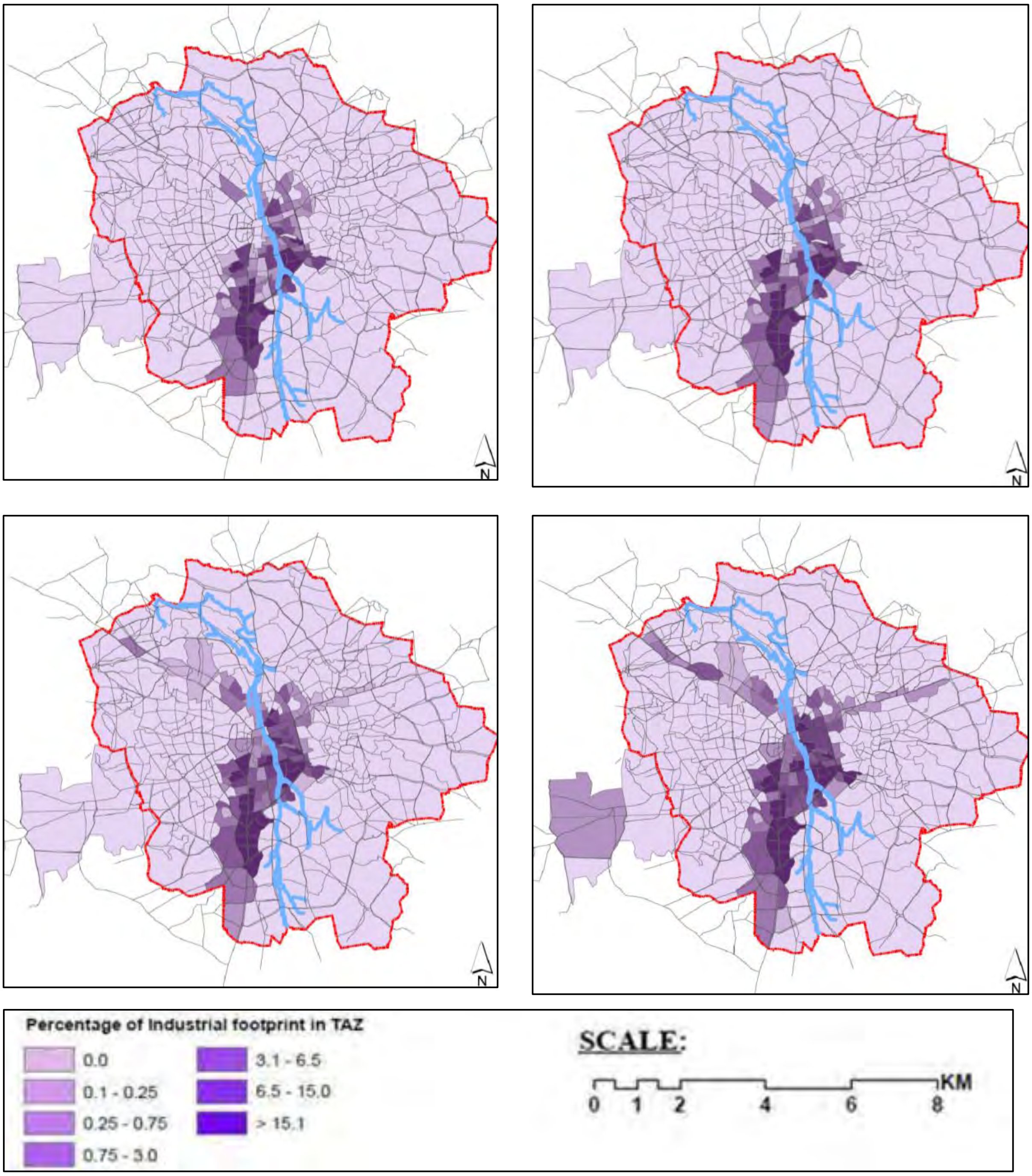

Figure 5-4: Map showing industrial development

(Start from upper left corner: 2011, 2016 and lower left corner:2021 and 2031)

Source: Land use Simulation: Study Estimates, 2012

5.4. Travel Demand Analysis

Travel demand analysis is a crucial part of predicting future demand in the transportation sector. The travel demand analysis guides the planning process in achieving a transportation supply that matches travel demand. Travel demand is assessed based on analysis of the travel behaviour of individuals. There is an emerging wing of research in transport planning concerning the relationship between land use and travel behaviour. A review of the relevant literature suggests that physical and socio-demographic variables of urban form affects travel behaviour, and consequently the environmental impact of transport (Hickman & Banister, 2005). Provided below are the variables used in the prescribed LCMP methodology, and their details.

Table 5-4: Variables used in LCMP methodology

Socio-Economic Variables	Land use Variables
SEG 1	Population density
SEG 2	Job-housing Ratio
SEG 3	Hawker area
Vehicleownership	Footpath area
Household size	Streetlights
Age	Parking areas
	Distance from city centre
	Access to destinations

Socio-Economic Group 1 (SEG 1): This group represents low-income households. These are identified as households living in kachha houses or independent houses without any assets (i.e. household assets like a television or telephone) and do not own any motorised vehicles.

Socio-Economic Group 2 (SEG 2): This group represents middle-income households, which are characterised as residing in independent houses or apartments and owning one motorised two-wheeler (scooter or motorbike).

Socio-Economic Group 3 (SEG 3): This group represents high-income households, which are characterised as residing in independent houses or apartments and owning a four-wheeler along with other assets.

Vehicle ownership: This refers to the average number of vehicles owned by a household in a particular TAZ.

Household size: This refers to the average number of members in the family.

Population density: Defined in Chapter2.

Job-housing ratio: – Defined in Chapter2.

Hawker area: defined as the road space covered by hawkers.

Footpath area: defined as the percentage of footpaths per road length in an area.

Streetlights: defined as the percentage of road length covered by streetlights.

Parking area: derived from the road inventory, and defined as the percentage of parking on roads in an area.
Distance from city centre: defined as the distance to the central commercial core of the city.
Access to destinations: defined as the average time taken to reach retail stores and other facilities nearby.

The travel demand analysis was conducted using the four-stage modelling, involving trip generation, trip distribution, mode choice, and trip assignment. The software 'Cube' (version 6.1 Voyager)[31]was used to execute the various stages of travel demand analysis.

5.4.1. Four-stage modelling

To understand and estimate future demand in the transport sector, the four-stage model was adopted. The modelling inputs are road network and TAZ-level data. The data aggregated at the TAZ level includes base-year information for the variables mentioned earlier like population, employment, job-housing ratio and other infrastructure. Conventionally, ascertaining travel demand is seen as a four-stage process, made up of:

- Whether or not to make a trip, which is called `trip generation',
- Where to go to, which is called `destination choice' or `trip distribution',
- Which mode of transport to use, which is called `mode choice' or `modal split', and
- Which route to take, which is used in the `assignment' process where trips are put onto the network.

Since the analytical units are more disaggregated, the analysis is conducted in a disaggregated manner (that is, by social group, gender and purpose).Also, the network assignment is conducted separately for NMT modes, PT and private vehicles. All four stages and the results are explained in more detail in the following sections. The process followed for the four-stage modelling is shown in Figure 5-5.

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[31] Cube Voyager (product by Citilabs) processed zonal data, and its scripting helped all four stages of modelling in unique ways (described in detail laterin this chapter).

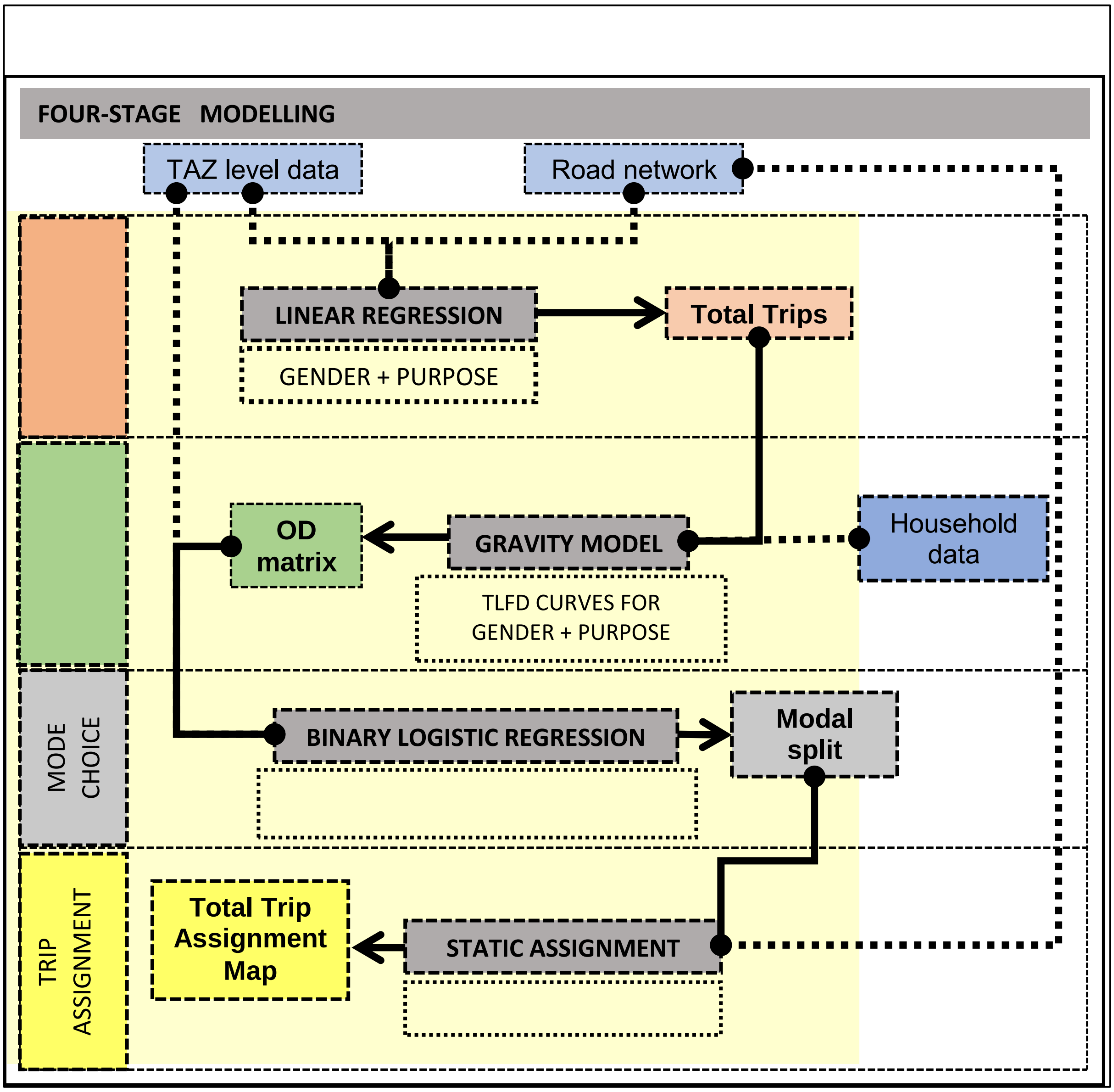


Figure 5-5: Methodology for ascertaining travel demand

Trip generation

As stated earlier, this stage considers how much an individual travels. Therefore, it aims to predict the total number of trips generated (i.e. produced and attracted in each TAZ). This study uses regression analysis in this instance, which is the method most commonly used for trip generation analysis. As stated earlier, the only diversion is the variables used and manner in which the regression equation is formed. The following trips are estimated for each TAZ.

- Work trips by women from SEG1 group
- Work trips by women from SEG2 group
- Work trips by women from SEG3 group
- Work trips by men from SEG1 group

- Work trips by men from SEG2 group
- Work trips by men from SEG3 group
- Shopping trips
- Educational trips
- Other purpose trips.

At the end of trip production, trips are further classified into the home end of an HB (home-based) trip, or as the origin of a NHB (non-home-based) trip. Trip attraction is defined as the non-home end of an HB trip, or the destination of an NHB trip (Ortúzar & Willumsen, 2011).

As stated earlier, regression analysis[32] was used to estimate the aforesaid trip ends. A linear regression method was used and the average trip rate per household from the sample was considered the dependent variable. The independent variables included socio-demographic variables like household size, vehicle ownership (extracted from the household survey), and land use variables like residential space, commercial space, educational area, job-housing ratio, industrial space, hawkers and even time to grocery shops (extracted from data collected from primary and secondary sources described earlier). The household survey location was geo-referenced and spatial overlay methods in GIS were used to transfer the spatial data (TAZ-level data) to the household survey database. The regression model was also run in two stages. In the first stage, only socio-demographic variables were introduced into the equations, which are done to account for the residential self-selection[33] problem. The equation formed in the first stage was then used as a control, after which land use and other built form variables were introduced into the equation.

For trip attraction, the trips attracted in each zone (aggregated from the household survey) were considered as the dependent variable, and floor space under non-residential land uses were considered as the independent variables. A linear regression equation was used to estimate the trip productions. Figure 5-6 shows the methodology used for ascertaining trip generation.

[32] Regression Analysis is a statistical process for estimating the relationship among variables. Here, it has been used to see the impact of change in socio-demographic variables and built form variables (independent variables) on travel behaviour (dependent variable).

[33] Self-selection: the tendency of people to choose neighbourhoods that facilitate their preferred mode of travel. Several studies have found this very important factor affects the travel pattern (more than built form).

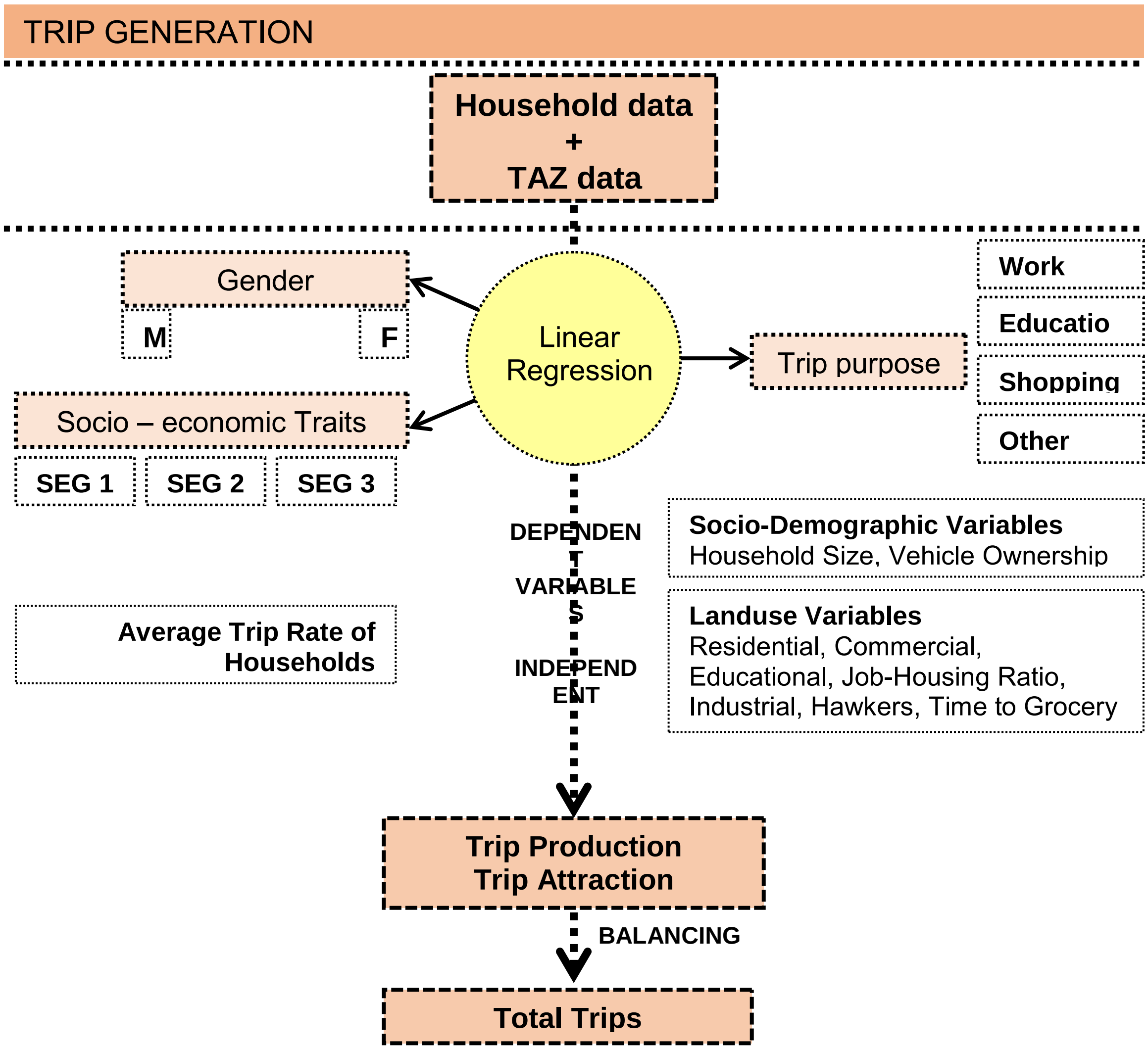


Figure 5-6: Methodology for ascertaining trip generation

Work-based trips: Considering the work trips produced by SEG 1, it is evident that the trip rates of both males and females increase with increasing household size, and decreases with increasing vehicle ownerships. The trip rate for females is greater than that for males where there is industrial land use. The job-housing ratio also has a negative relation with female trip rates, but a positive relation with male trip rates.

SEG1 production (female) =0.314 - 0.361*Vehicle Ownership + 0.020*HH Size +0.205*Industrial area - 0.105*Job-housing ratio

SEG1 production (male) = 1.683 - 1.881*Vehicle ownership + 0.076*HH Size -0.013*Industrial area + 0.114*Job-housing ratio

As for SEG 2 trip productions, the ownership of two-wheelers and household size are highly related to the trip rates for both genderes. Industrial has areas have a strong negative relationship with SEG2 work trip rates. However, the job-housing ratio shows a negative relationship with female trip rates, but a positive one with male trip rates.

SEG2 production (female) = -0.133 + 0.324*Two-wheeler ownership + 0.042*HH Size -0.153* Industrial area - 0.009*Job-housing ratio

SEG2 production (male) = -0.626 + 2.073*Two-wheeler ownership + 0.182*HH Size -0.045*Industrial area + 0.178*Job-housing ratio

As for SEG 3 trip productions, four-wheeler ownerships have a strong positive correlation with trip rates, whereas industrial areas are negatively related, indicating that individuals who own cars prefer to travel more and individuals belonging to SEG 3 do not live near industries.

SEG3 production (female) = 0.0001+ 0.309*Four-wheeler ownership -0.008*Industrial area + 0.003*Job-housing ratio

SEG3 production (male) = -0.001 + 1.655*four-wheeler ownership -0.004*Industrial area + 0.004*Job-housing ratio

In the case of trip production for work-based trips, the factors affecting trip rates vary across the three socio-economic groups. In low-income households (SEG 1), the trip rate was found to be negatively affected by vehicle ownership, whereas in the case of middle-income households (SEG 2), two-wheeler ownership stood as the dominant variable affecting the trip rate. Meanwhile, the high-income group (SEG 3) had the four-wheeler as the dominant determining factor affecting the trip rate. The job-housing ratio also plays important role in work-based trip productions.

Work trips for SEG1 are attracted largely to commercial areas and areas where the job-housing ratios are high. Industrial and residential areas also have a positive correlation for females, but a negative correlation for males, which indicates that SEG1 females generally work in industries or do housework in the residences.

SEG1 attraction (female) = 0.101+ 0.849*IND + 2.172*Job-housing ratio + 6.356*Commercial area + 0.328*Residential area

SEG1 attraction (male) =4.995 - 4.494*Industrial area + 14.342*Job-housing ratio + 29.247*Commercial area - 3.214*Residential area

Work trips for SEG 2 are attracted largely to commercial areas, and also where the job-housing balance is high. However, SEG 2 households have a negative relation with industrial and residential areas, indicating that they largely go to commercial or mixed land use areas for work.

SEG2 attraction (female) = 2.897- 4.720*Industrial area + 6.350*Job-housing ratio + 8.578*Commercial area - 1.949*Residential area

SEG2 attraction (male) = 20.2 - 30.734*Industrial area + 45.340*Job-housing ratio + 49.050*Commercial area - 15.146*Residential area

Work trips for SEG3 are attracted largely to areas where the job-housing ratio is high and has a negative relation with industrial areas. Work trips for females have a negative relation with commercial areas, whereas males have a positive relation.

SEG3 attraction (female) = 0.290 - 0.412*Industrial area + 0.158*Job-housing ratio - 0.214*Commercial area - 0.248*Residential area

SEG3 attraction (male) = 0.480 - 0.811*Industrial area + 0.603*Job-housing ratio + 0.802*Commercial area - 0.360*Residential area

In the case of trip attraction for work based trips, unlike the trip production, commercial areas and job-housing ratios emerged as the two most dominant factors affecting the trip rate. This is a clear indicator that most of the jobs or work-related locations are in the core commercial areas, where there are mostly businesses or trade centres (retail or wholesale) rather than service sector establishments. An exception for this was the case of low-income females, where the trip rate was mostly affected by industrial areas.

Educational trips: Education trips were produced largely where there are high job-housing ratios, and specifically, male trip rates were highly related with vehicle ownerships.

Education production (female) = -0.177 + 0.166*HH Size + 0.018*Industrial area + 0.135*Job-housing ratio

Education production (male) = -0.187 + 0.161*HH Size + 0.179*Vehicle ownership -0.119*Industrial area + 0.347*Job-housing ratio

Education trips are attracted largely to commercial areas, and where the job-housing ratios are high, as the schools are located nearby commercial areas. The attraction of education trips is negatively related to industrial areas, so the schools are not located near the industries.

Education attraction (female) = 5.112 - 8.783*Industrial area + 17.406*Job-housing ratio + 14.812*Commercial area - 2.229*Residential area

Education attraction (male) = 7.459-13.266*Industrial area + 25.973*Job-housing ratio + 21.768*Commercial area - 4.120*Residential area

Shopping trips: Shopping trip productions for SEG1 are highly related to industrial areas and also where job-housing ratios are high. Female trip rates are negatively related with four-wheeler ownerships. This means that people living in industrial areas have to make more trips for retail shopping.

Shop production (female) = 0.614 - 0.034*HH Size -0.275*Four-wheeler ownership + 0.196*Industrial area + 0.406*Job-housing ratio

Shop production (male) = 0.051 + 0.015*HH Size + 0.067*Industrial area + 0.085*Job-housing ratio

Shopping trips are attracted largely in commercial areas and where the job-housing ratios are high and have negative relations with industrial areas.

Shop attraction (female) = 3.885 - 7.748*Industrial area + 15.945*Job-housing ratio + 38.228*Commercial area - 1.817*Residential area

Shop attraction (male) = 1.343 - 2.633*Industrial area + 5.326*Job-housing ratio + 12.226*Commercial area - 0.931*Residential area

Other trips: Other trips like recreational, social, and religious trips are mainly produced where the job-housing ratios are high and made with vehicles by both females and males. These trips have a negative relation with industrial areas.

Others production (female) = 0.016 + 0.059*Vehicle ownership - 0.035*Industrial area + 0.083* Job-housing ratio

Others production (male) = -0.023 + 0.019*HH Size + 0.059*Two-wheeler ownership - 0.084*Industrial area + 0.007*Job-housing ratio

Other trips are mainly attracted to commercial areas and higher job-housing ratios, whereas they are negatively attracted to industrial areas.

Others attraction (female) = 0.504 - 1.693*Industrial area + 2.378*Job-housing ratio + 6.500*Commercial area - 0.198*Residential area

Others attraction (male) =1.235 - 3.083*Industrial area + 3.528*Job-housing ratio + 7.518*Commercial area - 0.670*Residential area

Concluding the regression analysis for trip generation, it can be seen that work trip production rates are highly affected by socio-economic variables like vehicle ownership and household size, whereas attractions are mainly affected by commercial areas and areas with high job-housing ratios. SEG1 trips are only attracted to industrial areas. At the same time, education trips are mainly produced in residential areas, but females prefer dropping their children to school by walking or by bicycle, while males use vehicles for the same. As for shopping, SEG1 has higher trip rates in industrial areas. Leisure trips or social trips are mainly made with vehicles. For analysing the trip productions and attractions spatially over the city, maps have been prepared from the data extracted from Cube after modelling the trip generation (Figure 5-7, Figure 5-8). It shows the number of trips produced and trips attracted in each TAZ, which gives an idea of the users' origins and destinations.

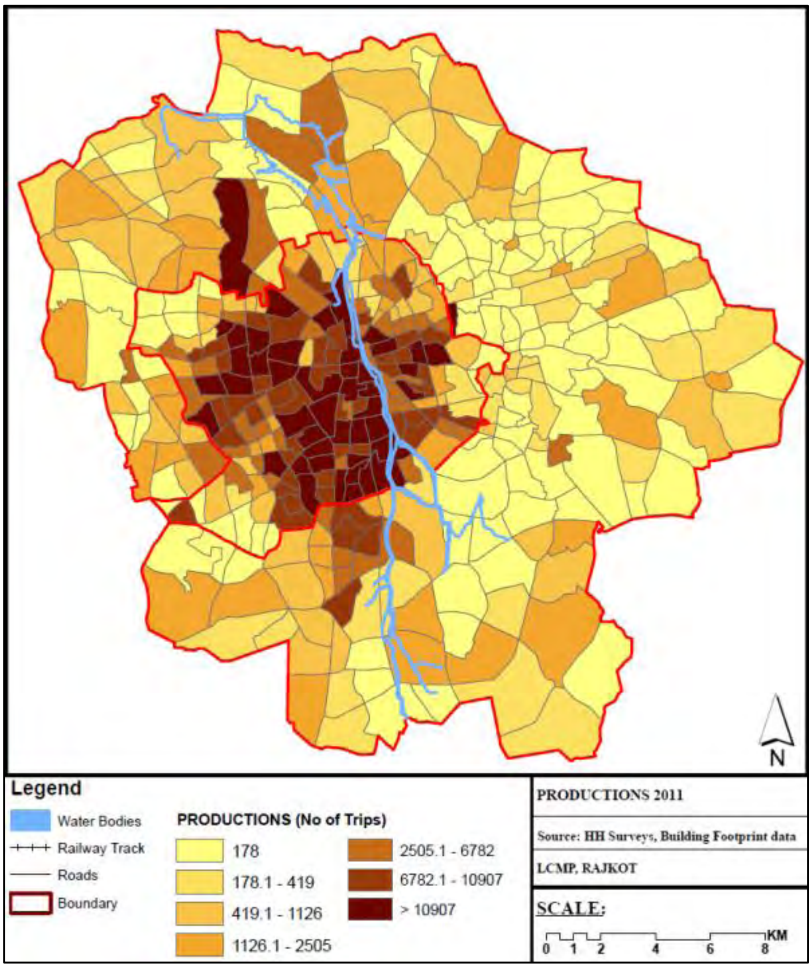


Figure 5-7: Map showing trip productions
Source: HH surveys, Building Footprint map

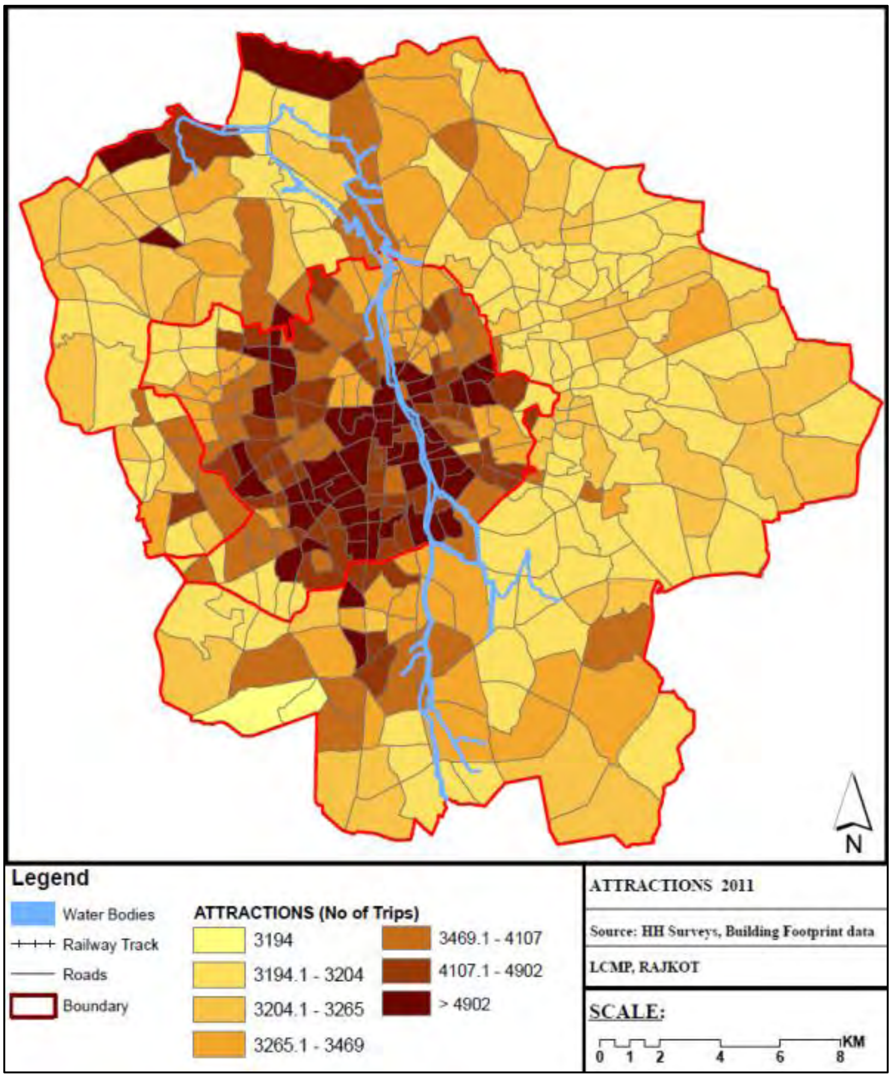


Figure 5-8: Map showing trip attractions
Source: HH surveys, Building Footprint map

The trip production map (Figure 5-7) shows that spatially, most trips are produced from the western side of the river, especially from the southern side of the city along Gondal Road. Trip rates are also seen to be high in the old city area due to high residential density. The number of trips produced outside the RMC area is not very high; indicating that the trip rates of households in villages is low in comparison to the households inside the RMC area. On the other hand, most trips are attracted to commercial and industrial areas (Figure 5-8). Very high trip attractions are found in the city core because of it being the commercial hub of city. High attractions are seen near the GIDC area and in the Atika industrial area, as Mavadi Road has intensive commercial activity and is near the marketing yard. The output takes the form of the number of trips produced and attracted for each purpose and for socio-economic groups SEG 1, 2 and 3. The number of trips varies for productions and attractions; however, logically the number of trips produced and attracted should be the same. The number of trips was equalised according to the number of trips produced (Table 5-5). The production of trips has been quantified from the household data and is more reliable than the attraction trips, which are quantified approximately from the land use and building footprint data.

Table 5-5: Trip generation for various purposes

Purpose	Productions trips	Attractions trips	Balanced Attraction
Work SEG1 (female)	63,885	56, 456	63,885
Work SEG1 (male)	300,513	222,632	300,513
Work SEG2 (female)	80,711	130,221	80,711
Work SEG2(male)	523,815	625,524	523,815
Work SEG3(female)	3,426	2,829	3,426
Work SEG3(male)	18,238	12,324	18,238
Education(female)	327,269	273,700	327,269
Education(male)	386,343	294,534	386,343
Shopping(female)	134,148	127,080	134,148
Shopping(male)	32,111	26,870	32,111
Other(female)	111,356	93,840	111,356
Other(male)	144,414	135,290	144,414
Total	2,126,229	1,944,844	2,126,229

Trip distribution

The second stage of the four-step transportation forecasting model is the distribution of trips from each origin to each destination (TAZ). The trip distribution exercise was conducted for various trip purposes (work, education, shopping and others) based on socio-economic group and gender. Trip distribution modelling was carried out by the use of the gravity model, using an exponential function and varied deterrence functions.

$f(cij) = \exp(-\beta cij)$

$f(cij)$ is a generalized function of the travel costs with one or more parameters for calibration. This function often receives the name of 'deterrence function' because it represents the disincentive to travel as distance (time) or cost increases.

Thus, along with the production and attractions (P-A), which were derived from the outputs of the trip generation phase, the distance decay values were computed from the spatial interaction for each of the P-A categories mentioned in the trip generation section, which represents the cost of travelling from one zone to another. Moreover, the external trips (i.e. I-E trips and E-I trips) are separated and have a separate decay curve (TLFD) computed from these. The impedance of the distance decay curve that will be used is the distance. As can be seen in the distance impedance best-fit curves later in the section, if we use the negative exponential curves to represent the distance decay function, there will be limited scopes of values (gaps) with improper ranks exceeding 100 per cent of the surveyed sample(s). The best-fit curve of this travel distance and travel frequency may be an ‘S’ shape, but such an ‘S’ shape function has resulted in an unfit curve in SPSS. Therefore, two shapes could represent the survey statistics with a certain travel time threshold, which may be set to separate a best representative distance impedance graph into two sub-graphs: one linear graph beside the negative exponential graph. Finally the negative exponential graph was used for further analysis. The methodology used for trip distribution is shown in Figure 5-9.

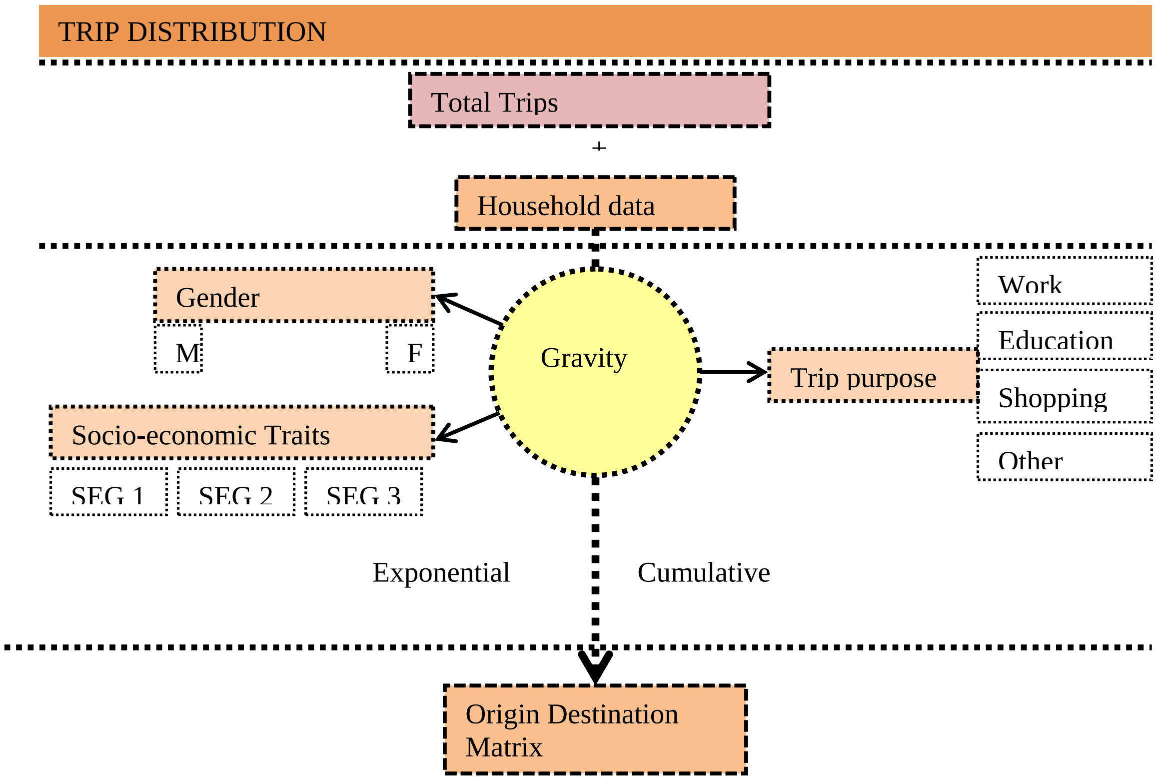


Figure 5-9: Methodology used for trip distribution

Further, trip length distribution curves with a cumulative distribution function and separate deterrence functions for each purpose are shown below gender-wise:

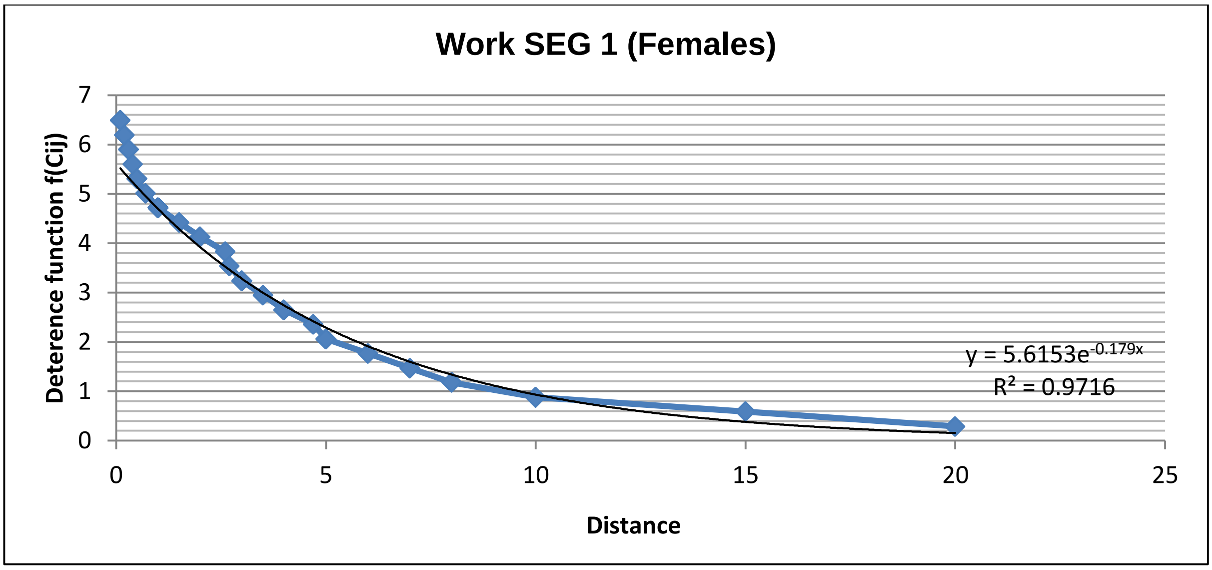


Figure 5-10: Trip distribution for females (work purpose) (SEG 1)

SEG1 females largely travel distances ranging from1 to 5km for work. Low-income females generally have shorter trips for their work because of their lower purchasing power.

Figure 5-11 Trip distribution for males (work purpose) (SEG 1)

Compared to SEG1 females, SEG1 males travel longer distances for work purposes. The typical distance range remains from 1 to 5km, but men make more trips in the 5 to 10km range. SEG1 females and males work largely in industries or do housework, so they prefer living nearer to their work places to keep travel costs low.

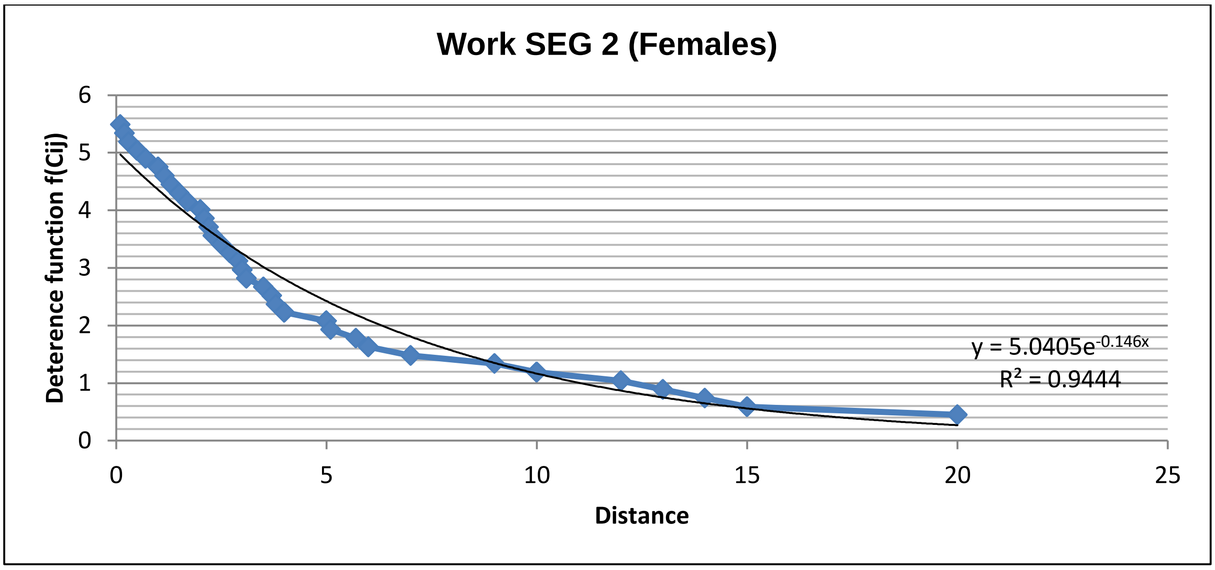


Figure 5-12: Trip distribution for females (work purpose) (SEG 2)

SEG2 females make slightly longer trips compared to SEG1 females because of their more frequent ownership of two-wheelers. They typically live slightly further away from their workplaces for their convenience.

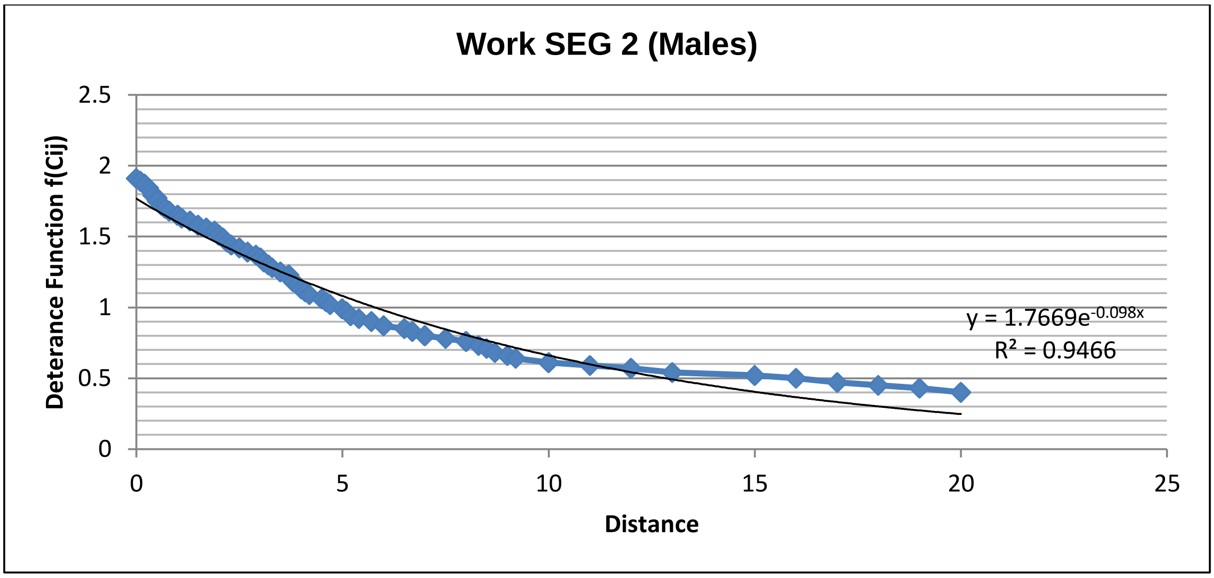


Figure 5-13: Trip distribution for males (work purpose) (SEG 2)

SEG 2 males account for half of all work trips, as most of Rajkot city falls into the middle income group owning two-wheelers with televisions and telephones as assets. Most of the trips covered by SEG 2 males are in the range of 2 to 6km, which is the average distance of all trips travelled for work in the city.

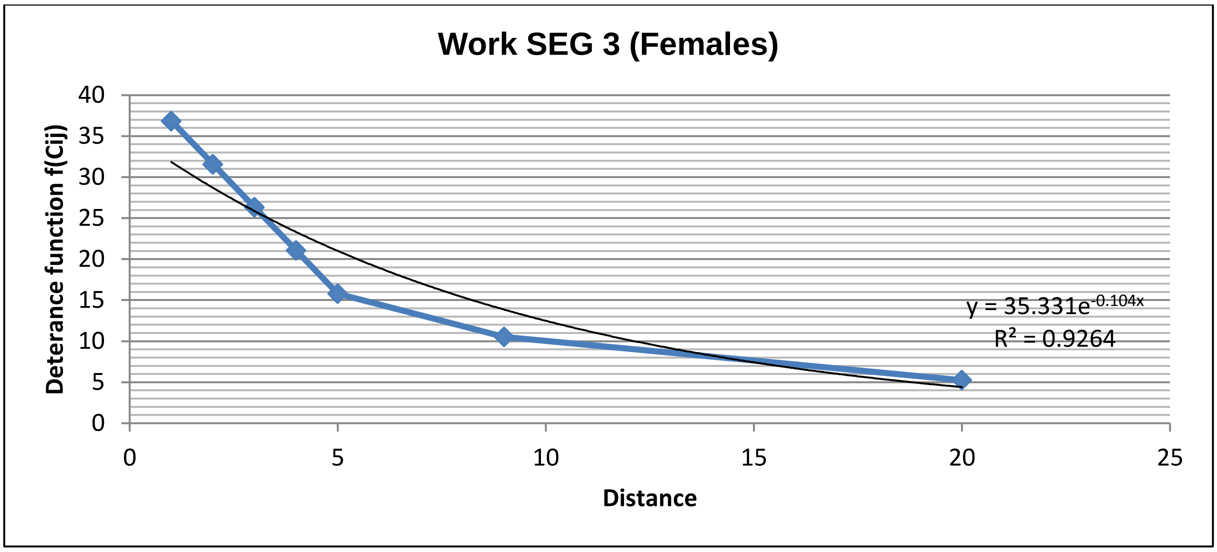


Figure 5-14: Trip distribution for females (work purpose) (SEG 3)

SEG 3 females make longer trips compared to SEG1 and SEG2 females or males. This is likely due to higher vehicular ownerships in the high income groups.

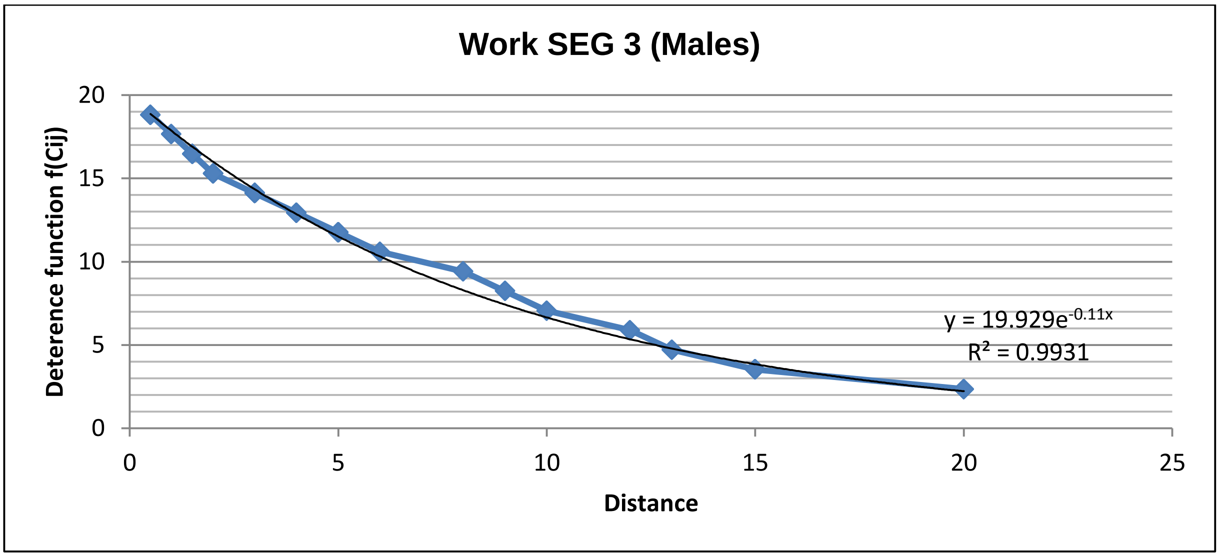


Figure 5-15: Trip distribution for males (work purpose) (SEG 3)

SEG 3 males also travel longer distances for work compared to SEG1 or SEG2 males. SEG 3 males have higher vehicle ownership and more car ownerships, which result in longer distances travelled. This group might not live particularly near to their workplaces due to their ability to afford more expensive travel costs.

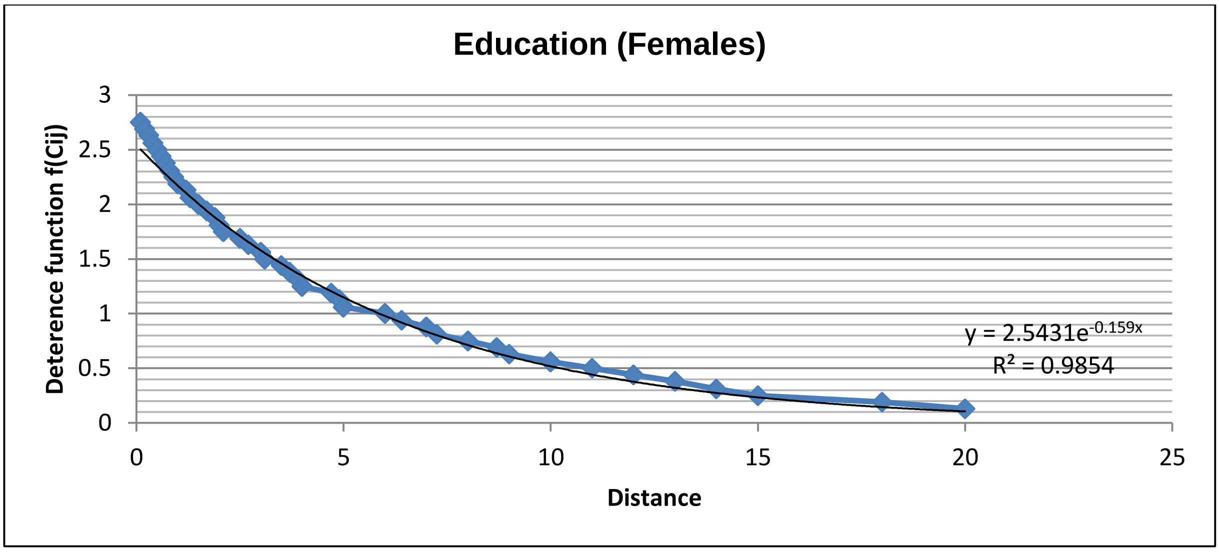


Figure 5-16: Trip distribution for females (education purpose)

Females are more likely than males to take responsibility for dropping their children to schools, and thus they make more trips for education as well as travel longer distances.

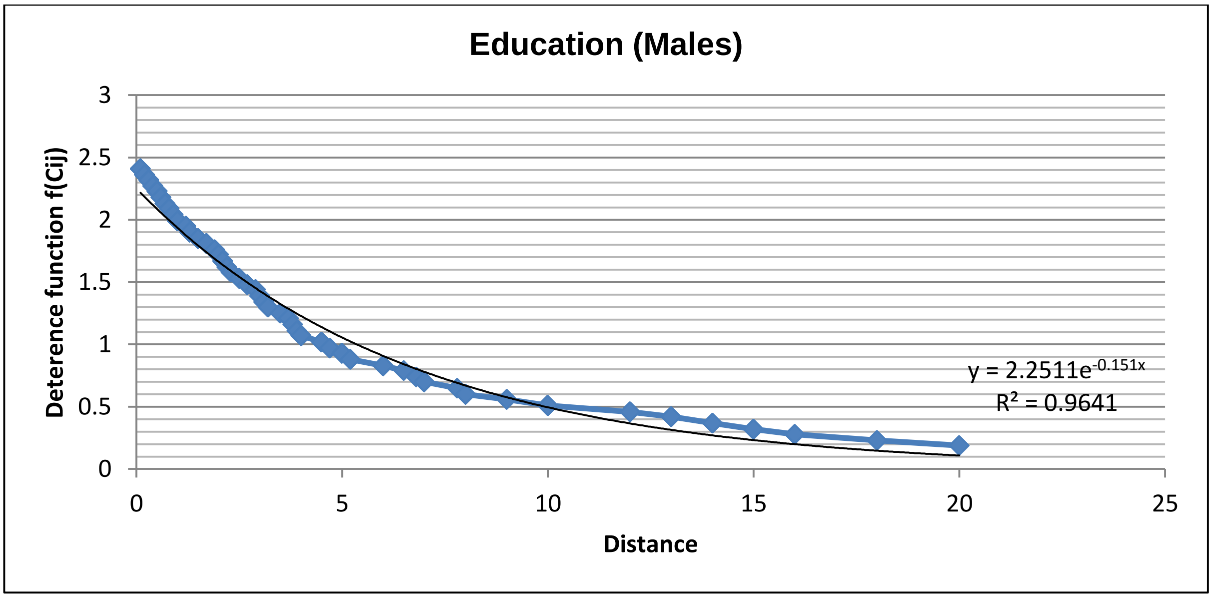


Figure 5-17: Trip distribution for males (education purpose)

A large number of education trips are made by parents dropping their children to schools. Males largely include education trips as part of a chained trip, the primary purpose being a work trip. So the distances travelled by males for education purposes are smaller.

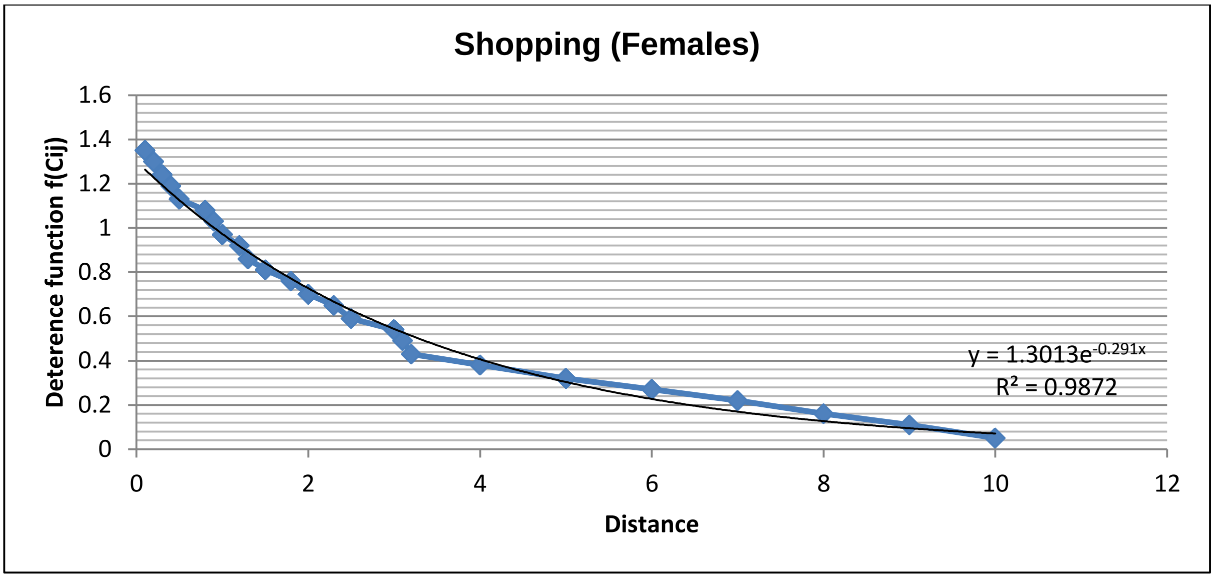


Figure 5-18: Trip distribution for females (shopping)

Shopping trips are mainly made by females, and the distance travelled is usually under 2km. Retail facilities are found very near to residences, but some households also travel longer distances to get access to fresh and cheap retail facilities.

Figure 5-19: Trip distribution for males (shopping)

Males on average travel further than females for shopping. Shopping from the nearby villages is mostly done by males.

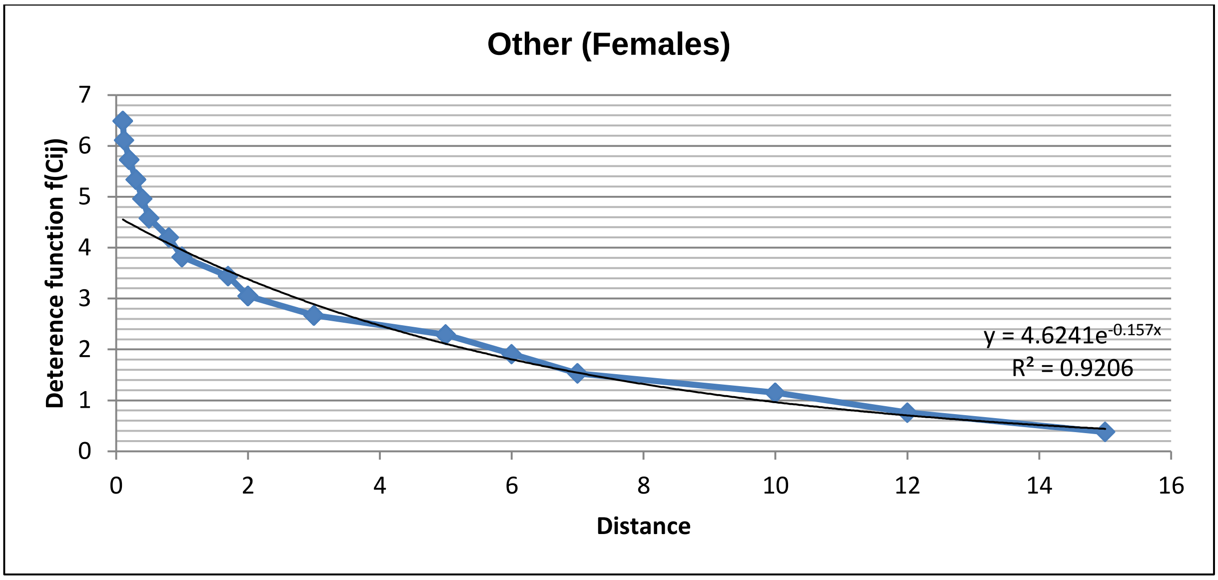


Figure 5-20: Trip distribution for females (other purpose)

Other trips like recreational, shopping, and social trips have longer distances travelled than education or shopping purposes for females. Females also travel longer distances for social and other leisure trips.

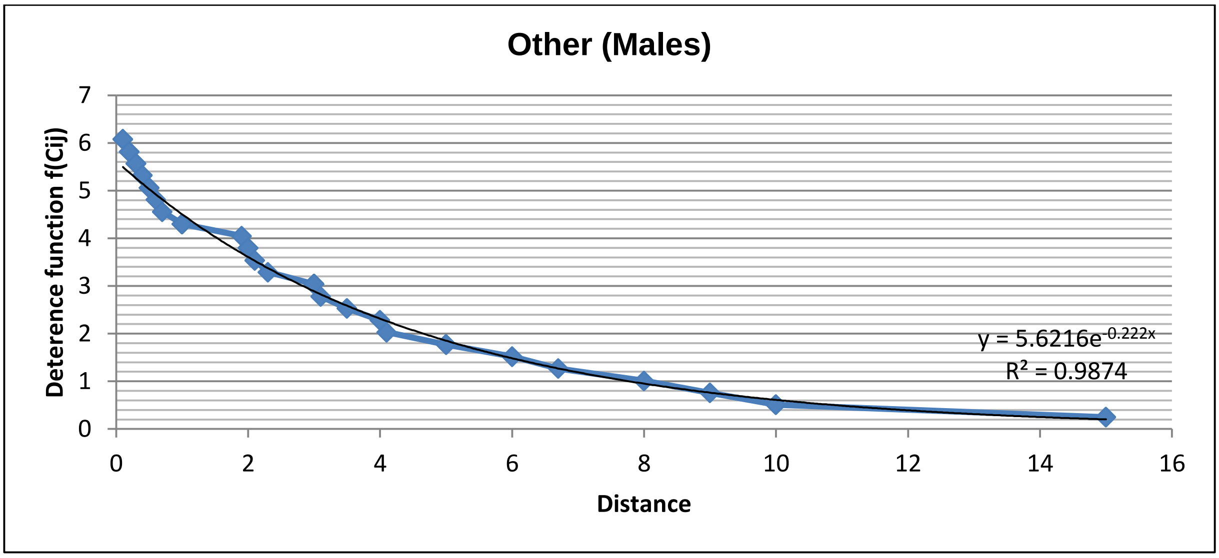


Figure 5-21: Trip distribution for males (other purpose)

Males make fewer trips for social or religious purposes, so they travel shorter distances for other trips. But these leisure trips generally have longer distances travelled by both males and females.

Most of the trips observed in the graphs are under 10km. Rajkot has a maximum of 6km distance from the centre to the end of the RMC boundary in all directions. A few exceptions to this include when higher income groups (SEG 3) travel greater distances due to their higher vehicular ownerships. The maximum number of trips in all the above cases was found to be between 4 and 6km.

The beta values from the regression equations on the above TLFD figures were used as inputs in the double-constraint gravity model analysis, which had the following formation. The inputs to these models area cost matrix computed using the TLFD curves, trips produced in each zone, and trips attracted to each. The output of this analysis is a trips distribution matrix, which for each of the disaggregated functions identifies the $T_{ij.}$

$T_{ij} = Pi\ [A_jF_{ij} / \sum A_jF_{ij}]$

Where:

Tij	= trips produced at i and attracted at j
Pi	= total trip production at i
Aj	= total trip attraction at j
Fij	= (friction factor) or computed using the TLFD curves
i	= origin zone
j	= destination zone

Mode choice

The mode choice plays an important factor in determining the carbon footprint of the city's transport sector, and hence is an important stage in a study aimed at comprehensive mobility with low carbon levels. The mode choice analysis was conducted through the binary logistic regression method. The regression analysis was done for purpose and mode. The purposes considered included work, education, shopping and others (as mentioned in the aforementioned stage), whereas the modes considered included auto, car, cycle, motorised two-wheeler and walking.

The dependent variable used for the regression analysis was mode choice. The regression model was constructed in three stages. In the first stage, socio-demographic variables such as household size, vehicle ownership and socio-economic groups 1, 2 & 3 (see previous stage) were considered. In the second stage, the stage one model was used as the control, and land use variables like population density, residential and commercial space, educational area, industrial space, job-house ratio, hawkers, and time to grocery, and distance from urban centre were considered. In the third and final stage, the trip distance was introduced into the equation.

One of the underlying principles of this modelling approach is that a trip-maker's mode choice is based on utility maximisation. The utility of using one mode of travel for a trip can be estimated using a mathematical function referred to as the 'utility function', which generates a numerical utility value/score based on several attributes of the mode (for the trip) as well as the characteristics of the trip maker (Chatterjee & Venigalla, 2011). After the binary logit regression analysis, the modal split stage involves deriving the utility functions to arrive at a probability of mode choice for various purposes. Finally the O-D matrix is divided into the mode trips. Figure 5-22 shows the flow of processes involved in this stage of travel demand modelling.

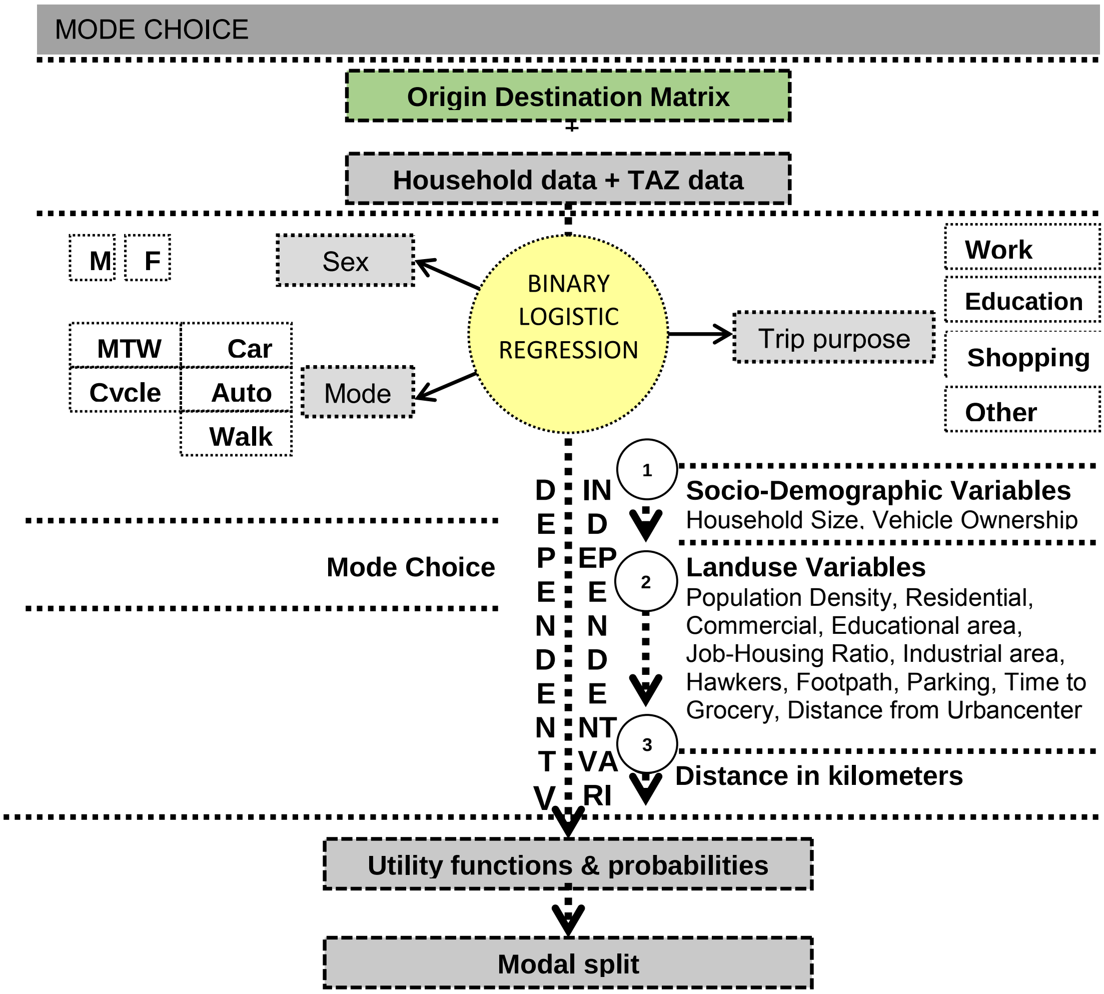


Figure 5-22: Flow chart of processes in mode choice modelling

Mode choice utility equations

To understand the dependency of various factors on mode choice, a binary logit model was computed for various trip purposes by gender, thereby deriving their mode choice utility equations using the variables. Before the regression analysis was done, a correlation matrix was computed for all variables in order to screen the significant variables. Through this process, the variables with a correlation coefficient ($0 \leq r \leq 1$) greater than 0.5 were chosen and considered for regression modelling. The regression modelling itself discards highly insignificant variables to finally arrive at the regression tables, given below, on the basis of trip purpose and gender. In these tables, SEG 1, SEG 2 and SEG 3 refer to the proportion of the three socio-economic groups mentioned in the earlier section of this chapter. The dependency of a variable is predominantly determined by the coefficient (a) and the exponential (b). Accordingly, the variables that show higher coefficient (a) and exponential (b) greater than 1 are chosen as the most significant variables in each mode choice under the various scenarios. The odds ratio values less than 1 indicate that a variable has the effect of reducing the probability of people choosing a particular mode, while a value greater than one indicates an increased probability. The regression tables for each mode, purpose-wise and gender-wise, are given below along with the corresponding utility equation formed out of them.

Work-based trips

The equation for walking for females and males has a positive relation with SEG1 and negative relation with SEG3. Walking is more preferred where there are hawkers and the job-housing ratio is higher. Walking is also affected by population density but negligibly. Surprisingly, people are not walking where the footpaths and streetlights are present in the current context.

Walk Female = -2.821+0.799(SEG1)-18.031(SEG3) -15.420(Footpath) +0.001(Population density)-0.479(Streetlights)

Walk Male = -1.053+0.794(SEG1)-0.738(SEG3)-0.573(Two-wheeler) +1.404(Hawker area) -0.255(Parking area)-14.928(Footpath) + 0.001(Population density) + 1.152(Job-housing ratio) +0.047(Distance km) - 0.953(Streetlights)

The utility equation for cycling is mainlyaffected by SEG1 for both females and males. Bicycles are also used where there are hawkers and when the distances of travel are shorter.

Cycle Female = -5.251+1.075(SEG1) +3.024(Hawker area) + 14.253(Footpath)

Cycle Male = -2.985+1.621(SEG1)-0.041(Distance km)

In the case of people's preference to travel to work by auto, SEG1 has a positive relation, whereas SEG3 has a negative relation due to the more prevalent ownership of private vehicles. Autos are used where population densities are high, and are not used for very long distances.

Auto Female = -4.248 + 0.665(SEG1) +0.125(Household size)-1.985(Job-housing ratio)

Auto Male = -2.718+1.075(SEG1)-18.321(SEG3) + 0.122(Household size)-0.581(Parking area)-0.052(Centre km)-0.002(Population density)

The utility equations for two-wheelers have a negative relation for females, indicating that theydo not use two-wheelers for work. SEG1 has a negative relation with the use of two-wheelers for work. For males using two-wheelers for work, SEG2 has a positive relation while that of SEG1 is negative. It also states that the use of two-wheelers is dependent on the availability of parking space. Very interestingly, the job-housing balance or the presence of hawkers or informal markets decreases the use of two-wheelers. Surprisingly, with the increase in distance from the city centre, the use of two-wheelers for work purposes decreases. It might due to the increased use of four-wheelers with increased distance from the city centre.

Two-Wheeler Female = -1.986-2.379(SEG1)-0.722(SEG2)

Two-Wheeler Male = 0.012-1.586(SEG1) + 0.841(SEG2)-0.717(SEG3) - 0.062(Household size) -0.790(Hawker area) + 0.357(Parking area) -0.041(Centre km) - 0.339(Jobs-housing ratio)

The utility equation for cars for females and males has a positive relation with SEG 3 and a negative relation with SEG1. Interestingly, the usage of four-wheelers is also dependent on the availability of parking space and it decreases with the increase in the job-housing.

Car Female = -6.838+3.580(SEG3)

Car Male = -2.408-3.852(SEG1)-0.858(SEG2) +2.957(SEG3) +0.740(Parking area)-3.402(Jobs-housing)-0.084(Distance km)

Education purpose

For education trips by walking, SEG1 is positively related for females and males. Again the walking trips for education are preferred where there are hawkers on the street and the job-housing ratio is high. People don't prefer to walk for education trips where there is parking on the roads and the distance to the urban centre is longer.

Walk Female = -1.877+0.835(SEG 1) + 0.085(Centre km)+ 0.001(Population density)-0.678(Streetlights)

Walk Male = -1.186+0.846(SEG1) +1.727(Hawker area)-0.437(Parking area) - 0.050(Centre km) +1.271(Job-housing ratio) +0.046(Distance km)-0.831(Streetlights)

Females rarely make education trips by cycle, but males prefer it when there are informal markets on roads.

Cycle Female = -2.619

Cycle Male = -2.158+1.620(Hawker area)

Autos are preferred for education purpose by males where there are hawkers on roads. SEG1 people do not prefer autos. Autos are also not preferred where the job-housing ratios and distance to the urban centre is high.

Auto Female = -2.533-0.703(SEG 1)

Auto Male = -0.313-0.684(SEG 1) +2.435(Hawker area) -1.124(Parking area)-0.270(Centre km) -0.002(Population density) - 1.329 (Job-housing ratio)

Cars are not preferred for SEG1 group for females as well as males.

Car Female = -4.360-1.715(SEG 1)

Car Male = -3.872-0.931(Parking area)

Shopping trips

For shopping trips, walking is preferred by females where there are hawkers and, at night, where streetlights are present. SEG2 females don't prefer walking for retail trips, whereas SEG1 males have a positive relation to walking for such trips. Males also walk for shopping where the job-housing ratio is high and population density is high. But population densities are significant only negligibly.

Walk Female = 0.232-0.525(SEG 2) + 1.692(Hawker area) - 0.409(Parking area) + 0.001(Population density) + 0.509(Streetlights)

Walk Male = -1.410+ 0.245(SEG1) + 0.001(Population density) + 1.010(Job-housing ratio)-1.182(Streetlights)

Females' preference to cycle when shopping was found to be determined by the footpath area, whereas for males it was determined by an SEG 1 predominant area.

Cycle Female = -6.180 + 49.687(Footpath)

Cycle Male = -4.997+0.966(SEG 1)

Auto trips for shopping is mainlymade by females and negatively related to the distance from the urban centre and parking on roads. The surprising outcome is that auto trips are not influenced by any socio-economic variable.

Auto Female = -0.318-2.286(Hawker area)-0.347(Parking area)-0.230(Centre km)-0.005(Population density)-0.053(Distance km)

Auto Male = -4.823+ 0.387(Household size)-0.261(Distance km)

Two-wheelers for shopping are not affected by the SEG1 households as it has a negative relation for females and males, whereas two-wheelers are also negatively influenced by the hawkers on roads or high job-housing ratio. Thus the areas withhigher job-housing ratios or higher population densities use two-wheelers in lesser proportion compared to other modes.

Two-Wheeler Female = -1.482-2.792(SEG 1)-4.381(Hawker area) +1.637(Parking area)-0.001(Population density)-3.886(Job-housing ratio)

Two-Wheeler Male = -3.018-1.939(SEG 1) +0.205(Household size) - 1.656(Job-housing ratio)

Other trips

For other trips also, like all other purposes, walking has a positive relation with SEG1 and a negative relation with SEG3. Walking is also not preferred for other purposes where there are no streetlights.

Walk Female = -2.226+1.626(Streetlights)

Walk Male = -0.199+ 0.861(SEG 1)-20.617(SEG 3) + 0.397(Parking area)-1.006(Streetlights)

For other purposes, cycle trips are positively impacted by SEG1 and footpaths.

Cycle Female = -9.531+4.749(SEG 1) +95.669(Footpath)

Cycle Male = -4.546

For other purposes by auth rickshaw, the distance from the urban centre was negatively related for males, whereas thejob-housing ratio was negatively related for females.

Auto Female = -2.072-4.196(Job-housing ratio)

Auto Male = -1.975-0.728(SEG 2)-0.236(Distance km)

For other trip purposes like religious, social and recreational trips, the use of two-wheelers is mainlydone by SEG2 and has a negative relation with SEG1. It also negativelyrelatedfor females having higher household size.

Two-Wheeler Female = -2.464+0.945(SEG 2) - 0.362(Household size)

Two-Wheeler Male = -0.945-2.907(SEG 1) - 0.985(Parking area)

For other trips, car use is mostly related to SEG3 and the availability of the parking spaces for females.

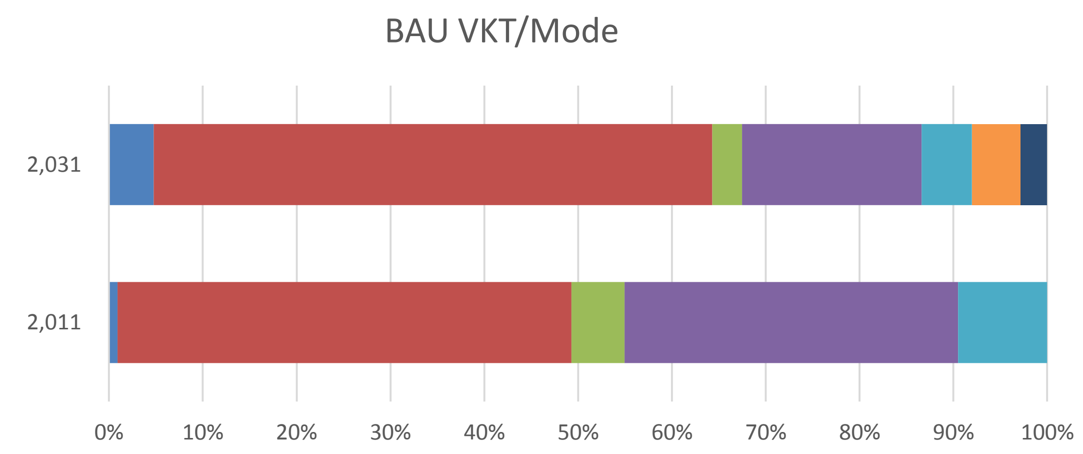
Car Female = -6.251+2.876(SEG 3) + 1.489(Parking area)

Car Male = -5.785+6.073(SEG 3)

Explaining each utility equation, formed by disaggregating by gender, mode and purpose, the mode choice model finally gave a split of the mode choice based on the number of trips obtained from the O-D matrix of the trip distribution‘s output.

Table 5-6: Purpose, mode and gender-wise trips

Mode	No. of trips	Proportion trip/purpose
Work		
Walk (female)	6,097	0.31
Walk (male)	520,776	26.20
Bicycle(female)	32,644	1.64
Bicycle (male)	39,271	1.98
PT(female)	56,045	2.82
PT(male)	22,290	1.12
Auto (female)	70,057	3.52
Auto (male)	27,862	1.40
Two-wheelers (female)	119,738	6.02
Two-wheelers (male)	1,042,978	52.47
Four-wheelers (female)	1,027	0.05
Four-wheelers (male)	49,052	2.47
Total work trips	1,987,838	100.00
Education		
Walk (female)	8,179	0.75
Walk (male)	350,310	32.25
Bicycle (female)	19,349	1.78
Bicycle (male)	68,546	6.31
PT(female)	56,752	5.22
PT(male)	75,041	6.91
Auto (female)	200,188	18.43
Auto (male)	93,801	8.64
Two-wheelers (female)	22,642	2.08
Two-wheelers (male)	76,979	7.09
Four-wheelers (female)	2,736	0.25
Four-wheelers (male)	111,666	10.28
Total education trips	1,086,189	100.00
Shopping		
Walk (female)	87,858	26.23
Walk (male)	16,281	4.86
Bicycle (female)	1,180	0.35
Bicycle (male)	987	0.29
PT(female)	44,687	13.34
PT(male)	504	0.15
Auto (female)	111,717	33.36
Auto (male)	1,259	0.38
Two-wheelers (female)	22,458	6.71
Two-wheelers (male)	44,136	13.18
Four-wheelers (female)	0	0.00
Four-wheelers (male)	3,840	1.15
Total shopping trips	334,907	100.00
Other		
Walk (female)	4,213	0.74
Walk (male)	191,239	33.57



	2,011	2,031
Car	52,190	895,579
Two Wheeler	2,779,206	11,180,438
Three Wheeler	326,246	597,186
Walk	2,042,852	3,590,913
Cycle	545,176	1,007,953
Bus	-	980,217
BRT	-	527,809

Figure 5-23: Vehicle kilometres travelled/mode for 2011 and 2031 (BAU scenario)
Source: Travel Demand Modelling

The results are similar to the modal share of the city in 2011. But for 2031, two-wheeler and car trips are drastically higher, whereas NMT trips are down to 29 per cent from 48 per cent in 2011.

Trip assignment

The fourth and final stage of the four-step modelling is done to establish and obtain reasonable link flows and to identify heavily congested links. The inputs given for the trip assignment is the modal split having number of trip from each TAZ to its destination TAZ with the modal split and the road network which was skimmed in the before the first step of the four-stage modelling. The assignment of traffic volumes is done by choosing the route with the minimum travel cost to reach the destination, and in this case we have used distance as a proxy for travel cost. This model is also a capacity-constrained model, which means that traffic is not assigned to the route or road segment where the maximum capacity has been reached. The traffic volume assignment for this study has been conducted separately for motorised vehicles, bicycles and pedestrians. The assignment for pedestrians and bicycles was done separately so as to identify sections and routes where these demands will be high, and thus the roads that will need transport infrastructure and will support these movements. The flow of processes involved in this stage of travel demand modelling is shown in Figure 5-24.

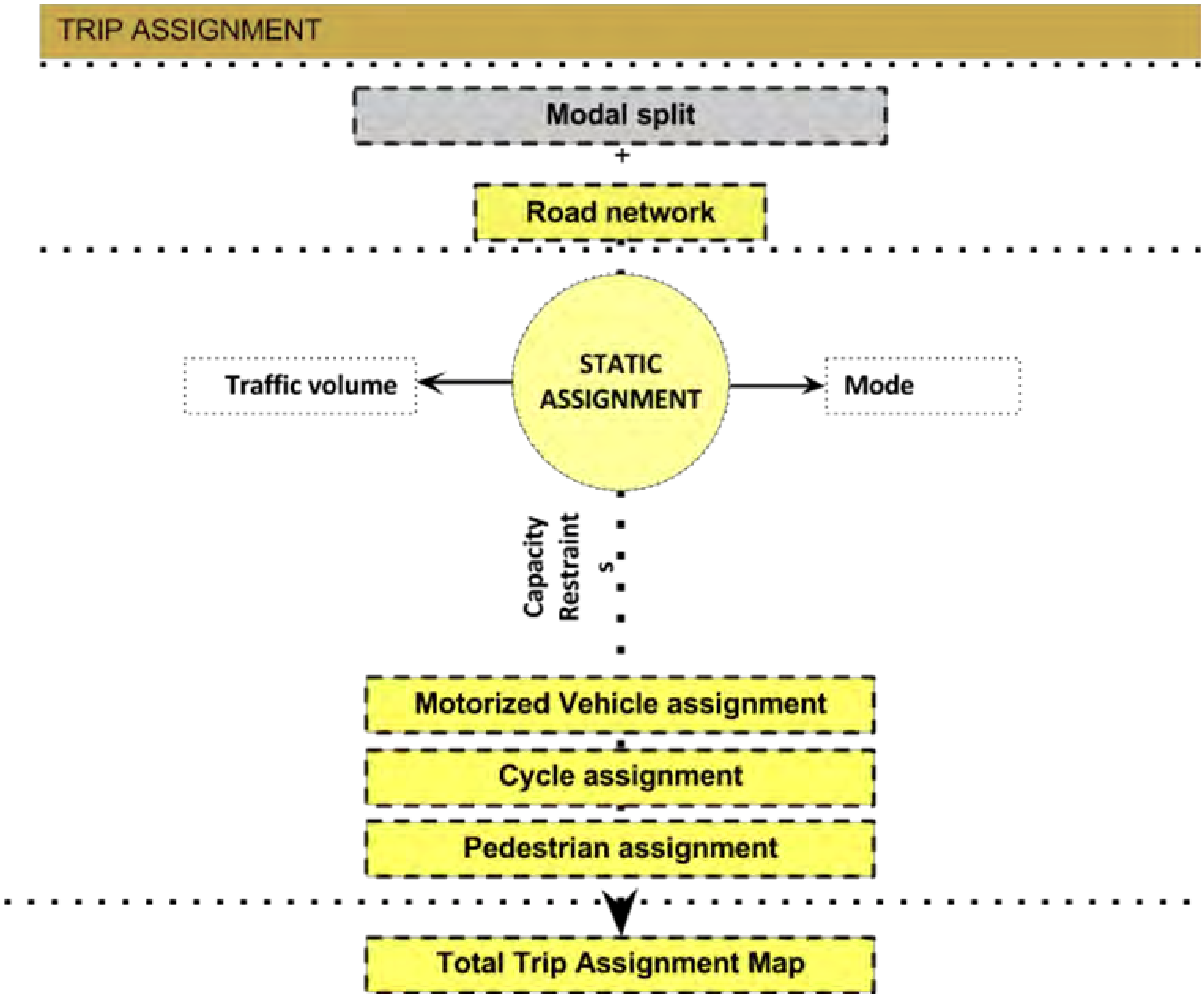


Figure 5-24: Trip assignment flow diagram

Looking at the trip assignment process, the modal split of trips obtained as an output from the previous stage for females and males was combined and assigned on the link node network of Rajkot. The assignment was done on the basis of the route with the lowest cost incurred in reaching the destination. Three separate modelling assignments (traffic or trip (Figure 5-25), walk (Figure 5-26) and bicycle assignment (Figure 5-27)) have been carried out to validate whether the model fully represents the existing situation. Thus from the trip or traffic assignment, it has been observed that traffic volumes are higher on the eastern side of the river and the old city area. Volumes are also higher on the arterial roads like Gondal Road, Dhebar Road, 80ft Road, Bhavnagar Road, Kalawad Road, Jamnagar Road, National Highway8 and Mavadi Road. It resembles the actual traffic characteristics of the city shown in Chapter 3 of this study. The pedestrian and bicycle volume assignments also show people largely walking around the old city streets and on the internal roads of the city, which also reflects the true picture.

Summing up trip assignment, it reflects the actual condition of traffic volumes in the city. The BAU scenario also states the projections for three selected horizons, keeping the conditions and infrastructure constant, i.e. assuming the future scenario with the ongoing conditions and without any interventions.

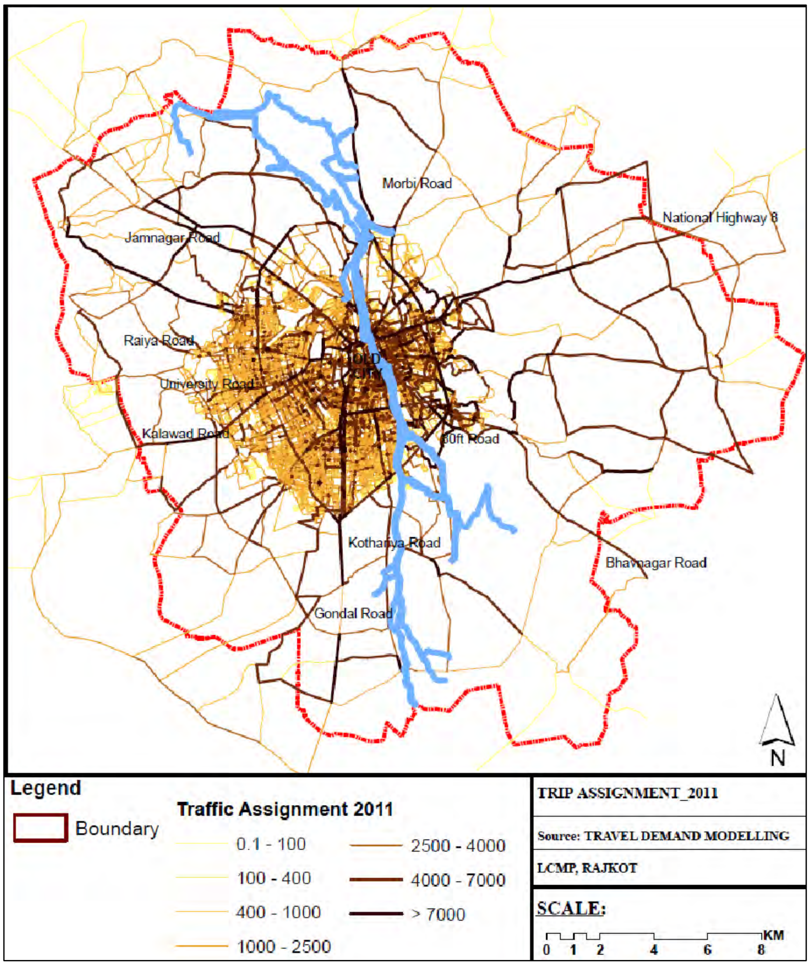


Figure 5-25: Trip assignment, 2011

Source: Travel demand modelling

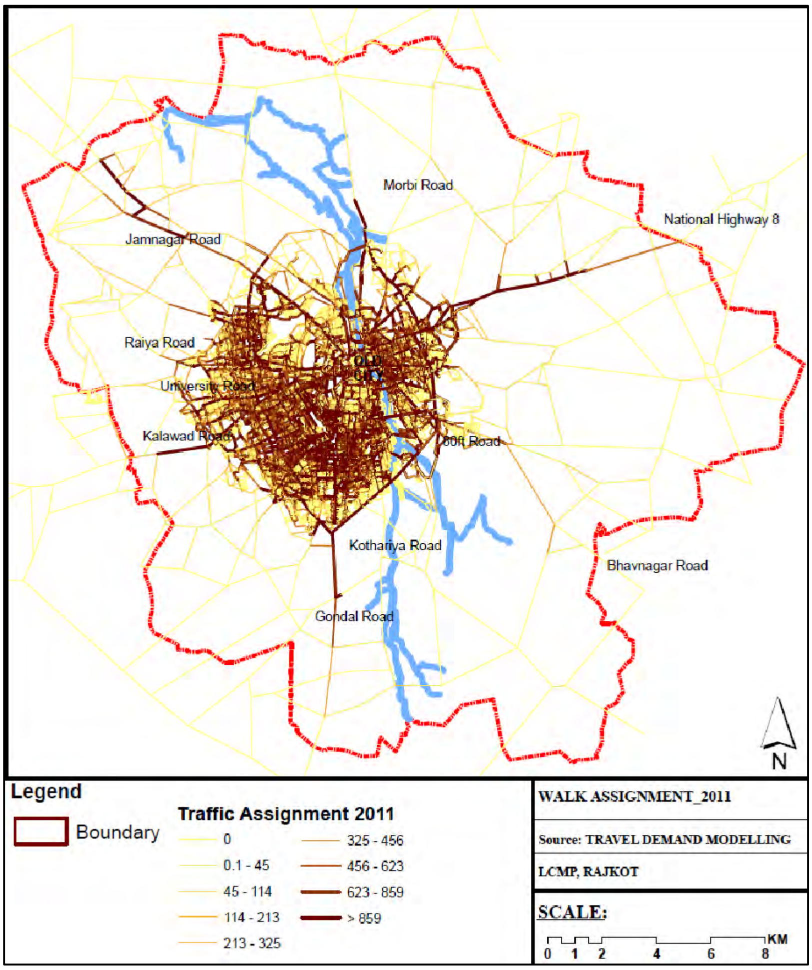


Figure 5-26: Walk assignment 2011

Source: Travel demand modelling

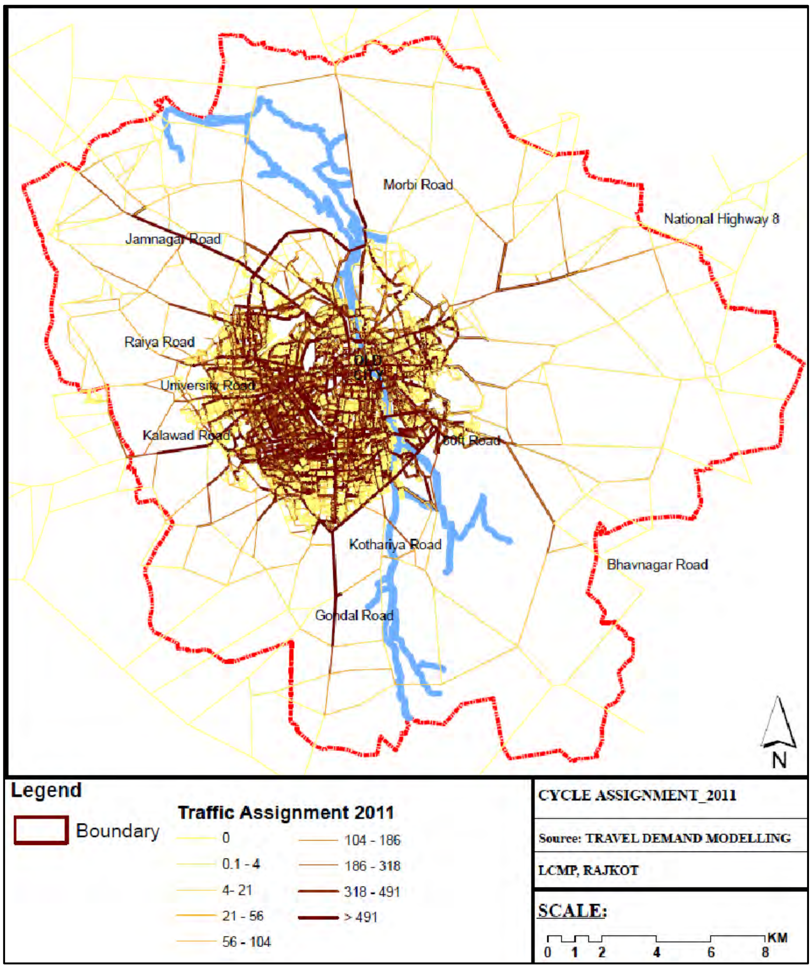


Figure 5-27: Cycle assignment 2011
Source: Travel demand modelling

5.5. Travel Demand for the Horizon Years

The travel demand forecasting has been conducted for the horizon years of 2016, 2021 and 2031 using the four-stage modelling, consisting of trip generation, trip distribution, mode choice and trip assignment. For the modelling, various variables have been projected such as population, employment, job-housing ratios, vehicle ownership, as well as the land use variables like commercial, industrial and residential land uses within a TAZ. First, as stated earlier, the populations of the study areas are projected for the three horizon years, and the projected population is subsequently divided into the three socio-economic groups (SEG1, SEG2 and SEG3) as per their proportions in 2011.Now it is assumed that the per capita income in Rajkot will rise in the coming years, and there will therefore be population shifts from SEG1 to SEG2 computed as 3, 6and 12 per cent for 2016, 2021 and 2031 respectively. This essentially means the 3 per cent of the total population estimated in the SEG1 group today will be considered as SEG2 in 2016. Likewise, the shifts from SEG2 to SEG3 are computed as 2, 4 and 8 per cent for 2016, 2021 and 2031 respectively.

Starting with trip generation, all the outputs of each step have been compared for all the horizon years. Table 5-7 shows the productions and attractions for 2016, 2021 and 2031.

Table 5-7: Production-attraction for horizon years

Purpose	P-A (2011)	P-A (2016)	P-A (2021)	P-A (2031)
Work SEG1 (female)	63,885	73,086	70,094	77,917
Work SEG1 (male)	300,513	328,564	300,513	346,336
Work SEG2 (female)	80,711	100,156	126,728	188,754
Work SEG2(male)	523,815	660,295	523,815	1,254,343
Work SEG3(female)	3,426	5,495	8,878	18,937
Work SEG3(male)	18,238	29,313	18,238	101,551
Education(female)	327,269	400,231	470,416	672,091
Education(male)	386,343	475,883	386,343	824,358
Shopping(female)	134,148	164,535	189,817	267,901
Shopping(male)	32,111	39,938	32,111	67,006
Other(female)	111,356	140,114	174,784	259,253
Other(male)	144,414	173,197	144,414	310,364
Total	2,126,229	2,590,807	2,446,151	4,388,811

The proportion of trips by SEG2 and SEG3 groups for the purpose of work increases with the advancement in horizon years, which indicates an increase in the use of private vehicles. The total trips also increase from 2.1 million to 4.3 million, which is almost twice the number of the existing trips. The distribution curves have also been kept constant for the horizon years by simply changing the number of trips obtained from productions and attractions. As for the mode choice, the probabilities have changed according to the changes in land use and values of some variables.

By the increase in SEG3 households and vehicle ownerships, the use of two-wheelers and four-wheelers are expected to increase in the future years. The walking and bicycle share is likely to reduce if adequate infrastructure is not provided in the newer areas of development. The trip assignment shows the presence of bottlenecks and emphasises the need for road infrastructure improvement for future years. The maps denoting volume increases on the roads in 2016, 2021 and 2031 are shown in Figure 5-28, Figure 5-29 and Figure 5-30. The assignments of 2016, 2021 and 2031 indicate volume increases on the existing roads, and show congestion on all the roads of the city by 2031. Even internal roads would tend to be congested.

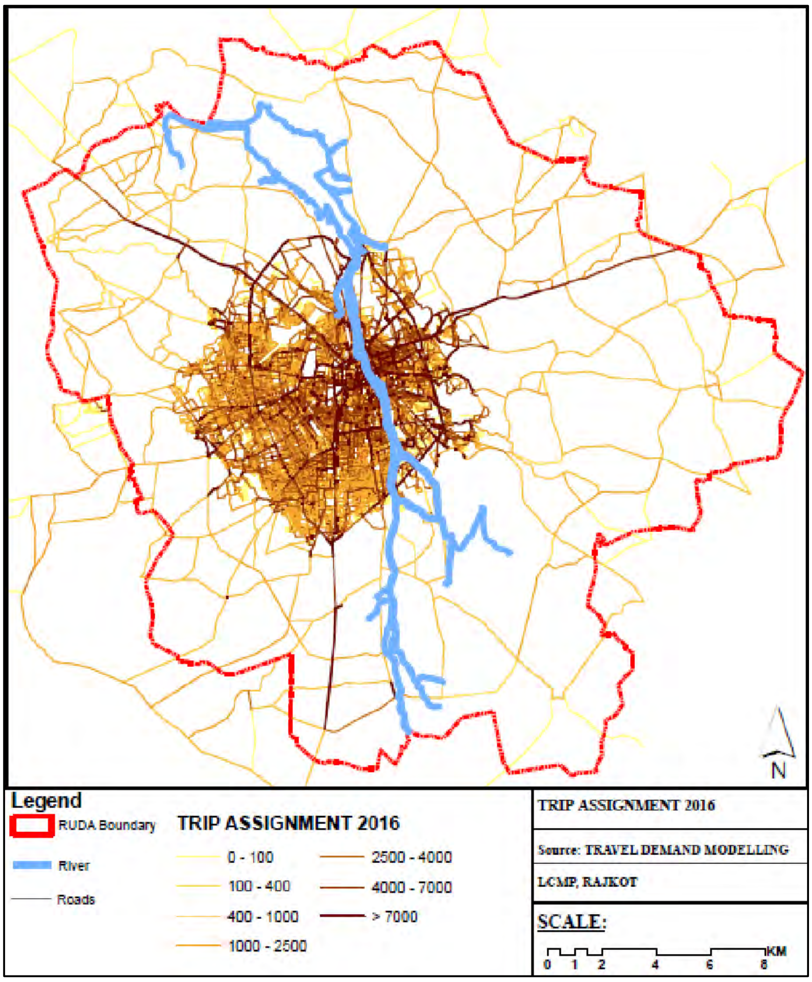


Figure 5-28: Trip assignment, 2016
Source: Travel demand modelling

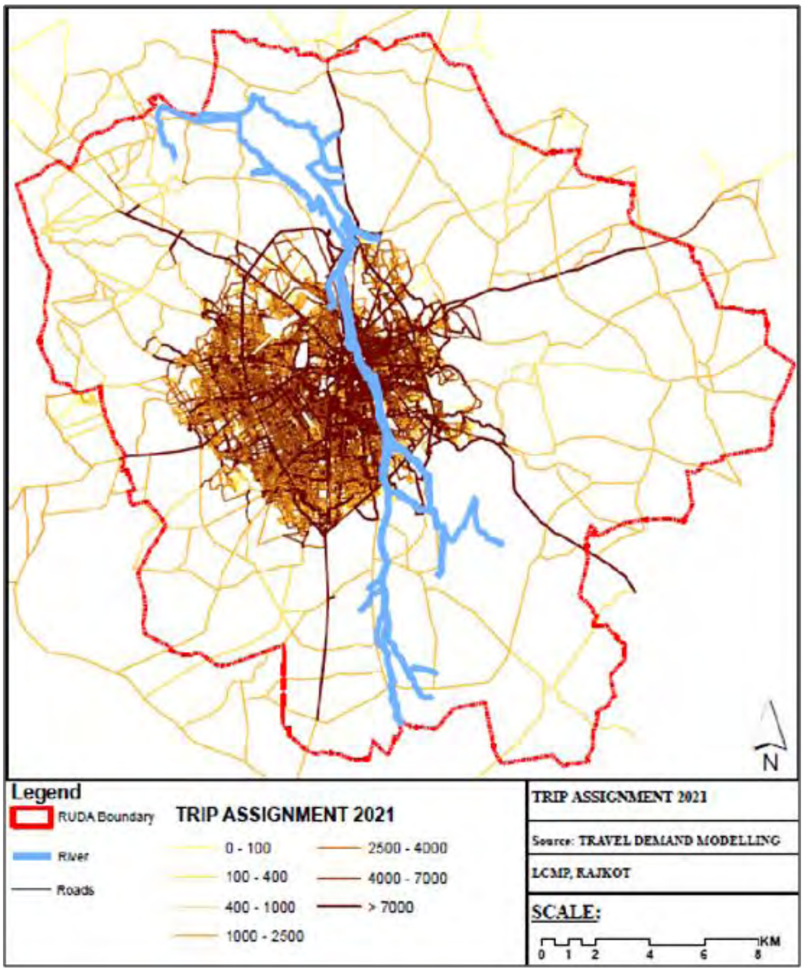


Figure 5-29: Trip assignment 2021
Source: Travel demand modelling

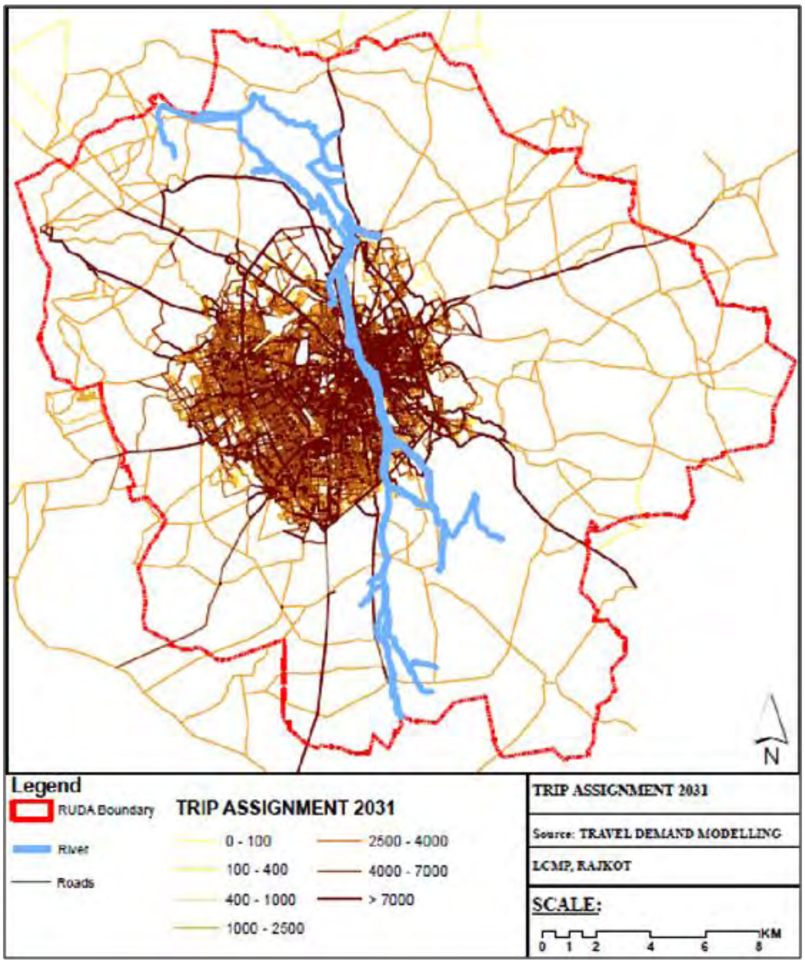


Figure 5-30: Trip assignment 2031
Source: Travel demand modelling

Table 5-8: Demand for transport

Mode	2011		2016		2021		2031	
Passenger Transport	Pass. Km.	%	Pass. Km.	%	Pass. Km.	%	Pass. Km.	%
Car	52,190	0.91	144,941	1.82	382,405	3.18	895,579	4.77
2-wheeler	2,779,206	48.37	3,926,754	49.22	6,630,505	55.12	11,180,438	59.53
3-wheeler	326,246	5.68	401,002	5.03	481,731	4.00	597,186	3.18
Walking	2,042,852	35.55	2,471,720	30.98	2,971,006	24.70	3,590,913	19.12
Cycling	545,176	9.49	656,952	8.23	808,780	6.72	1,007,953	5.37
Bus	0	0.00	301,605	3.78	527,809	4.39	980,217	5.22
Mass Transit	0	0.00	75401	0.95	226,204	1.88	527,809	2.81
Total	5,745,670	100.00	7,978,375	100.00	12,028,441	100.00	18,780,095	100.00

Table 5-8 illustrates the demand for both motorised and non-motorised transport modes in the city. The values are for passenger kilometres/mode. In the BAU scenario, the share of travel increases significantly; however, its overall share remains fairly low. Because the city will expand in all directions, the overall share of passenger kilometres travelled using private automobiles (cars +two-wheelers) also increases. Even though the total passenger kilometres travelled by walking and bicycle increases significantly, their shares in the overall passenger mobility in Rajkot decreases as the share of motorised modes increase. At present, there is no public transport in Rajkot; however, it is assumed that eventually there will be a bus service in Rajkot and also a BRT service, as a result of which about 8 per cent of the total passenger kilometres will be travelled using buses as a mode in Rajkot.

As stated earlier, by 2030 the per capita annual disposable income of Indians living in urban areas is likely to grow from around INR 65,000 at present to INR 2,39,000 (Mckinsey Global Institute, 2010). At the same time, motorised vehicles are also likely to grow threefold. From the elasticity values presented in the earlier chapter, it is known that Vehicle Kilometres Travelled (VKT) and private vehicle usage and income have a positive correlation. Moreover, the existing development control and zoning regulations place strong restrictions on the density of development, forcing decentralisation of activities in parts of the city, and inducing sprawling development. All of these have an influence on projected trip lengths in the business-as-usual scenario. The city has an average trip distance travelled in the lower ranges of around 2 to 4 kilometres. Individuals living in the outer parts of the city, in the case of the BAU scenario, might have to travel, on average, more than 6.5 kilometres each way for work purpose trips. Because of the sprawling development of the BAU scenario for the year 2030, a large section of the population will reside in peripheral locations, and therefore more than 60 per cent of the population will reside in outer areas where mean trip lengths for work-purpose travel could exceed 6.5 kilometres. Because of this sprawl, the average trip length in the city is likely to increase from 3.8 km in the present scenario to 6.5 km in the BAU scenario, with an average travel time of27 minutesin2031. With increasing trip distances and travel times, the areas with high walk shares will also shift to private vehicles. The people living in the outskirts of the city will tend to use private vehicles for commuting in the absence of a public transport system, making the present NMT share decline and increase in the private mode share. In the BAU scenario, because of an increase in per capita income and motorised vehicle ownership, there is an overall reduction in locations that have a high probability of residents choosing walking as a mode.

5.6. Energy and Environment Modelling

Energy for motorised transport

The energy for motorised transport can be calculated based on the following equation for each fuel.

$$Fuel\ consumption = Vehicle\ kilometres\ traveled\ (VKT) \times Average\ fuel\ efficiency$$

VKT values for different vehicle categories are already estimated in the previous section (refer Figure 5-23). The average fuel efficiencies of different vehicle categories for the existing stock of vehicles are obtained on the basis of the petrol pump survey (Table 5-9). The future efficiencies (default values) are provided in Annexure 6 of the CMP toolkit, and the same were used here.

Table 5-9: Average fuel efficiency of the existing vehicle fleet in Rajkot

	Mode/Fuel type	Fuel efficiency (average) km/litre
1	**2-Wheeler**	
a	Petrol	52.83
2	**3-Wheeler**	
a	CNG	32.51
b	Diesel	28.10
c	Petrol	19.54
3	**Bus**	
a	Diesel	3.70
4	**Car**	
a	CNG	18.77
b	Diesel	17.82
c	LPG	26.00
d	Petrol	16.07
5	**Truck**	
a	Diesel	7.94

The next step is to estimate the mix of vehicles in terms of their fuel usage. This mix for the base year is obtained from the sample of vehicles in the petrol pump surveys. In the case of the future, the fuel mix for vehicles is kept the same as the base year, except in the case of three-wheelers, where it is assumed that all three-wheelers will use gas as fuel. The vehicle mix according to fuel for the base year is given in Table 5-10.

Table 5-10: Vehicle type and fuel mix

Vehicle type	VKT (million)	% Fuel type			
		Petrol	Diesel	Gas	Electricity
Cars	52,190	39%	37%	24%	
MUV					
2Ws	2,779,206	100%			
3Ws	326,246	3%	34%	63%	
Taxis					
Buses	0		100%		
HDVs			100%		
LDVs			100%		
Metros / Trams					100%

The fuel use for base year and horizon year of 2031 in the BAU scenario are presented in Table 5-11. Because of the increase in trip rates and steep rise in the use of two-wheelers and cars, the consumption of petrol, diesel and gas is likely to multiply almost ten times by the year 2031.

Table 5-11: Vehicle type and fuel consumed

Vehicle type	Fuel consumed (million litres or million kg) 2011				Fuel consumed (million litres or million kg) 2031			
	Petrol	Diesel	Gas	Electr-icity	Petrol	Diesel	Gas	Electr-icity
2Ws	9.80	0.00	0.00		96.45	0	0	
Cars	5.61	4.89	2.45		39.34	34.34	17.17	
MUVs	0.18	0.57	0.00		1.68	5.37	0	
Taxis	0.00	0.22	0.00		0	1.49	0	
3Ws	0.04	0.46	0.81		0	0	4.07	
Buses	0.00	3.51	0.00		0	41.35	0	
HDVs	0.00	4.25	0.00		0	21.94	0	
LDVs	0.00	1.59	0.00		0	7.97	0	
Total	15.62	15.50	3.26		137.47	112.46	21.24	

CO_2 Emissions

Fuel use can be converted to CO_2 emissions using default coefficients for different fuels provided in Table 5-12.

Table 5-12: CO_2 emission coefficients for different fossil fuels

Fuel	GigagramCO_2/PJ	kg CO_2/tonne of fuel	kg CO_2/litre of fuel
Motor spirit (Petrol)	69.30	3101	2.30
High speed diesel (Diesel)	74.1	3214	2.71
Compressed Natural Gas (CNG)	56.1	1691	1.69*
Liquefied Petroleum Gas (LPG)	63.1	2912	2.91*

* For CNG and LPG it is per kg of fuel

The total CO_2 emissions have been calculated based on the above and the results are presented for each mode used in Rajkot in Table 5-13.

Table 5-13: CO_2 emissions for various types of vehicles in 2011, 2031

Vehicle type	Annual CO_2 emissions (million tonnes) 2011			Annual CO_2 emissions (million tonnes) 2031		
	Petrol	Diesel	Gas	Petrol	Diesel	Gas
2Ws	0.023	0.000	0.000	0.083	0.000	0.000
Cars	0.013	0.013	0.004	0.232	0.228	0.071
MUVs	0.000	0.002	0.000	0.009	0.032	0.000
Taxis	0.000	0.001	0.000	0.000	0.010	0.000
3Ws	0.000	0.001	0.001	0.000	0.000	0.003
Buses	0.000	0.009	0.000	0.000	0.107	0.000
HDVs	0.000	0.011	0.000	0.000	0.197	0.000
LDVs	0.000	0.004	0.000	0.000	0.074	0.000
Total	0.037	0.042	0.005	0.324	0.647	0.074

It is obvious that the share of distance travel by two-wheelers in the overall passenger kilometre is high, and therefore the CO_2 emissions from the two-wheelers will increase tenfold in the coming two decades. There is also a significant increase in the CO_2 emissions by cars in the BAU scenario.

Local emissions

The emissions of local pollutants can be calculated by multiplying the VKTs with emission coefficients. In Table 5-14 the emission of air pollutants in Rajkot from different vehicles for the base year is shown. In the base year, it is also clear that two-wheelers operating on petrol are the major contributor to air pollution, especially particulate matter. Cars and buses contribute to most of the SO_2pollution in Rajkot.

Table 5-14: Emissions of other air pollutants in 2011

Veh. Type	Annual PM2.5 emissions (tonnes)			Annual PM10 emissions (tonnes)			Annual NOx emissions (tonnes)		
	Petrol	Diesel	Gas	Petrol	Diesel	Gas	Petrol	Diesel	Gas
2Ws	61.26	0.00	0.00	72.07	0.00	0.00	153.14	0.00	0.00
Cars	5.09	178.32	1.53	5.99	209.78	1.53	652.13	988.39	132.46
MUVs	0.15	20.62	0.00	0.17	24.25	0.00	18.85	114.27	0.00
Taxis	0.00	6.92	0.00	0.00	8.14	0.00	0.00	37.18	0.00
3Ws	0.00	0.00	1.61	0.00	0.00	1.61	0.00	0.00	10.65
Buses	0.00	75.10	0.00	0.00	88.35	0.00	0.00	1528.17	0.00
HDVs	0.00	125.69	0.00	0.00	147.87	0.00	0.00	3236.02	0.00
LDVs	0.00	19.33	0.00	0.00	22.74	0.00	0.00	100.50	0.00
Total	66.50	425.96	3.14	78.23	501.13	3.14	824.12	6004.54	143.11
Veh. Type	Annual CO emissions (tonnes)			Annual HC emissions (tonnes)			Annual SO_2 emissions (tonnes)		
	Petrol	Diesel	Gas	Petrol	Diesel	Gas	Petrol	Diesel	Gas
2Ws	4153.91	0.00	0.00	4919.60	0.00	0.00		0.00	
Cars	2812.32	2577.96	906.87	438.15	163.03	5.09		72.18	
MUVs	81.29	298.05	0.00	12.66	18.85	0.00		10.01	
Taxis	0.00	93.14	0.00	0.00	5.89	0.00		3.13	
3Ws	0.00	0.00	97.56	0.00	0.00	5.53		0.00	
Buses	0.00	573.07	0.00	0.00	196.99	0.00		33.83	
HDVs	0.00	1597.03	0.00	0.00	530.13	0.00		0.00	
LDVs	0.00	392.08	0.00	0.00	35.34	0.00		0.00	
Total	7047.51	5531.32	1004.43	5370.42	950.24	10.63	0.00	119.15	0.00
Veh. Type	Annual BC emissions (tonnes)			Annual OC emissions (tonnes)					
	Petrol	Diesel	Gas	Petrol	Diesel	Gas			
2Ws	3.06	0.00	0.00	24.50	0.00	0.00			
Cars	0.25	89.16	0.03	2.04	53.50	0.92			
MUVs	0.00	0.41	0.00	0.09	12.37	0.00			
Taxis	0.00	3.46	0.00	0.00	2.08	0.00			
3Ws	0.00	0.00	0.03	0.00	0.00	0.97			
Buses	0.00	22.53	0.00	0.00	22.53	0.00			
HDVs	0.00	0.00	0.00	0.00	0.00	0.00			
LDVs	0.00	0.00	0.00	0.00	0.00	0.00			
Total	3.32	115.56	0.06	26.63	90.47	1.88			

The total emissions by mode in the BAU scenario for 2031 are presented in Table 5-15.There is a substantial increase in the emission of polluting gases, especially from two-wheelers, as their number and passenger kilometres travelled are high. Significantly, as the number of passenger kilometres travelled by cars and buses also increase in future years, it is observed that these modes also contribute substantially to the air pollution level, especially SO_X and NO_X emissions.

Table 5-15: Emissions of other air pollutants in 2031

Veh. Type	Annual PM2.5 emissions (tonnes)			Annual PM10 emissions (tonnes)			Annual NOx emissions (tonnes)		
	Petrol	Diesel	Gas	Petrol	Diesel	Gas	Petrol	Diesel	Gas
2Ws	61.26	0.00	0.00	72.07	0.00	0.00	153.14	0.00	0.00
Cars	5.09	178.32	1.53	5.99	209.78	1.53	652.13	988.39	132.46
MUVs	0.15	20.62	0.00	0.17	24.25	0.00	18.85	114.27	0.00
Taxis	0.00	6.92	0.00	0.00	8.14	0.00	0.00	37.18	0.00
3Ws	0.00	0.00	1.61	0.00	0.00	1.61	0.00	0.00	10.65
Buses	0.00	75.10	0.00	0.00	118.34	0.00	0.00	2047.02	0.00
HDVs	0.00	125.69	0.00	0.00	147.87	0.00	0.00	3236.02	0.00
LDVs	0.00	19.33	0.00	0.00	22.74	0.00	0.00	100.50	0.00
Total	66.50	451.46	3.14	78.23	531.13	3.14	824.12	6523.39	143.11
Veh. Type	**Annual CO emissions (tonnes)**			**Annual HC emissions (tonnes)**			**Annual SO_2 emissions (tonnes)**		
	Petrol	**Diesel**	**Gas**	**Petrol**	**Diesel**	**Gas**	**Petrol**	**Diesel**	**Gas**
2Ws	4153.91	0.00	0.00	4919.60	0.00	0.00		0.00	
Cars	2812.32	2577.96	906.87	438.15	163.03	5.09		72.18	
MUVs	81.29	298.05	0.00	12.66	18.85	0.00		10.01	
Taxis	0.00	93.14	0.00	0.00	5.89	0.00		3.13	
3Ws	0.00	0.00	97.56	0.00	0.00	5.53		0.00	
Buses	0.00	767.63	0.00	0.00	263.87	0.00		45.31	
HDVs	0.00	1597.03	0.00	0.00	530.13	0.00		0.00	
LDVs	0.00	392.08	0.00	0.00	35.34	0.00		0.00	
Total	7047.51	5725.89	1004.43	5370.42	950.24	10.63	0.00	119.15	0.00
Veh. Type	**Annual BC emissions (tonnes)**			**Annual OC emissions (tonnes)**					
	Petrol	**Diesel**	**Gas**	**Petrol**	**Diesel**	**Gas**			
2Ws	3.06	0.00	0.00	24.50	0.00	0.00			
Cars	0.25	89.16	0.03	2.04	53.50	0.92			
MUVs	0.00	0.41	0.00	0.09	12.37	0.00			
Taxis	0.00	3.46	0.00	0.00	2.08	0.00			
3Ws	0.00	0.00	0.03	0.00	0.00	0.97			
Buses	0.00	30.18	0.00	0.00	30.18	0.00			
HDVs	0.00	0.00	0.00	0.00	0.00	0.00			
LDVs	0.00	0.00	0.00	0.00	0.00	0.00			
Total	3.32	123.21	0.06	26.63	90.47	1.88			

It can be observed that in the horizon year of 2031 in the BAU scenario, with increasing vehicle kilometres travelled, CO_2 emissions will decrease from 0.8 to 0.67 million tonnes in 2031. The emissions for 2011 and those projected for 2031 are shown in

Table 5-16: Emissions for base and different horizon years

Gases	2011 (tonnes)	2016 (tonnes)	2021 (tonnes)	2031 (tonnes)
PM2.5	43.32	103.00	239.15	521.10
PM10	50.80	120.95	281.00	612.50
SO_2	119.15	23.96	58.42	130.63
NO_X	481.27	1373.87	3347.16	7490.61
CO(million tonnes)	1644.92	3113.87	6654.55	13777.82
CO_2(million tonnes)	0.08	0.20	0.49	1.08
HC	6331.28	1986.35	3566.35	6398.17
BC	8.13	22.96	56.33	126.59
OC	118.98	118.98	118.98	118.98

Source: Sim-Air Modelling, Study Estimates, 2012

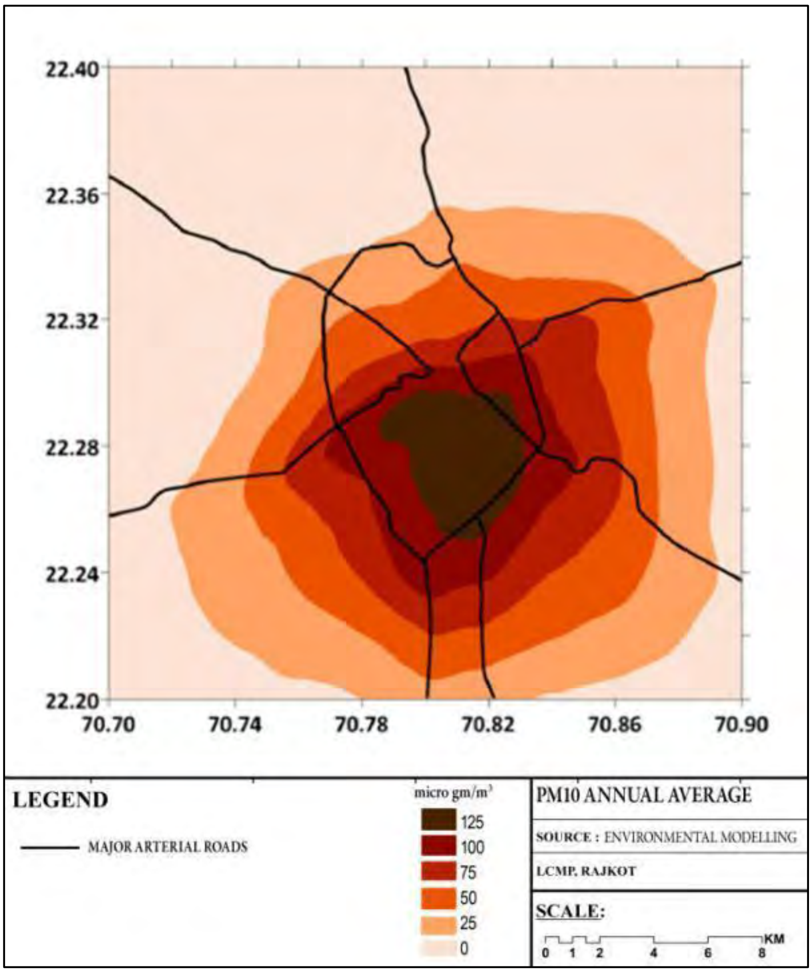


Figure 5-31: PM_{10} Annual Average
Source: Environmental modelling

Air pollution can affect our health in many ways. Numerous scientific studies have linked air pollution to health problems including: (1) aggravation of respiratory and cardiovascular disease; (2) decreased lung function; (3) increased frequency and severity of respiratory symptoms, such as coughing and difficulty breathing; (4) increased susceptibility to respiratory infections; (5) effects on the nervous system, including the brain, such as IQ loss and impacts on learning, memory, and behaviour; (6) cancer; and (7) premature death. The health problems caused by increasing CO and NO_X in the air are headaches, nausea, vomiting, dizziness, and fatigue, whereas HC along with NO_X and sunlight forms ozone and other greenhouse gases. CO_2 and PM can cause severe breathing problems, hyper tension, lung and heart disease, asthma problems, etc. (World Health Organization, 2005).

5.7. Conclusion

The BAU Scenario, with modelling of the base and horizon years, gives an overall idea of the situation prevailing in the city and how it can affect the future if there are no major interventions. By modelling the BAU scenario, the actual condition on the road has been obtained, disaggregating it by the number of total trips made in a day, the mode used by each trip, distance travelled by each trip, the number of vehicles or volumes on each road, and the probable emissions in 2031. The inferences and the outputs from this are used for further proposals to improve the transport situation and make the city more liveable and sustainable.

Chapter 6: Low-Carbon Scenario

6.1. Introduction

There is no agreed definition of Low-Carbon Development (LCD), but the common denominator is the use of less carbon for economic growth (Mulugetta & Urban, 2010). The LCD scenario in this study aims to lower greenhouse gas (GHG) emissions from the transport sector, which is the fifth-highest carbon-emitting sector (Barker, 2007). Vehicle ownership and the use of private vehicles are increasing rapidly. To lower GHG emissions from the transport sector, the focus here remains on the traditional transportation modes like walking and cycling. The next important mode, from the planning and policy formulation point of view, is public transport as its usage causes a decrease in per capita road space, allowing it to be considered a more sustainable mode as compared to private vehicles. Recently, there have been proposals to implement BRT in cities, irrespective of the city's size and their population's demand. The LCD strategy takes into consideration the demands of the city's population as well their modal preferences. The plan also takes into consideration the supply side of infrastructure in accordance to people's demand, which as shown in the earlier chapters of this report is lacking in the quality, reliability and safety of the service. In the case of the LCD scenario for Rajkot, two aspects of low-carbon development are addressed by meaningful interventions in the General Development Control Regulations (GDCR). The first aim is to reduce the total carbon resulting from travel in the city. The second aim is to maintain economic growth, wherein it is assumed that the total activities that are likely to develop in the city are kept constant. Moreover, accessibility between activities that tend to cluster, and individuals' accessibility to these activities, has not been compromised. The spatial configuration of the urban area thus achieved will be supportive of economic development, given that other economic drivers are in place. Low-Carbon Development thus talks about lowering carbon emissions by not only shifting to non-motorised modes of transport, but also changing the land use patterns and accessibility to destinations. The types of interventions or strategies this study considers are those based on land use, non-motorised transport, public transport, and technological interventions.

6.2. Low-Carbon Development Methodology

The BAU scenario focuses on the modelling of individuals' revealed preferences. Revealed preference, however, does not take into account supply side infrastructure gaps. Thus the stated preference surveys[34] were conducted along with household surveys to understand people's demand. The two questions asked identified: the mode that would be preferred if the current mode were not available; and the preferred mode for each purpose if walk, cycle and bus infrastructure were in place. A short question was also asked, giving scenarios for improvements of infrastructure in terms of travel cost, travel time, comfort and safety of the people.

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[34] The 'stated preference surveys' were conducted to identify estimates of relative utility weights (rather than absolute values) thereby avoiding the problem of stated intention.

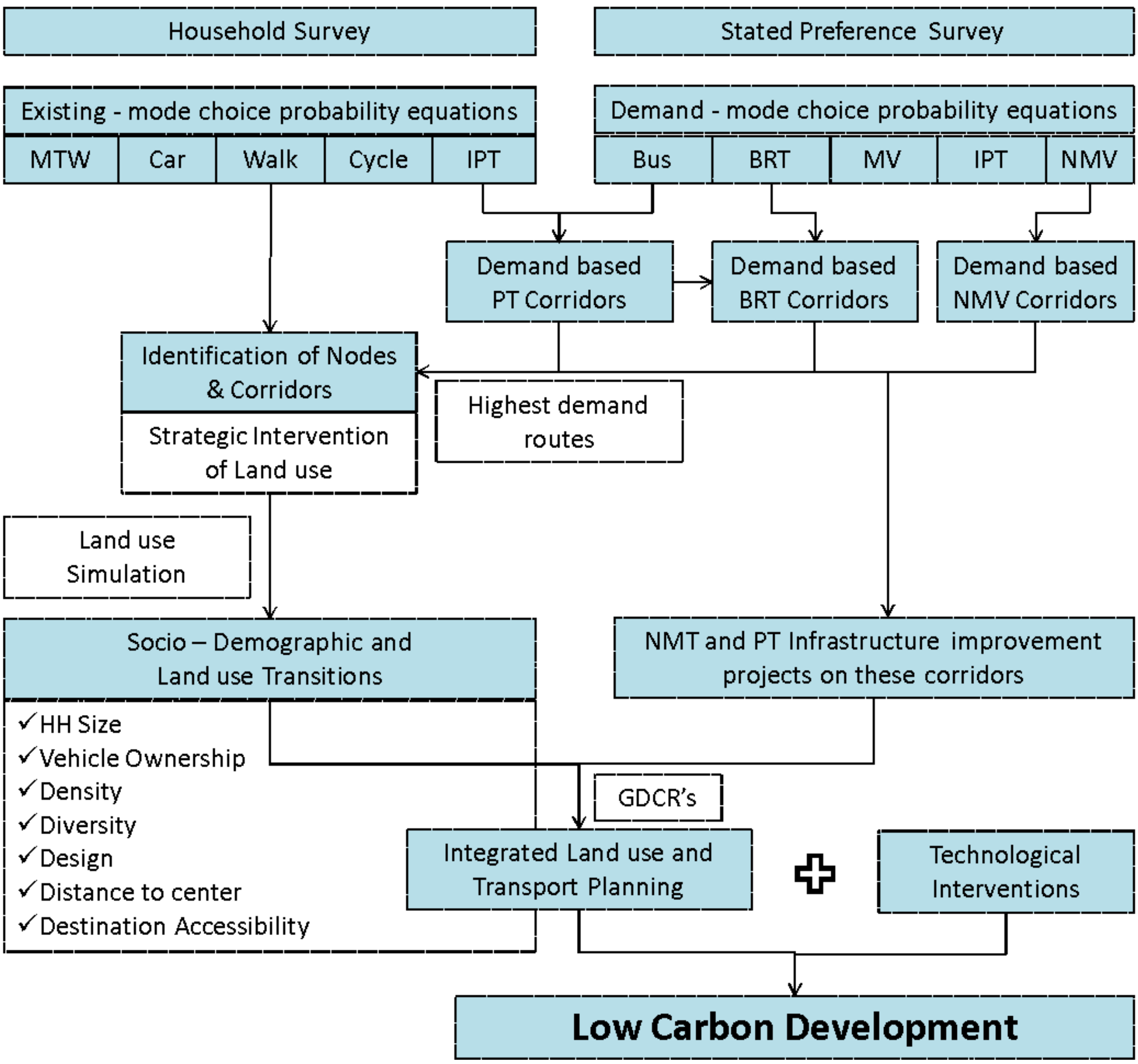


Figure 6-1: Flowchart showing low-carbon development methodology

From these stated preference surveys, new mode choice probabilities were determined and assigned on the routes. This exercise resulted in estimating the demand for transport infrastructure on the city's network. The routes with high travel demand were selected as the corridors of infrastructure development in the city. This approach promises to decrease the demand-supply infrastructure gap and increase people's preference for low-carbon modes for shorter trips. This however, ensures low travel or low-carbon emissions only to a certain extent. To achieve low-carbon emissions through lower mobility and higher accessibility, it is important to integrate land use and transportation. The identification of high demand routes of travel lead to the selection of nodes and corridors of development for controlling city sprawl. The intention is to plan the densities and diversities of land use, supporting lower mobility and in turn lowering carbon emissions. Concentrating developments in these nodes and corridors can control the sprawl and bring opportunities closer to people. Thus, travel behaviours are expected to be altered by running the land use simulation and allotting new commercial and residential densities, and a job-housing mix, to concentrate development near the centre. Combining road infrastructure improvements and land use interventions gives the integrated land use transport plan. However, it is also important to suggest changes in the types of fuel and vehicles to reduce overall transport emissions. All these four strategies, namely: land use strategy, non-motorised transport strategy, public transport strategy and technology strategy, are modelled individually and then combined for the Low-carbon Comprehensive Mobility Plan as shown in Figure 6-1.

6.3. Land Use Strategy

The number of kilometres an individual travels and the mode chosen for different trips will depend on the structure of the city in which the individual resides, on the distribution of population and employment within the city, on the size of the city, and on its road and transit networks (Wegener, 1999). Most studies on the impact of land use on travel behaviour identify that the provision of higher density, mixed land use, public transport service accessibility and a pedestrian-friendly built environment can reduce vehicle dependence and thereby lower transport emissions.

6.3.1. Concept

There is a concept of ‘five Ds’ of built forms affecting travel behaviour. The original ‘three Ds’ were density, diversity, and design (Cervero & Kockelman, 1997), followed later by destination accessibility and distance to transit (Ewing & Cervero, 2010). Density is always measured as the variable of interest per unit of area. The area could be gross or net, and the variable of interest could be population, dwelling units, employment, building floor area, etc. Population and employment are sometimes summed to compute an overall activity density per unit of area (Ewing & Cervero, 2010). As population and employment densities increase, experts expect that the vehicle kilometres travelled or the daily trips per person would decrease, and walk, cycle and transit trips would increase. Diversity measures pertain to the number of different land uses in a given area and the degree to which they are represented in land area, floor area or employment. Entropy measures of diversity are widely used in travel studies, wherein low values indicate single-use environments and higher values more varied land uses. Jobs-to-housing or jobs-to-population ratios are less frequently used. As diversity or the land use mix increases, experts expect that the vehicle kilometres travelled or daily trips per person decreases, and walk, cycle and transit trips increases.

Design considers street network characteristics within an area. Street networks vary from dense urban grids of highly interconnected, straight streets to sparse suburban networks of curving streets forming loops. Measures include the average block size, proportion of four-way intersections, and number of intersections per square mile. Design is also occasionally measured as: sidewalk coverage; average building setbacks; average street widths; or numbers of pedestrian crossings, street trees, or other physical variables that differentiate pedestrian-oriented environments from auto-oriented ones. If the street network has grid patterns, shorter distances and appropriate pedestrian facilities on streets, experts expect that the vehicle kilometres travelled or daily trips per person would decrease, and walk, cycle and transit trips would increase. Destination accessibility measures include ease of access to trip attractions, which might be regional or local (Handy, 1992). In some studies, regional accessibility is simply the distance to the central business district, while in others, it is the number of jobs or other attractions reachable within a given travel time, which tends to be highest at central locations and lowest at peripheral ones. Distance to transit is usually measured as an average of the shortest street routes from the residences or workplaces in an area to the nearest railway station or bus stop. Alternatively, it may be measured as transit route density, distance between transit stops, or the number of stations per unit area (Cervero, 2002). As the distance to the urban centre decreases, experts expect that the vehicle kilometres travelled or daily trips per person would decrease, and walk, cycle and transit trips would increase (Figure 6-2). It is also important that the changes in built form are made through plans and policy documents.

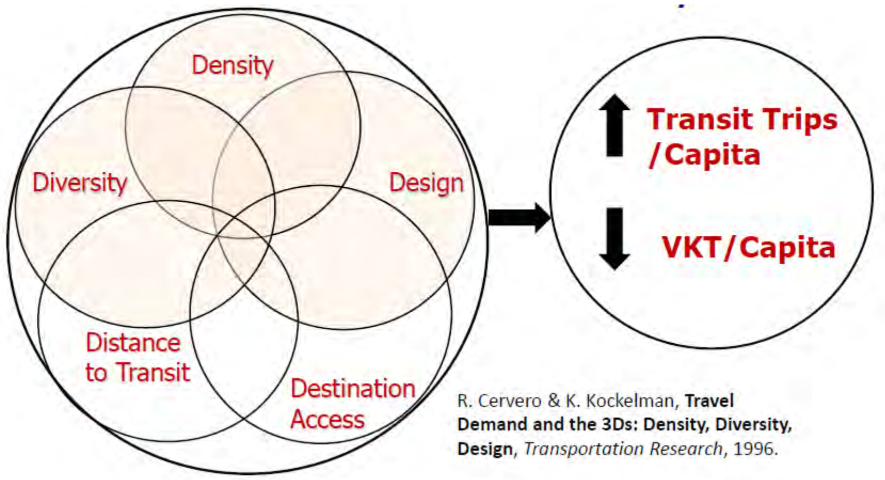


Figure 6-2: An overview of the 6-Ds concept

The configuration of land use is dependent upon the macro-level Development Plan, CDP and the micro-level town planning schemes[35]. The General Development Control Regulations (GDCR) are the specifications to guide the Development Plan (DP) and town planning schemes. The GDCR regulates the Floor Space Index (FSI), setbacks and the size of the building to be developed on the land. Thus, the changes in the built form need to be addressed by the DP, TP schemes and the GDCR. Listed below (Table 6-1) are the indicators that arise from this concept to reduce vehicle kilometres travelled, increase the probability of non-motorised transport and public transport mode choice, and the planning tools or mechanisms to implement these changes in built form:

[35] Urban planning in Gujarat is a two-step process. The first step is to prepare a Development Plan, and second is to prepare town planning schemes for smaller portions of the development area. The Bombay Town Planning Act, 1915, empowered the local authorities to control the use of land and development through instruments of zoning and building regulations (Gujarat Development Control Regulations, i.e. GDCR), and acquire land for public purposes by preparing Town Planning Schemes.

Table 6-1: List of indicators

Indicator	Variables	Planning tool	Mechanism
Density	Net population density	Zoning regulation and floor area ratio	Development Plan and GDCR
	Net job density		
Diversity	Job-housing balance	Zoning regulations, local area planning	Development Plan and Town Planning Schemes
Design	Road junction kernel density Public transport stops kernel density	Planning of transport network	Development Plan and Town Planning Schemes
Destination	Access to jobs by self-owned motorised vehicles	Zoning regulation and planning of transport network	Development Plan and Town Planning Schemes
	Access to job by transit network		
Distance from transit stop	Distance from transit stop	Planning public transit network	Public Transit Authority

Sources: (Ewing & Cervero, 2010; Stead & Marshall, 2001; Munshi, 2013)

Rajkot is a compact city, and to keep it that way it is clear that in the LCD scenario, urban development will have to be contained within certain nodes, thereby also ensuring improved accessibility to jobs through both the transport and public transport networks. There are some major nodes identified at intervals of 4km, which is the city's average trip length, whereas minor nodes are identified at an interval of 1km each (Figure 6-3). The nodes must have more than 10,000 jobs and be equitably distributed to ensure proper access to jobs from all areas. These employment nodes and surrounding areas will have a coarse network of roads and road junctions as well as good public transport connectivity to ensure good job accessibility by public transit, and to public transit networks. In addition, all these nodes and the connecting networks will incorporate urban design elements, which will ensure the safety particularly of pedestrians and cyclists on these roads. The first purpose was to restrict sprawl, which was achieved in the LCD scenario.

The second objective was to attract more development towards the existing employment sub-centres. In the BAU scenario, even though these locations are more attractive for firms to establish, the existing GDCR, FSI norms restrict the amount of area that can develop at this location. Therefore, in the LCD scenario, it is proposed to have an FSI of four in the identified major nodes and an FSI of 3 in the minor nodes, whereas the corridors connecting these nodes would have an FSI of 2. From a low-carbon transport perspective, it is important that these locations have a higher land-use diversity and entropy index. Some of this development occurs naturally because of the self-organisation of the land uses, as retail development is only confined up to the first floor, so development of higher floors is controlled to achieve a more balanced and mixed development of the four land uses: commercial, industrial, institutional and residential.

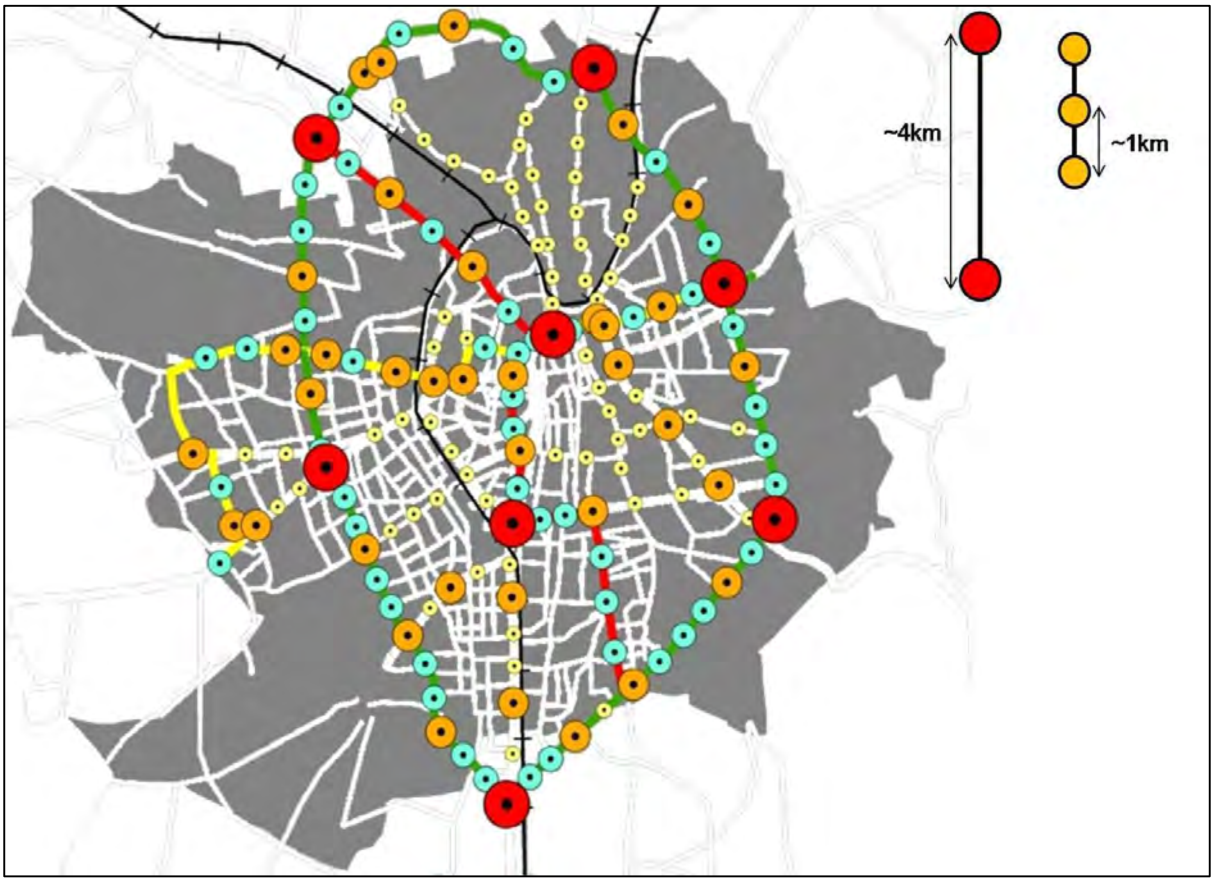


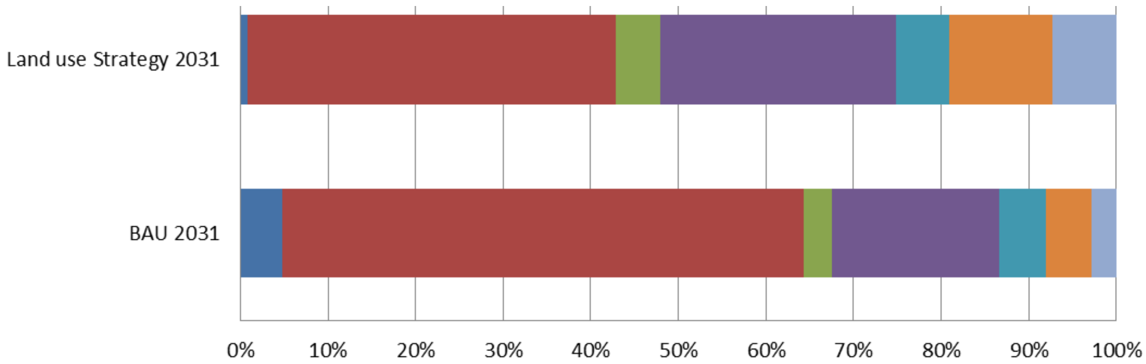
Figure 6-3: Node and corridor development strategy
Source: Study estimates

6.3.2. Impacts on travel pattern

In Rajkot, the choice of motorised vehicles increases with the rise in vehicle ownership levels and per capita incomes. With the passing years, even household size is decreasing as there is a preference for nuclear families over joint families. All these values have been projected based on past trends, and are reflected in mode choice probability. Allotting higher densities to the nodes and corridors has been done by land use simulation. By proposing higher FSI and greater diversities, it is assumed necessary to change the mode choice probabilities and vehicle kilometres travelled as the city becomes compact and more activities are concentrated at existing commercial zones.

Observing the mode choice in the BAU and LCD scenarios, both favour higher use of two-wheelers over other modes in all parts of the city. These results are a reflection of the attitudes of the current residents. It can be seen that in the BAU scenario, more than 40 per cent of the population would reside at locations where the probability of choosing a two-wheeler as a mode for work-purpose travel is more than 60 per cent. In the LCD scenario, the proportion of individuals residing at locations that have high two-wheeler choice probabilities decreases. However, the proportion of residents is still high when compared to the present scenario in the greater than 40 per cent choice probability category. However, the proportion of the population living in TAZs is substantially lower in the subsequent two categories, that is, categories representing 50-80 per cent mode choice probabilities. Therefore, the weighted mode choice of two-wheel motorcycles is lower in the LCD scenario as compared to the present scenario. This means that there are sufficient locations where positive mode choice change can be achieved (from motorised to non-motorised modes). The probability of walking and cycling remains low compared to the present share, but is higher than the projected share in BAU. However, to retain residents in their current non-motorised mode choices in many parts of the city, in addition to the built-form interventions, other measures will be needed to change individual travel behaviour attitudes in favour or non-motorised modes and public transit modes of travel. The share of public transport would increase to around 12 per cent as the system comes into place, which was absent in the BAU scenario. With the land use strategy in place, the major impact would be felt on the vehicle kilometres travelled, which due to the concentration of activities nearer to the centre causes a reduction in the average trip length ().

In the present situation, individuals residing in the old city and its surrounding locations to the east show a higher probability of choosing walking as their preferred mode. In the BAU scenario, because of an increase in per capita income and motorised vehicle ownership, there is an overall reduction in locations that have a high probability of residents choosing walking as a mode. In the LCD scenario, in addition to walking as a preferred mode of choice and a reduction in vehicle kilometres travelled (VKT), other desired shifts are anticipated such as increased probabilities of people choosing cycling and public transit modes. For non-work purpose travel, it is estimated that the population choosing to walk would increase in both BAU and LCD scenarios. This is plausibly because a strong relationship exists between the built-form measure diversity index with both the location of most land uses and the choice of walking for non-work purpose travel. Considering that these obligatory trips constitute about 20 per cent of the total trips in the city, these can be considered significant in the overall context of the city. The residential and commercial footprints as predicted for BAU as well as LCD scenarios are shown in Figure 6-5, Figure 6-6, Figure 6-7 and Figure 6-8.



	BAU 2031	Land use Strategy 2031
Car	895579	153217
2 wheeler	11180438	7609667
3 wheeler	597186	914529
Walk	3590913	4870706
Cycling	1007953	1093875
Bus	980217	2154322
Mass Transit (Metro /BRT)	527809	1312719

Figure 6-4: Modal share/vehicle kilometres travelled (land use strategy)

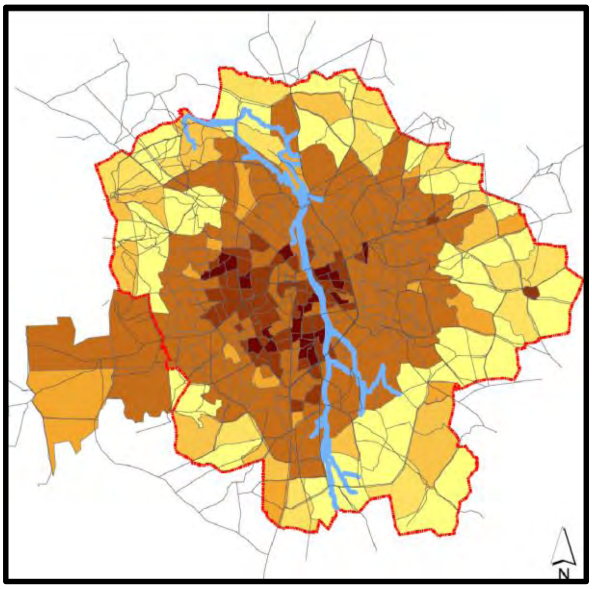


Figure 6-5: Residential footprint in 2031 (BAU)
Source: Land use simulation, Study estimates

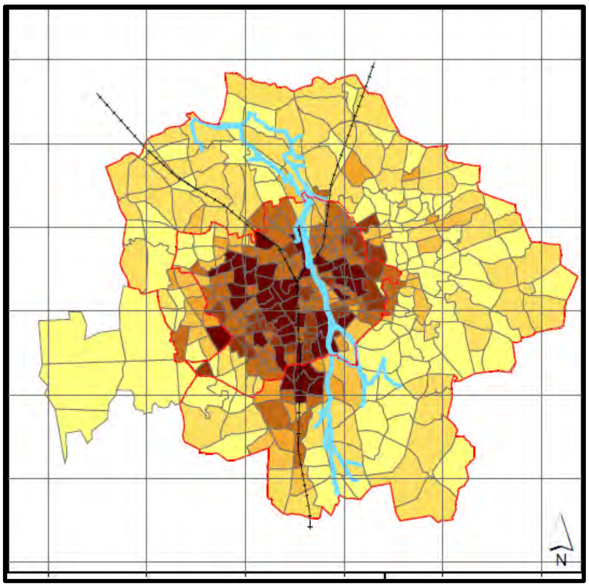


Figure 6-6: Residential footprint in 2031 (LCD)
Source: Land use simulation, Study estimates

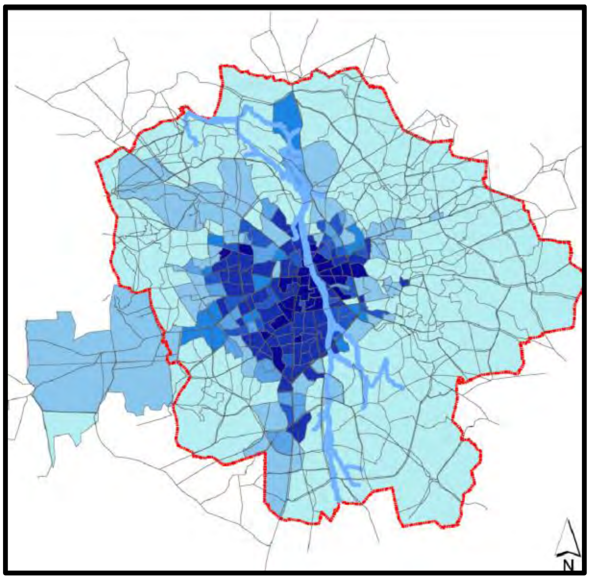


Figure 6-7: Commercial footprint in 2031 (BAU)
Source: Land use simulation, Study estimates

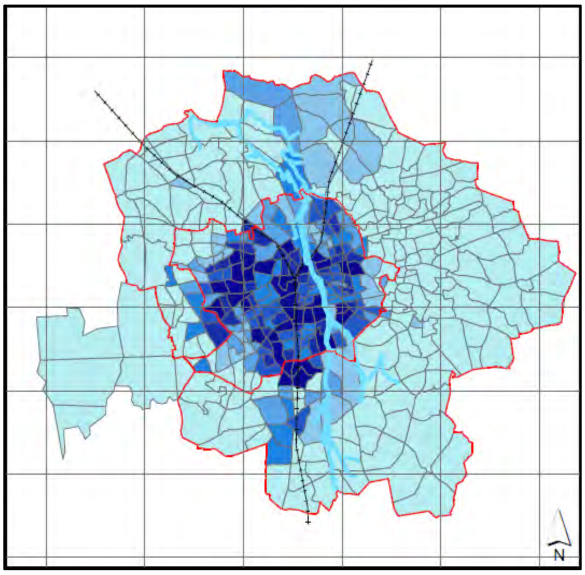


Figure 6-8: Commercial footprint in 2031 (LCD)
Source: Land use simulation, Study estimates

As stated earlier, by 2030 the annual per capita income of Indians living in urban areas is likely to grow (Mckinsey Global Institute, 2010). At the same time the number of motorised vehicles is likely to grow threefold. It is evident that VKT and income are positively correlated. Moreover, the existing development control and zoning regulations place strong restrictions on the density of development, forcing decentralisation of activities in parts of the city and inducing sprawl. These restrictions have an influence on the projected trip lengths in the BAU scenario. The inner parts of the city have an average trip distance that is in the lower range of around 1 to 3 kilometres. In the BAU scenario, individuals living in the outer parts of the city would have to travel, on average, over 7 to 8 kilometres per way for work-purpose trips. The number of jobs increases as we move from the periphery towards the central core of the city, following the conventional relation that improved access to destinations reduces vehicle kilometres travelled. The VKT by residents decreases as we move towards the central core areas. Because of the sprawling development in the BAU scenario for the year 2030, a large section of the population would reside in peripheral locations. Due to this sprawl, in the BAU scenario, the average trip length in the city is likely to increase from the present 3.8km to 6km. In the LCD scenario, where built form is used to influence reduction in travel distance, two things have been achieved.

Firstly, the development is confined largely to the presently developed area, so the distance from the core of the city to its periphery is considerably lower as compared to the BAU scenario. Secondly, in the LCD scenario, because the density of jobs and population is substantially increased at the nodes identified as employment sub-centres, the mean trip length of population residing at these locations and those around it are considerably lower when compared with the BAU scenario. The mean trip length in the LCD scenario is likely to be 3.9km, which is the same as the present mean trip length. As a result, considerable savings in CO_2 emissions are expected relative to the BAU scenario. The mean trip length for non-work purpose travel (shopping, recreation and social purpose trips) is 1.6km, which is equivalent to the mean trip length for walk trips, and thus it is assumed that non-work purpose travel can be made by walking. In the LCD scenario, because of a good mix of land use and higher density of population, the majority of non-work purpose trips would be in less than 1 kilometre. Since these values also comply with the observed walking distance ranges, they are therefore more favourable for walking if other supporting conditions like safety and proper walking infrastructure on streets are satisfied. The CO_2 emissions after implementing the land use strategies are presented in Table 6-2. As expected, the CO_2 from cars and two-wheelers reduce considerably.

Table 6-2: CO_2 emissions (LU–LCD scenario)

Vehicle type	Annual CO_2 emissions (million tonnes)	
	2031 (BAU)	2031 (LU scenario)
2Ws	0.08	0.02
Cars	0.53	0.06
MUVs	0.04	0.01
Taxis	0.01	0.00
3Ws	0.00	0.00
Buses	0.14	0.51
HDVs	0.20	0.03
LDVs	0.07	0.01
Total	1.08	0.64

Table 6-3: Emissions of other air pollutants, year 2031 (Land use scenario)

Veh. type	Annual PM 2.5 emissions (tonnes)			Annual PM10 emissions (tonnes)			Annual NOx emissions (tonnes)		
	Petrol	Diesel	Gas	Petrol	Petrol	Diesel	Gas	Diesel	Petrol
2Ws	41.61	0.00	0.00	48.95	0.00	0.00	104.02	0.00	0.00
Cars	0.78	178.32	1.53	0.92	32.30	0.24	100.41	152.19	20.40
MUVs	0.06	20.62	0.00	0.07	2.43	0.01	7.55	11.45	0.77
Taxis	0.00	6.92	0.00	0.00	1.63	0.00	0.00	7.45	0.00
3Ws	0.00	0.00	1.61	0.00	3.95	1.66	0.00	8.57	11.00
Buses	0.00	75.10	0.00	0.00	362.58	0.00	0.00	6271.71	0.00
HDVs	0.00	125.69	0.00	0.00	29.63	0.00	0.00	648.49	0.00
LDVs	0.00	19.33	0.00	0.00	4.56	0.00	0.00	20.14	0.00
Total	42.45	371.53	1.91	49.94	437.09	1.91	211.98	7120.01	32.17
Veh. Type	**Annual CO emissions (tonnes)**			**Annual HC emissions (tonnes)**			**Annual SO_2 emissions (tonnes)**		
	Petrol	Diesel	Gas	Petrol	Diesel	Gas	Petrol	Diesel	Gas
2Ws	2821.44	0.00	0.00	3341.52	0.00	0.00		0.00	
Cars	433.02	396.94	139.63	67.46	25.10	0.78		11.23	
MUVs	32.58	29.86	5.25	5.08	1.89	0.03		1.01	
Taxis	0.00	18.67	0.00	0.00	1.18	0.00		0.63	
3Ws	0.00	59.78	100.85	0.00	4.51	5.72		0.53	
Buses	0.00	2351.89	0.00	0.00	808.46	0.00		140.23	
HDVs	0.00	320.04	0.00	0.00	106.24	0.00		0.00	
LDVs	0.00	78.57	0.00	0.00	7.08	0.00		0.00	
Total	3287.04	3255.75	245.73	3414.06	954.46	6.53	0.00	119.15	0.00
Veh. Type	**Annual BC emissions (tonnes)**			**Annual OC emissions (tonnes)**					
	Petrol	Diesel	Gas	Petrol	Diesel	Gas			
2Ws	2.08	0.00	0.00	16.64	0.00	0.00			
Cars	0.04	13.73	0.00	0.31	8.24	0.14			
MUVs	0.00	0.04	0.00	0.04	1.24	0.01			
Taxis	0.00	0.69	0.00	0.00	0.42	0.00			
3Ws	0.00	1.68	0.03	0.00	1.01	1.00			
Buses	0.00	92.46	0.00	0.00	92.46	0.00			
HDVs	0.00	0.00	0.00	0.00	0.00	0.00			
LDVs	0.00	0.00	0.00	0.00	0.00	0.00			
Total	2.12	108.60	0.04	16.99	103.36	1.14			

Table 6-3 presents the emissions levels of other pollutants if the land use strategy were implemented. The emission coefficients used to compute the air pollution level in all low-carbon development scenarios are different from the BAU scenario, and are in line with what has been proposed in (Guttikunda & Mohan, 2014). It is assumed that the fuel mix and emission coefficients are similar to BAU, therefore all the buses operate on diesel, and all the three-wheelers operate on CNG as in the BAU. The NOx and SOx emissions are higher compared to the base year; however the savings are considerable when compared to the BAU scenario.

6.4. Non-Motorised Transport Strategy

In addition to the benefits generated from the LU strategy, it is observed that higher walking or cycling mode choice probabilities can be achieved with better walking and cycling infrastructure (Cervero et al., 2009; Boer et al., 2007). Cervero also says that along with land use parameters like density and diversity, design parameters like intersection density, street density, design of footpaths, cycle tracks, and access to the land use or infrastructure also plays an important role in reducing VKT or encouraging low-carbon emitting modes like walking and cycling. Thus, concentrating commercial and residential land use is alone not enough, and adequate infrastructure ensuring access to destinations based on demand is also important. NMT infrastructure accounts for wide and barrier-free footpaths, cycling lanes, safe crossings for NMT on intersections, NMT-accentuated signals, streetlights on NMT lanes, etc.

6.4.1. Indicators

The NMT assignment has been conducted separately for motorised vehicles so that the passenger car unit (PCU) conversions do not neglect pedestrians and cyclists for both the BAU and LCD scenarios. The same indicators for walking and cycling assignments have been used as in the BAU scenario, which have been classified as:

- Footpath
- Accidents
- Paving
- Road width
- Land use mix
- Density
- Speeds on roads
- Parking
- Encroachment

While revealed preference gives the demand or the route choice based on the existing infrastructure, it does not take into account the possibility of infrastructure changes. As explained in Chapter 4, where the stated preference surveys were conducted along with the household surveys, every individual was asked to choose an alternative mode in the absence of the present mode of travel, and the mode of travel if the NMT and PT infrastructure were to change in that area. After this, the stated preference assignment was conducted to get the preferred demand by mode. The present demand for walking and cycling was found to be the highest on internal roads (Figure 6-9, Figure 6-10). However, in the LCD scenario, while land use has been concentrated on major nodes and corridors, infrastructure provisions for NMT, in terms of footpaths and cycle lanes to these nodes, have been provided. Interventions have been suggested such as forbidding on-street parking along the footpaths, formalising the street vendors' industry by permitting them to use the ground floor space of buildings, creating major attractions, lighting up footpaths and cycle lanes, speed restrictions, etc. Along with this, even other attractions like markets, schools, universities, religious shrines, etc., which are used daily, have been provided with the aforementioned NMT infrastructure. Thus in the LCD scenario, the demand for walking and cycling also increases in the areas with major attractions, as do the links connecting these nodes and corridors.

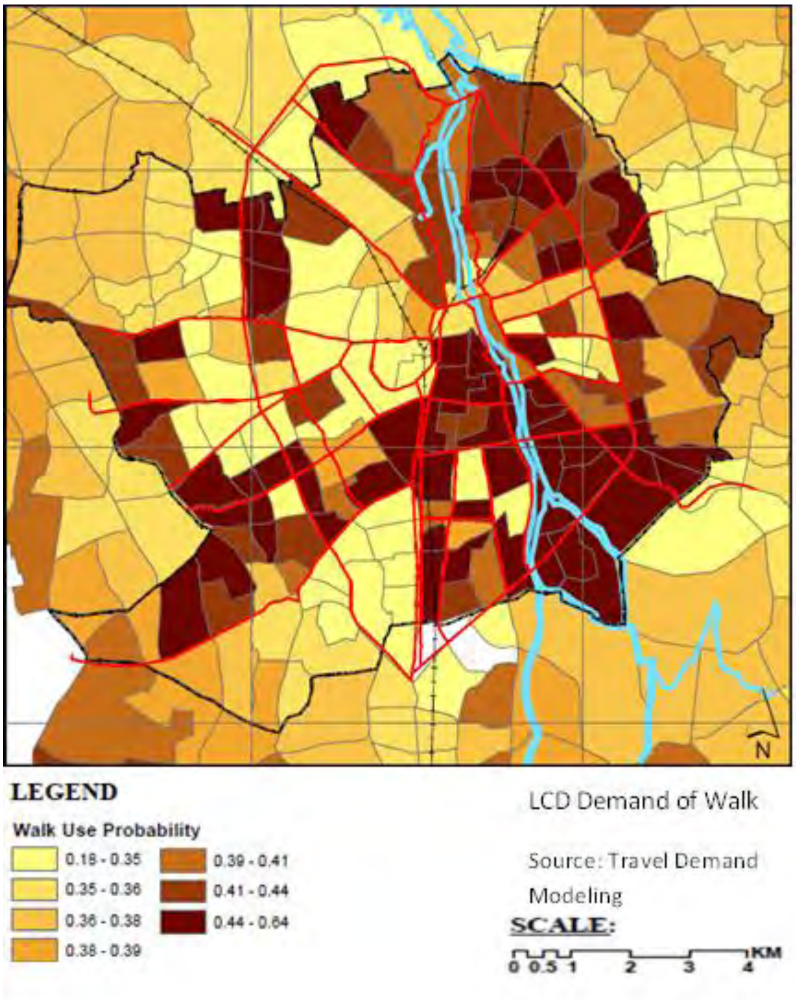


Figure 6-9: LCD demand for walking
Source: Travel Demand Modelling

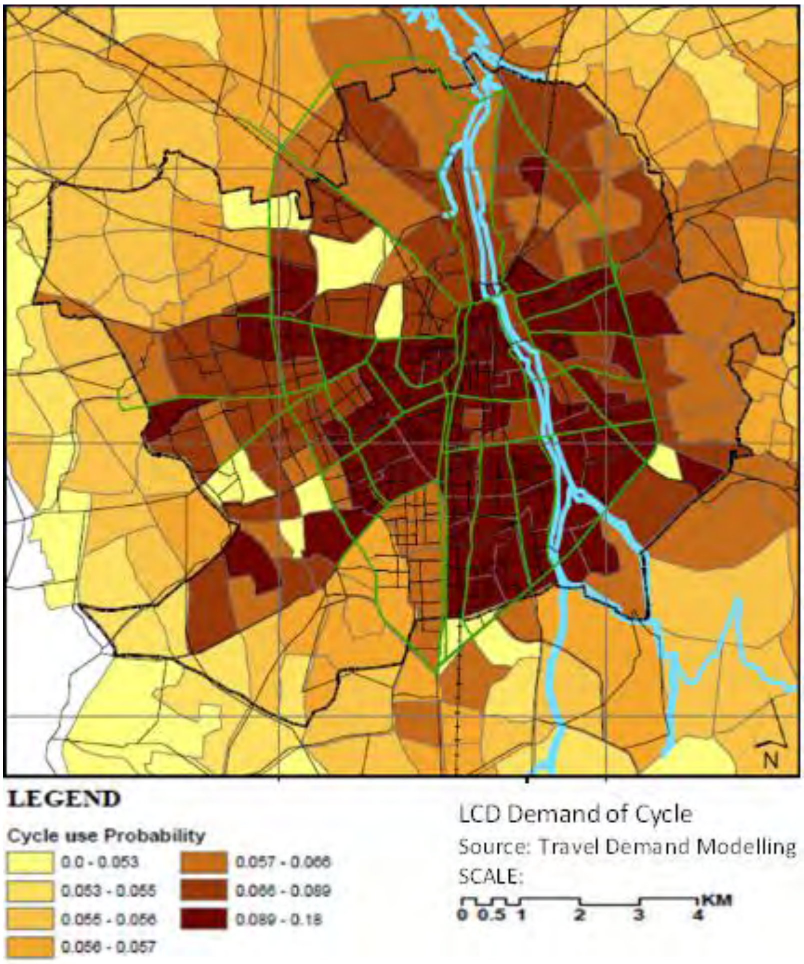


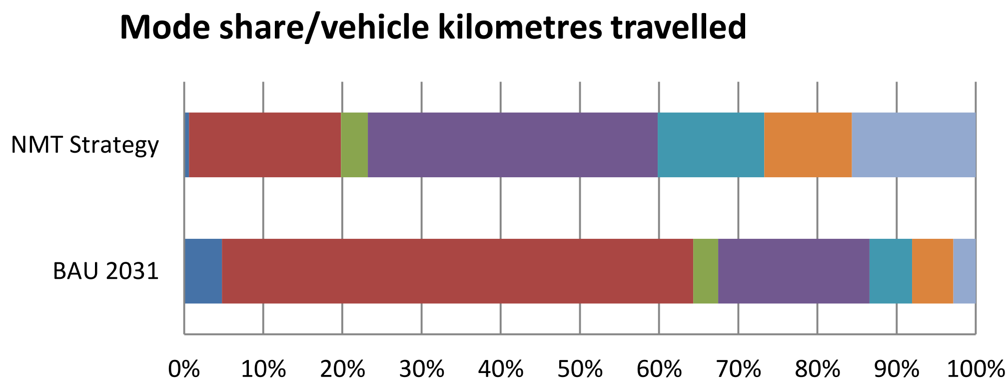
Figure 6-10: LCD demand for cycling
Source: Travel Demand Modelling

6.4.2. Impacts on travel pattern

As stated in the land use strategy, it has been assumed that income levels, vehicle ownership and household size over the years would change, thus changing the mode choice probabilities. According to the analysis, the use of motorised vehicles is highly related to vehicle ownership, thus reducing the mode share of NMT in the BAU scenario. However, in the LCD scenario, a hierarchy of nodes and corridors of development and high attractions have been identified that are well connected with footpaths and cycle lanes with better levels of accessibility from all aspects.

Observing the mode choice in both future scenarios, the BAU scenario shows a reduction in the modal share of walking and cycling due to high vehicle ownership and increasing distances for 2031 (Figure 6-11). The LCD scenario, however, retains the present 38 per cent of walk share for the next twenty years by concentrating activities and providing better infrastructure to pedestrians based on demand. The probability of walking to work increases for those residing in nearby high attraction zones, and that of walking for shorter trips experiences much larger increases as the accessibility to facilities increase. The cycling share in the LCD scenario increases 10 to 14 per cent relative to the present, i.e. as people would feel safer cycling on the roads of the city due to a substantial provision of cycling infrastructure and reduced distances. While the probability of cycling remains the same for lower income groups (who lack the purchasing power for vehicles), it however increases for school and college students, who earlier used a school bus or an auto-rickshaw. Some youth who work near their place of residence are expected to shift from using two-wheelers to cycles. Despite this, the share of cycling remains low due to negative social attitudes toward cycle usage, i.e. a cycle is used by those who cannot afford a vehicle. The share of public transport buses and BRT has also increased marginally, as the access and egress becomes safer and more comfortable. The difference remains marginal as only pedestrians and cycle riders travelling large distances shift to public transport.

In addition to the old city and some of the eastern parts, even the southern and northern part of Rajkot would have higher shares of cycling, whereas the share of walking will be retained throughout the city, with it being greater towards the nodes and corridors of attractions. The western part of the city, which has recently grown, might experience resistance in shifting to non-motorised modes of transport, even for short trips. Along with short trips, trips for educational purposes and some of the work trips would have shifted to non-motorised modes.



	BAU 2031	NMT Strategy
Car	895579	105958
2 wheeler	11180438	3257287
3 wheeler	597186	582298
Walk	3590913	6217094
Cycling	1007953	2285457
Bus	980217	1875449
Mass Transit (Metro /BRT)	527809	2658935

Figure 6-11: Modal share/vehicle kilometres travelled (NMT strategy)
Source: Low-Carbon strategy modelling, Study Estimates

The existing development control and zoning regulations plan discourages mixed use development, making the streets in commercial zones unsafe to walk or cycle at night. Although the practice of providing footpaths exists in almost all cities of India, footpaths are narrow and have barriers restricting usage. Even dedicated cycle lanes provided in some cities are used by two-wheelers or for vehicle parking. In some places, the provision of footpaths and cycle lanes has been in areas with very little demand. These issues have reduced the number of people walking and cycling, leading to an increase in vehicle ownership. Thus, the vehicle kilometres travelled have increased over the years with an increased number of people shifting home to the periphery, enabled by the ownership of private motorised vehicles. All these have affected the projected trip lengths in the BAU scenario. With NMT infrastructure in place, even middle and higher income groups would shift to walking for short trips for retail or religious purposes. The provision of better NMT infrastructure would account for approximately 40 per cent of all short trips, as educational trips and some work trips shift to non-motorised transport, thereby decreasing the usage of vehicles for these trips and in turn reducing vehicular emissions. By implementing the NMT scenario over the land use scenario, because of the resulting shift towards walking and bicycle modes it is observed that the CO_2 emissions drop by another 18 per cent (Table 6-4) and likewise there is also considerable reduction in other air pollutants (Table 6-5).

Table 6-4: CO_2 emissions (LU+NMT – LCD scenario)

Vehicle type	Annual CO_2 emissions (million tonnes)		
	2031 (BAU)	2031 (LU scenario)	2031 (LU + NMT scenario)
2Ws	0.08	0.06	0.06
Cars	0.53	0.08	0.08
MUVs	0.04	0.01	0.01
Taxis	0.01	0.00	0.00
3Ws	0.00	0.00	0.00
Buses	0.14	0.44	0.44
HDVs	0.20	0.04	0.04
LDVs	0.07	0.01	0.01
Total	1.08	0.65	0.64

Table 6-5: Emissions of other air pollutants, year 2031 (NMT scenario)

Veh. type	Annual PM 2.5 emissions (tonnes)			Annual PM10 emissions (tonnes)			Annual NOx emissions (tonnes)		
	Petrol	Diesel	Gas	Petrol	Petrol	Diesel	Gas	Diesel	Petrol
2Ws	16.06	0.00	0.00	18.90	0.00	0.00	40.15	0.00	0.00
Cars	0.54	178.32	1.53	0.64	22.34	0.16	69.44	105.24	14.10
MUVs	0.04	20.62	0.00	0.05	1.68	0.01	5.22	7.92	0.53
Taxis	0.00	6.92	0.00	0.00	1.13	0.00	0.00	5.15	0.00
3Ws	0.00	0.00	1.61	0.00	2.52	1.06	0.00	5.46	7.01
Buses	0.00	75.10	0.00	0.00	420.89	0.00	0.00	7280.23	0.00
HDVs	0.00	125.69	0.00	0.00	20.49	0.00	0.00	448.47	0.00
LDVs	0.00	19.33	0.00	0.00	3.15	0.00	0.00	13.93	0.00
Total	16.64	401.37	1.23	19.58	472.20	1.23	114.82	7866.40	21.64
Veh. Type	**Annual CO emissions (tonnes)**			**Annual HC emissions (tonnes)**			**Annual SO_2 emissions (tonnes)**		
	Petrol	**Diesel**	**Gas**	**Petrol**	**Diesel**	**Gas**	**Petrol**	**Diesel**	**Gas**
2Ws	1089.17	0.00	0.00	1289.94	0.00	0.00		0.00	
Cars	299.46	274.50	96.56	46.65	17.36	0.54		7.76	
MUVs	22.53	20.65	3.63	3.51	1.31	0.02		0.70	
Taxis	0.00	12.91	0.00	0.00	0.82	0.00		0.44	
3Ws	0.00	38.06	64.21	0.00	2.87	3.64		0.34	
Buses	0.00	2730.09	0.00	0.00	938.47	0.00		162.78	
HDVs	0.00	221.33	0.00	0.00	73.47	0.00		0.00	
LDVs	0.00	54.34	0.00	0.00	4.90	0.00		0.00	
Total	1089.17	0.00	0.00	1289.94	0.00	0.00		0.00	
Veh. Type	**Annual BC emissions (tonnes)**			**Annual OC emissions (tonnes)**					
	Petrol	**Diesel**	**Gas**	**Petrol**	**Diesel**	**Gas**			
2Ws	0.80	0.00	0.00	6.42	0.00	0.00			
Cars	0.03	9.49	0.00	0.22	5.70	0.10			
MUVs	0.00	0.03	0.00	0.02	0.86	0.00			
Taxis	0.00	0.48	0.00	0.00	0.29	0.00			
3Ws	0.00	1.07	0.02	0.00	0.64	0.64			
Buses	0.00	107.33	0.00	0.00	107.33	0.00			
HDVs	0.00	0.00	0.00	0.00	0.00	0.00			
LDVs	0.00	0.00	0.00	0.00	0.00	0.00			
Total	0.83	118.40	0.02	6.67	114.81	0.74			

6.5. Public Transport Strategy

The "five Ds" of built form concept includes the variables of destination access, distance to city centre, density, diversity and design. Cities are sprawling, and there is a need for infrastructure provision in the city periphery as a larger number of people chose to live in these areas. The access to nearer destinations can be improved by NMT infrastructure, but for longer distances, a safer and sustainable mode is public transport. With sprawling cities and increasing income levels, there is an increase in vehicle ownership as has been discussed throughout the report. People in the absence of PT, therefore, have no other means but to resort to private vehicles. While it is mostly richer people who live in these locations, it is specific to Indian cities that a diverse income group can also be found in the periphery. The poor living in these locations spend a high portion of their income on travel. Public transport can serve to mitigate the economic and environmental burden that increased vehicle ownership has imposed on the cities or population. Public transport not only includes the infrastructural aspect, but also the accessibility component, land use integration, NMT and PT infrastructure.

6.5.1. Indicators

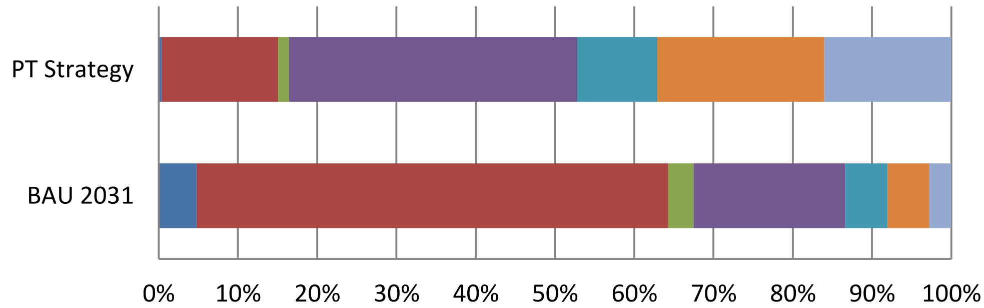
As Rajkot did not have an operational public transport system in the BAU scenario, the demand for public transport has been obtained by combining the stated preference surveys and by observing the present auto-rickshaw routes operating as public transport in the city. The PT routes were decided based on the demand of PT, and the study of land use and road widths. The indicators that influence PT choice are density, job-housing ratios, vehicle ownerships, income levels, kernel density of PT stops, and accessibility to transit. The demand estimation for PT, which was explained in a previous section, was found to be highest on arterial roads, and particularly in the centre of the city where there are presently major attractions. With interventions of higher land use densities, job-housing ratios at identified nodes and NMT infrastructure in place, PT would integrate with land use at these major nodes. In the LCD scenario, the crux has been the improvement of infrastructure in terms of accessibility, comfort, safety and security. PT infrastructure includes an increased number of PT stops covering distant areas, increased demand-based frequency, and an increased public transport network. Integrating this improved infrastructure with land use at proposed nodes would result in a higher ridership. For a small-sized city like Rajkot, the peak hour peak direction traffic (PHPDT) and road width presently render the BRT system infeasible, but this could, however, be implemented on the high frequency public transport routes at a later period in time when feasible volumes are achieved.

6.5.2. Impacts on travel pattern

In Rajkot, the absence of a public transport system has increased the share of auto-rickshaws and two-wheelers. This, coupled with an increase in income levels and vehicle ownership, would cause an increase in per capita road space usage and massive congestion issues. By improving and expanding infrastructure, accessibility to public transit, and integrating land use, it is assumed that the mode choice probabilities would change. Public transit routes have been provided based on the demand and road widths connecting all major origins and destinations of the city. Observing the

BAU and LCD scenarios, a major difference that comes to light is the city's modal share. A more balanced modal share is observed in LCD, having an almost equal share of public transit, BRT and two-wheelers at 21 per cent, 16 per cent and 15 per cent respectively, and the largest proportion of trips, i.e. 46 per cent, being made by walking and cycling (Figure 6-12). Thus, integrating land use and improving NMT and PT infrastructure can lead to a more desirable modal share in the city with lower vehicle kilometres travelled. Aside from short trips, other trips such as educational trips and some proportion of work trips can be expected to shift to public transport away from two-wheelers with the provision of better infrastructure. Some non-daily, long-distance trips for social and recreational purposes would also be converted from vehicle to PT trips. Low and middle income groups that account for 80 per cent of the total population of the city would only shift to public transport. Females in India generally have a low vehicle ownership, and would therefore tend to use public transport more frequently than males. Residents of the eastern part of the city who are employed in the western part, those going longer distances for work, and those having greater accessibility to PT stops, will tend to shift to public transport.

Modal share/vehicle kilometres travelled



	BAU 2031	PT Strategy
Car	895579	78700
2 wheeler	11180438	2906857
3 wheeler	597186	270066
Walk	3590913	7205484
Cycling	1007953	2003241
Bus	980217	4172086
Mass Transit (Metro /BRT)	527809	3172601

Figure 6-12: Modal share/vehicle kilometres travelled (PT strategy)

Source: Low-Carbon strategy modelling, Study Estimates

The lack of proper public transport has resulted in an increase in vehicle ownership and vehicle kilometres travelled, in turn increasing emissions. The capacity of individuals to travel in cities such as Rajkot is fewer than 1.4 trips per day. The corresponding percentage of their total income spent on transport, however, exceeds 20 per cent even for this low trip rate. In other words, given the characteristics of the transport supply, the people of Rajkot spend the same portion of their income making 1.5 trips per day as paying for all of the other basic services. Public transport is a boon for the economically weaker section that cannot afford vehicles and have to travel long distances. With cities sprawling, increasing population and inequality, cities need a public transport system to travel from peripheral areas to the centre of the city. It has also been seen in the cities of India that despite an operational public transport system, it is inefficient, unreliable and uncomfortable, and at times inaccessible. Thus, along with the running of buses, the accessibility to stops for all users, safety and comfort of PT users and inter-modal integration is needed. Thus, the integration of land use, non-motorised transport and public transport can reduce the vehicle kilometres travelled by around 16 per cent. Even though in the PT scenario there is a considerable reduction in the use of private automobiles, given the use of buses increases, and as these are assumed to be running on diesel, there is not a large reduction in CO_2 emissions (Table 6-6). There is also a small increase in the other pollutants compared to the NMT scenario, especially NOx and SOx (Table 6-7). This re-iterates the fact that fuel technology interventions are a must in addition to the previously discussed scenarios for low-carbon transport development.

Table 6-6: CO_2 emissions (LU+NMT+PT – LCD scenario)

Vehicle type	Annual CO_2 emissions (million tonnes)			
	2031 (BAU)	2031 (LU scenario)	2031 (LU +NMT scenario)	2031 (LU+NMT+PT scenario)
2Ws	0.08	0.06	0.06	0.02
Cars	0.53	0.08	0.08	0.04
MUVs	0.04	0.01	0.01	0.00
Taxis	0.01	0.00	0.00	0.00
3Ws	0.00	0.00	0.00	0.00
Buses	0.14	0.44	0.44	0.47
HDVs	0.20	0.04	0.04	0.02
LDVs	0.07	0.01	0.01	0.01
Total	1.08	0.65	0.64	0.57

Table 6-7: Emissions of other air pollutants, year 2031 (PT scenario)

Veh. type	Annual PM 2.5 emissions (tonnes)			Annual PM10 emissions (tonnes)			Annual NOx emissions (tonnes)		
	Petrol	Diesel	Gas	Petrol	Petrol	Diesel	Gas	Diesel	Petrol
2Ws	14.33	0.00	0.00	16.86	0.00	0.00	35.83	0.00	0.00
Cars	0.40	178.32	1.53	0.47	16.59	0.12	51.58	78.17	10.48
MUVs	0.03	20.62	0.00	0.04	1.25	0.00	3.88	5.88	0.39
Taxis	0.00	6.92	0.00	0.00	0.84	0.00	0.00	3.83	0.00
3Ws	0.00	0.00	1.61	0.00	1.17	0.49	0.00	2.53	3.25
Buses	0.00	75.10	0.00	0.00	387.26	0.00	0.00	6698.54	0.00
HDVs	0.00	125.69	0.00	0.00	15.22	0.00	0.00	333.10	0.00
LDVs	0.00	19.33	0.00	0.00	2.34	0.00	0.00	10.35	0.00
Total	14.77	360.97	0.62	17.37	424.67	0.62	91.29	7132.39	14.12
Veh. Type	**Annual CO emissions (tonnes)**			**Annual HC emissions (tonnes)**			**Annual SO_2 emissions (tonnes)**		
	Petrol	**Diesel**	**Gas**	**Petrol**	**Diesel**	**Gas**	**Petrol**	**Diesel**	**Gas**
2Ws	971.99	0.00	0.00	1151.16	0.00	0.00		0.00	
Cars	222.42	203.89	71.72	34.65	12.89	0.40		5.77	
MUVs	16.73	15.34	2.70	2.61	0.97	0.02		0.52	
Taxis	0.00	9.59	0.00	0.00	0.61	0.00		0.33	
3Ws	0.00	17.65	29.78	0.00	1.33	1.69		0.16	
Buses	0.00	2511.95	0.00	0.00	863.48	0.00		149.77	
HDVs	0.00	164.39	0.00	0.00	54.57	0.00		0.00	
LDVs	0.00	40.36	0.00	0.00	3.64	0.00		0.00	
Total	1211.15	2963.17	104.20	1188.42	937.49	2.11	0.00	119.15	0.00
Veh. Type	**Annual BC emissions (tonnes)**			**Annual OC emissions (tonnes)**					
	Petrol	**Diesel**	**Gas**	**Petrol**	**Diesel**	**Gas**			
2Ws	0.72	0.00	0.00	5.73	0.00	0.00			
Cars	0.02	7.05	0.00	0.16	4.23	0.07			
MUVs	0.00	0.02	0.00	0.02	0.64	0.00			
Taxis	0.00	0.36	0.00	0.00	0.21	0.00			
3Ws	0.00	0.50	0.01	0.00	0.30	0.29			
Buses	0.00	98.75	0.00	0.00	98.75	0.00			
HDVs	0.00	0.00	0.00	0.00	0.00	0.00			
LDVs	0.00	0.00	0.00	0.00	0.00	0.00			
Total	0.74	106.68	0.01	5.91	104.13	0.37			

6.6. Technology Strategy

Overall, the transport sector is responsible for about 10 per cent of India's total energy demand. Between 2002 and 2007, the CO_2 emission load from cars increased by 73 per cent and from two-wheelers by 61 per cent (World Energy Council, 2011). The transport sector mainly relies on fossil fuels. This dependence is linked to the domination of internal combustion engine-driven technology globally. Advancement in battery technology and environmental concerns have led to a diffusion of electric and hybrid-driven technologies in the US, Japan and China; however, these technologies have a negligible presence in India. In order to improve air quality in Indian cities, natural gas has been used as an option, and as a result a fuelling infrastructure for compressed natural gas (CNG) has been built in many cities (Clarke et al., 2013). Therefore, in the BAU scenario, a greater diffusion of CNG-based vehicles is expected, and gas emerges as a substantial fuel option. However, besides the CNG no major shifts in fuel choices were considered.

In the LCD scenario, the transport sector is expected to diversify towards natural gas and electricity due to strong climate policies and a high carbon price. Bio-fuels are expected to gain share through blending in the case of petrol and diesel. The fuel mix considered for 2031 is provided in Table 6-8, and considers an overall fuel mix that is broadly consistent with a fuel mix for 2030 under the sustainable low-carbon scenario (refer to Figure 7 of the revised CMP toolkit). In the next fifteen years, it is assumed that electric vehicle will become a mainstream option and supporting infrastructure will be created for charging, etc. But it can be assumed that by 2031 about 10-15 per cent of total transport energy demand will be satisfied by electricity and gas (the assumed fuel use/mode is presented in Table 6-8). As stated earlier, the emission coefficients used to compute the air pollution level in all low-carbon development scenarios are different from the BAU scenario and in line with (Guttikunda & Mohan, 2014).

Table 6-8: Fuel mix for LCD scenario, 2031

Vehicle type	VKT (million) *	% Fuel type			
		Petrol	Diesel	Gas	Electricity
Cars & MUVs	78,700	40%	30%	20%	10%
2Ws	2,906,857	90%	0%	0%	10%
3Ws	270,066	0%	25%	75%	0%
Buses	4,172,086	0%	80%	20%	0%
BRT	3,172,601	0%	80%	20%	0%

*Based on implementation of land use, PT, NMT scenarios.

The overall demand for transport is much lower in the LCD scenario than in BAU due to demographic transition, sustainable transport planning, improvements in urban design, promotion of public transport and non-motorised transport. This demand reduction delivers substantial co-benefits in terms of energy security, local environment quality and health.

6.6.1. Environmental impacts

Ideally, these changes in fuel technology should have been incorporated into the BAU scenario itself as suggested by Dhar et al. (2013). In this instance, they have been showcased separately to distinguish the benefits that can be generated by demand management strategies (land use, PT and NMT). The emissions of air pollutants that are expected in 2031 if the land use scenario is adopted are presented in Table 6-2 and Table 6-3. Owing to the substantial reduction in the use of private automobiles as compared to the BAU scenario, the pollution levels are also low, especially the NOx an SOx levels. Likewise, the air pollutants that are expected in 2031 if NMT and PT strategies are adopted are presented in Table 6-4, Table 6-5 and Table 6-6, Table 6-7. In the PT scenario, as some of the road space is freed up from a greater portion of trips being made using PT, it is expected that car use will increase. Second, the consumption of diesel and air pollution resulting from the use of diesel as fuel is also expected to increase. The CO_2 emissions in 2031 would reduce by 60 per cent from 1.08 million tonnes estimated in the BAU scenario to 0.33 million tonnes in the technology/LCD scenario. Moreover, in the technology scenario, a further 27 per cent saving in carbon from the PT scenario can be achieved (Table 6-9, Table 6-10). The per capita emissions would also reduce to 0.11 tonnes from the 0.73 tonnes estimated in the BAU scenario.

Table 6-9: CO_2 emissions (LU+NMT+PT+Tech – LCD scenario)

Vehicle type	Annual CO_2 emissions (million tonnes)				
	2031 (BAU)	2031 (LU scenario)	2031 (LU+NMT scenario)	2031 (LU+NMT+PT scenario)	2031 (LU+NMT+PT+ Tech.scenario)
2Ws	0.08	0.06	0.06	0.02	0.02
Cars	0.53	0.09	0.09	0.06	0.05
MUVs	0.04	0.01	0.01	0	0.00
Taxis	0.01	0	0	0	0.00
3Ws	0.00	0	0	0	0.00
Buses	0.14	0.34	0.25	0.32	0.25
HDVs	0.20	0.03	0.03	0.02	0.01
LDVs	0.07	0.01	0.01	0.01	0.00
Total	1.08	0.55	0.45	0.45	0.33

Table 6-10: Emissions of other air pollutants, year 2031 (Technology scenario)

Veh. type	Annual PM 2.5 emissions (tonnes)			Annual PM10 emissions (tonnes)			Annual NOx emissions (tonnes)		
	Petrol	Diesel	Gas	Petrol	Petrol	Diesel	Gas	Diesel	Petrol
2Ws	3.19	0.00	0.00	3.75	3.04	0.00	7.96	18.91	0.00
Cars	0.45	178.32	1.53	0.53	18.44	0.13	57.31	86.86	11.64
MUVs	0.01	20.62	0.00	0.02	0.53	0.02	1.66	2.51	1.68
Taxis	0.00	6.92	0.00	0.00	0.00	0.00	0.00	0.00	0.42
3Ws	0.00	0.00	1.61	0.00	0.00	0.36	0.00	0.00	2.41
Buses	0.00	75.10	0.00	0.00	0.00	88.53	0.00	0.00	466.63
HDVs	0.00	125.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LDVs	0.00	19.33	0.00	0.00	0.00	0.99	0.00	0.00	4.60
Total	3.65	18.71	90.04	4.29	22.01	90.04	66.93	108.28	487.38
Veh. Type	**Annual CO emissions (tonnes)**			**Annual HC emissions (tonnes)**			**Annual SO_2 emissions (tonnes)**		
	Petrol	**Diesel**	**Gas**	**Petrol**	**Diesel**	**Gas**	**Petrol**	**Diesel**	**Gas**
2Ws	216.00	98.54	0.00	255.81	94.56	0.00		1.54	
Cars	247.14	226.54	79.69	38.50	14.33	0.45		6.34	
MUVs	7.14	6.55	11.52	1.11	0.41	0.06		0.22	
Taxis	0.00	0.00	2.88	0.00	0.00	0.02		0.00	
3Ws	0.00	0.00	22.06	0.00	0.00	1.25		0.00	
Buses	0.00	0.00	1674.63	0.00	0.00	47.97		0.00	
HDVs	0.00	0.00	0.00	0.00	0.00	0.00		0.00	
LDVs	0.00	0.00	3.47	0.00	0.00	0.95		0.00	
Total	470.28	331.63	1794.25	295.43	109.30	50.70	0.00	119.15	0.00
Veh. Type	**Annual BC emissions (tonnes)**			**Annual OC emissions (tonnes)**					
	Petrol	**Diesel**	**Gas**	**Petrol**	**Diesel**	**Gas**			
2Ws	0.16	1.29	0.00	1.27	0.78	0.00			
Cars	0.02	7.83	0.00	0.18	4.70	0.08			
MUVs	0.00	0.01	0.00	0.01	0.27	0.01			
Taxis	0.00	0.00	0.00	0.00	0.00	0.00			
3Ws	0.00	0.00	0.01	0.00	0.00	0.22			
Buses	0.00	0.00	1.77	0.00	0.00	53.12			
HDVs	0.00	0.00	0.00	0.00	0.00	0.00			
LDVs	0.00	0.00	0.00	0.00	0.00	0.00			
Total	0.18	9.14	1.78	1.46	5.75	53.43			

6.7. Summary

The LCMP study for Rajkot presents the LCD scenario for 2016, 2021 and 2031, and strategises it as land use, NMT, PT and technologies, shows a large decline in the use of private vehicles, vehicle kilometres travelled and CO_2 emissions. If all the scenarios and strategies are implemented, carbon emissions can be reduced by more than 60 per cent to 0.11 tonnes per capita, which is lower than the current desired standards of 0.5 to 2.7 tonnes for Indian cities (Dhar et al., 2013). Now that the indicators mentioned in chapters 3 and 4 have been examined for both the BAU and LCD scenarios, a collective table representing the results of all scenarios is shown below in Table 6-11:

Table 6-11: Comparison of different strategies

Variables	BAU 2031	Land use 2031	NMT 2031	PT 2031	Technology scenario
Modal shares	NMT – 29% PT – 11% Private – 57%	NMT – 38% PT – 22% Private – 40%	NMT – 48% PT – 23% Private – 29%	NMT – 44% PT – 29% Private – 27%	NMT – 44% PT – 29% Private – 27%
Average travel time (min)	27	16	16	16	16
Average trip length (km)	6.0	3.9	3.9	3.9	3.9
Land use mix intensity	-NA-	City Centre: 0.80 Major nodes: 0.75 Minor nodes: 0.50 Corridors: 0.40	City Centre: 0.80 Major nodes: 0.75 Minor nodes: 0.50 Corridors: 0.4	City Centre: 0.80 Major nodes: 0.75 Minor nodes: 0.50 Corridors: 0.40	City Centre: 0.80 Major nodes: 0.75 Minor nodes: 0.50 Corridors: 0.40
% of road with >2 m footpath	8%	8%	35%	35%	35%
% of lit roads	83%	83%	88%	88%	88%
% of lit footpaths	35%	35%	100%	100%	100%
% of roads with cycle lanes	1.7%	1.7%	10%	10%	10%
Accident rate (per million population)	217	190	147	138	138
PM2.5 (tonnes)	521.10	415.88	419.24	376.35	317.09
PM10 (tonnes)	612.50	488.94	493.01	442.66	368.25
SO_2 (tonnes)	130.63	119.15	119.15	119.15	119.15
NO_X (tonnes)	7490.61	7364.15	8002.86	7237.80	5683.62
CO (tonnes)	13777.82	6788.53	4927.44	4278.52	4101.95
CO_2 (million tonnes)	1.08	0.65	0.64	0.57	0.52
Per capita CO_2 (tonnes)	0.73	0.212727	0.213333333	0.19	0.17875
HC (tonnes)	6398.17	4375.05	2383.49	2128.02	1923.32
BC (tonnes)	126.59	110.76	119.25	107.43	81.51
OC (tonnes)	126.63	121.50	122.21	110.41	100.60

Chapter 7: LCMP Projects

This chapter encapsulates the projects to achieve low carbon development for the horizon years. The projects are phased for immediate actions, i.e. in 2016 or for future development in 2031. The current block costs of these projects have also been listed along with the projects to be implemented.

7.1. LCMP Elements

The low-carbon Comprehensive Mobility Plan aims to achieve low carbon emissions in the transport sector by promoting greater use of non-motorised transport, which emits zero carbon, and to promote the public transport system, which is more effective than private vehicles in terms of costs as well as carbon emissions. The low-carbon scenario indicates that by 2031, emissions would have reduced by 31 per cent on account of a mutually supportive land use and transport policy, and the provision of NMT and PT infrastructure. The low-carbon scenario also includes adaption of new fuel technologies by 2031, further reducing emissions compared to the BAU scenario. The projects to be included in line with the plan would also support the abovementioned strategies. The phasing of the projects would be according to the chart shown in Figure 7-1. This inverted triangle first prioritises NMT infrastructure, followed by PT infrastructure, carpooling or sharing of vehicles and finally, the use of private vehicles. This does not include land use changes or interventions for sustainable transport. In this project, as for the low-carbon scenario, land use interventions will also help in reducing emissions.

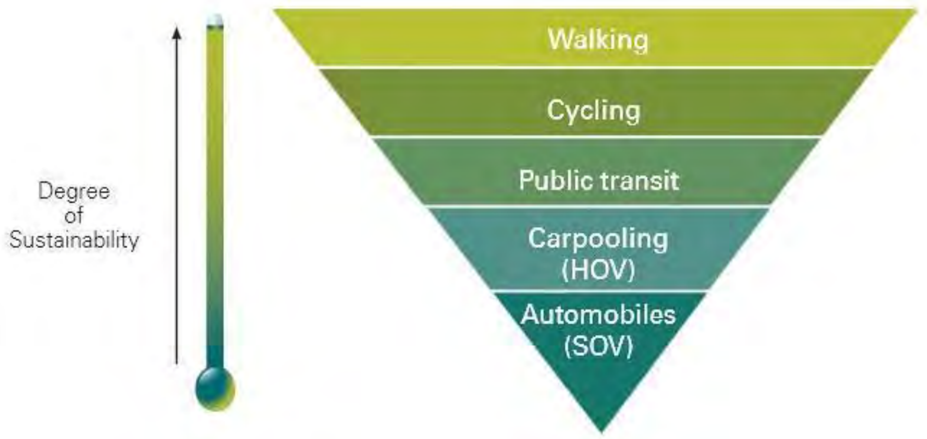


Figure 7-1: The inverted triangle of sustainability

7.1.1. Land use plan

The land use plan is part of the low-carbon scenario, and includes residential, commercial and industrial developments. The land use interventions involve proposed modifications to the GDCR and DP for higher residential and commercial densities, and higher job-housing ratios at the identified major nodes and corridors. Design elements include higher intersection density, having commercial or retail situated on the ground floor and first floor, with residential on the upper floors to make streets active and safer, and designs of bus stations for all, including the low income group and disabled. The GDCR should be altered so as to allow setbacks only at the front of the building, while open space can be permitted at the back resulting in uniformity in the alignment of buildings. Thus, the proposed land use projects suggest modifications in the densities and diversities at major and minor nodes, and urban design changes are necessary to make streets livelier throughout the day for a safer and more walkable city.

7.1.2. Non-motorised transport plan

Pedestrian plan

All streets in the city should provide pedestrian facilities and access, and pedestrian needs should be considered at every location in the city. A 180km-long pedestrian network has been identified. The pedestrian corridors identified in this network are defined as high quality routes that are interconnected, providing quality facilities for pedestrian users and accessibility throughout the city. Considerations must be made for the basic needs of all users, which include the connectivity and convenience of facilities, space to travel, routes free of obstructions, and the conveyance of a general character and feeling of security and safety. Footpaths in the city must provide a comfortable environment for pedestrians and be free of obstructions wherever possible. The pedestrian network should have the following minimum infrastructure:

- Minimum clear (unobstructed) and continuous sidewalks are to be provided, particularly in areas near high-pedestrian volume generators and high-use transit corridors,
- Public realm elements would have a strong influence on the character of the city, and function as primary elements of area-linkages, and
- City-identified components (plantings, street furniture, etc.), unique to various precincts, should be considered in an integrated manner when issuing guidance to developers and in corridor improvement projects.

Bicycle plan

A bicycle network has also been identified based on demand and analysing points of origins and destinations of cyclists. A bicycle network is important in establishing cycling as a viable mode of travel in the city. Bicycle-friendly designs include shared lanes, bicycle lanes and separated pathway facilities. Adequate space to ride, smooth surfaces clear of obstacles, a connected cycling system, continuity, parking and other amenities at destinations, character, a sense of security and safety, traffic education, and enforcement of operations and regulations are key to the success of the cycling strategy. Bike stations at strategic locations also need to be provided. In Rajkot, despite almost 38 per cent of people surveyed preferring to walk, and 11 per cent preferring to cycle, only 7 per cent of footpaths are walkable and less than 1 per cent of roads have a separate cycle track. Thus, a network of walkable footpaths (greater than or equal to 2m in width) and cycle tracks have been identified where there is a preference to use these modes. It is also recommended that every road with a right-of-way greater than 6m should compulsorily have a footpath, at least on one side.

A list of infrastructure improvement interventions that have been identified with a view towards facilitating cycling and walking in Rajkot is shown in Table 7-1.

Table 7-1: Non-motorised transport projects

Sl. No	Infrastructure types	Link descriptions	Unit (km)
1.	Footpath (widened)	80ft. Road	3.4
2.	Footpath (widened)	Dhebar Road	8.4
3.	Footpath (widened)	University Road	13.7
4.	Footpath (widened)	Kalawad Road	5.2
5.	Footpath (widened)	Raiya Road	24
6.	Footpath (widened)	Canal Road	0.75
7.	New Footpath	Kothariya Road	16.5
8.	New Footpath	Jamnagar Road	14.7
9.	New Footpath	Gonadl Road	7.0
10.	New Footpath	Kuwadva Road	3.1
11.	New Footpath	Mavdi Road	7.2
12.	New Footpath	Hospital Chowk to Race Course Road	2.8
13.	New Footpath	St. Kabir Road	1.8
14.	Dedicated cycle track	Raiya Road	24
15.	Dedicated cycle track	Kuwadva Road	3.1
16.	Dedicated cycle track	Jamnagar Road	14.7
17.	Dedicated cycle track	Gondal Road	7.0
18.	Dedicated cycle track	80ft. Road	3.4
19.	Dedicated cycle track	Kothariya Road	16.5

7.1.3. Public transport plan

The LCMP identified principles and policies that prioritised more sustainable modes of travel and the needs of pedestrians and cyclists in the city, particularly in the centres of activity. The LCMP goals, which include ‘enabling public transit, walking and cycling as the preferred mobility choices for more people’ and ‘advancing environmental sustainability’, are reflected here. Specific policies and associated objectives, e.g. transportation choice, walking and cycling, transit choice, and goods movement, are also reflected in this plan. The streets in the plan are classified as arterial, sub-arterial, collector and local roads. Streets lower in the hierarchy are expected to be reached by walking and cycling. However, connectivity on long distances on arterials would be covered by public transport. Since no citywide public transport exists in Rajkot, a public transport network has been identified through the use of a demand-based model. With this, transport infrastructure such as buses, bus stops and terminals are also considered. The public transport projects, as listed in Table 7-2, would increase the coverage and length of bus routes with an increased bus fleet and an appropriate number of bus stops ensuring frequency. This plan would also require PT accentuated signals, connectivity of pedestrians and cyclists to PT stops, and parking spaces for private vehicles near bus stops and bus terminals.

Table 7-2: Public transport projects

PHASE – I (2011-2016)

Sl. No	Infrastructure types	Descriptions
1.	Bus requirement	161 standard buses, 600 mini buses
2.	Bus depot	4 units near Airport, near PTC Chowk, Nana Mauva Road and Gondal Chowk
3.	Bus stops	724 shelters

PHASE –II (2016-2021)

Sl. No	Infrastructure types	Descriptions
1.	Bus requirement	65 standard buses, 85 mini buses
2.	BRT corridor	24 km

PHASE –III (2021-2031)

Sl. No	Infrastructure types	Descriptions
1.	Bus requirement	449 standard buses, 752 mini buses
2.	Bus depot	2 units in the south and west of Outer Ring Road
3.	BRT Corridor	27 km

7.1.4. Road network plan

An arterial road provides a high quality environment for all modes of transportation, with varying degrees of interaction with adjacent land uses, and is composed of high volume or lower operating speed traffic movement. This type of road serves mixed land uses, and gives highest priority to goods, vehicle and transit movement. The arterial roads in the city are Kalawad Road, Gondal Road, Dhebar Road, 80ft Road, Jamnagar Road, Mavdi Road and Kothariya Road. Presently, much of the transit, private vehicle and goods movement traffic in the city is along these roads, and will continue to be so in the future. However, many of these routes also serve as pedestrian corridors and need to provide quality facilities for pedestrians as well. The LCMP plan accords the highest priority to walking, cycling and transit, yet accommodates reasonably high volumes of goods and vehicle traffic. In Rajkot, the road width is inconsistent, creating bottlenecks and hampering the traffic flow. Such stretches have been identified, which need to be widened so that a consistent road width can be maintained. Additionally, an increased number of bridges across the river are proposed to facilitate better connectivity between the eastern and western parts of the city (Table 7-3).

Table 7-3: Road network projects

Sl. No	Infrastructure types	Descriptions
1.	River bridge	1 bridge between Kaiser-e-Hind and Indira bridges
2.	River bridge	1 bridge between Indira bridge and Doodhsagar
3.	Junction improvements	75 junctions with signals, crosswalks and signs
4.	New roads	Outer Ring Road of 55km, and other roads of length 100km

7.1.5. Safety, security and traffic management

Safety, security and traffic management take into consideration the type of pavement, traffic speeds and the percentage of lit roads. In the BAU scenario, only 70 per cent of roads and 30 per cent of footpaths are lit, which should ideally be 100 per cent. Pedestrian and bicycle accentuated signals, cross walks and bicycle lanes at intersections would reduce the speed of vehicles, lowering the number of accidents.

7.2. Block Cost Estimates

A block cost estimation of the projects has been prepared, which covers road works, road/pavement marking, street furniture, landscaping, electrification, traffic signals and other miscellaneous items. Generally, costs are estimated on the basis of the rates decided by the government, and in some cases a lump sum amount has been determined by considering similar projects or on a rule-of-thumb basis. In addition to road network improvements, a citywide transport network is also proposed, for which the infrastructure requirements have been calculated on the basis of future demand arising from the demand model. Table 7-4 shows the related costs of the network.

Table 7-4: List of projects

Projects	Unit	Unit cost (in Cr.)	Total cost (in Cr.)	2016 (in Cr.)	2021 (in Cr.)	2031 (in Cr.)
Non-motorised transport						
Footpath	378km	0.22/km	84.03	52.15	20	11.88
Cycle lane	161km	0.48/km	80.96	51.80	0	29.16
Public transport						
Bus requirement	ST- 675 Mini- 1443	0.4 0.25	270 360	64 169	26 3	180 188
Bus shelter	724	0.03 /shelter	21.72	21.72	0	0
Bus depot	6	6	36	24	0	12
BRT	51km	12/km	612	0	288	324
Traffic management						
Junction improvements	75	0.5	37.5	20	17.5	0
Signage and road markings	248km	0.03/km	7.23	5.23	0	2
Road works						
New roads	54km	1.66/km	358	0	0	358
River bridges	2km	4/km	8	1.6	0.8	5.6
Street furniture			5.8	4.0	0	1.8
Street lights			74.6	33.9	25.6	15
Total			**1955.84**	**447.4**	**380.9**	**1127.4**

7.3. Stakeholder Workshop to Identify Projects

The stakeholder workshop on LCMP for Rajkot city was held on 30th of November, 2013 at the RUDA building in Rajkot. It was held to get suggestions on the new methodology of the comprehensive mobility plan adopted for Rajkot city. The workshop included a presentation by Dr. Talat Munshi on the BAU and Low-Carbon Scenarios (LCS), and projects identified as part of the LCMP project. The presentations were followed by a rich discussion with stakeholders, which gave some new perspectives and suggestions on the implementation of this project in the city after making a Detailed Project Report (DPR) for the same.

Introduction of the Project: Ms. Alpana Mitra from the Rajkot Municipal Corporation introduced the LCMP project by explaining its importance for suggesting changes in the ongoing development plan of Rajkot. She added that the LCMP team had been working diligently on the project, and had devised the project proposals, which could be further detailed out for implementation. She further praised the project by saying that the comprehensive mobility plan toolkit had been changed as per the LCMP proposals developed for three cities, namely Rajkot, Vishakhapatnam and Udaipur, with the help of funding from UNEP, Denmark. She then asked Dr. Talat Munshi to begin his presentation.

Figure 7-2: Image showing participants in the workshop

Low-carbon Comprehensive Mobility Plan for Rajkot city: Dr. Talat Munshi started the presentation thanking Ms. Alpana Mitra and the whole of Rajkot Municipal Corporation for their support and guidance in studying the city. He thanked the Rajkot authorities for providing building footprint-level data in GIS format, which was of great help to the team. He moved forward with the presentation, starting with the city's basic demographics and growth pattern. Citing the potential for growth and the considerable population increase in the last decade, he emphasised the likely increase in demand for infrastructure in the coming years. He discussed the trend of increasing vehicle ownership, fatal accidents and carbon emissions in the city, showing trend lines for the past ten years. He then identified the need to model the land use and transport scenarios for the next twenty years in recognition of the increase in population and vehicle ownerships. He presented the types of data that were needed along with their sources, and the modelling methodology. He went on to show the analysis of the modal share and the vehicle kilometres travelled by people, illustrating the travel behaviour of the city. Projecting the population for 2031 and the per capita space requirement[36] for residential and commercial spaces, the land use simulation for 2031 showed haphazard city sprawl in all directions. Depicting the BAU scenario with current transport infrastructure, he presented a map showing congestion on all the present roads with increasing numbers of vehicles on the road, and longer travel times due to sprawled land use.

Figure 7-3: Ms. Alpana Mitra from RMC, introducing the project

Envisioning the future of the city, Dr. Munshi stated that the team had attempted to strategise the growth of the city and lower carbon emissions from transport. To find the best possible strategy for the city's sustainable growth, the four strategies considered were the land use strategy, non-motorised transport strategy, public transport strategy and technology strategy. He noted that the land use strategy proposed in the LCMP project conceptualised the node-corridor development, where some of the major and minor nodes are identified and expected to have higher mixed use and densities than other parts of the city. The major and minor nodes identified can also act as the transport hubs with interchange stations and the highest connectivity to public transport and non-motorised transport facilities. Dr. Talat Munshi drew everyone's attention by saying the present modal share of non-motorised transport in Rajkot is 48 per cent, which is likely to go down to 29 per cent in 2031 given the increasing trend of vehicle ownerships. He presented the need for a non-

[36] The per capita space requirement for residential space has been derived from the projected change in household size in twenty years.

motorised transport strategy with a better network of continuous pedestrian footpaths and cycle lanes for cyclists. He outlined the public transport strategy, which involved higher frequency and better quality public transport options for people travelling distances too long to walk or cycle. Finally, the technology strategy was considered, which assumed a 20 per cent transfer of petrol vehicles to bio-fuel, CNG and electricity vehicles, leading to a 20 per cent reduction in carbon emissions. These strategies were further expanded for the types of projects that can provide an approximate costing. He concluded the presentation by encouraging suggestions from the authorities on the two projects that could be taken further by the team. He then opened the floor for discussion and comments. The presentation was followed by a discussion in which several questions were raised and addressed regarding the duration of the plan and the type of technical staff needed. A point was raised concerning the feasibility of running public transport in such a small city, where it has failed till now. It was suggested that public transit planning should not be the first objective of the present CDP, as certain routes were being planned by the Rajkot Municipal Corporation and a separate process was underway for planning the transit system. After deliberation, it was decided that this plan would also consider public transport provided by the bus system, and will not concentrate on identifying BRT/Metro corridors upfront, as these will be identified in time on the basis of need and demand.

Figure 7-4: Dr. Talat Munshi presenting LCMP for Rajkot city

Municipal Commissioner Mr. Ajay Bhadoo suggested that the LCMP report should concentrate on preparing DPRs to support pedestrian and bicycle movement in the city. Several points were raised regarding the cycle tracks lying idle on the new Ring Road, and therefore whether such tracks should be built throughout the city. There was also discussion on raising FSI in certain parts of the city. Questions were raised regarding widening roads to accommodate the number of vehicles. Dr. Munshi and the LCMP team addressed these questions. Mr. Bhadoo expressed his pleasure that Rajkot city was the focus of such a detailed study.

Figure 7-5: Commissioner Ajay Bhadoo commenting on the presentation

The team addressed road-widening questions by acknowledging that roads will have to keep on widening, given the current trends of motorization. Each car would then require three parking slots, one each at origin (home), destination (office) and intermediate destination (grocery store, for example). The provision of such facilities would have to be at the cost of investments in education and health which would not be desirable. The team also expressed its views on sustainable transport, which involve the provision of non-motorised transport infrastructure network throughout the city to lower carbon emissions, demand less road space in future years and abate city sprawl. They mentioned that sustainable transport in Rajkot also calls for public transport in the form of feasible mini buses. The team also clarified that rather than increasing densities on the corridor, it is beneficial to allow more mixed use on the streets with concentrated densities on the nodes, connecting to the public transport corridors. Town Planning Officer Mr. B.H. Rupani from RMC argued in favour of a TOD development similar to that being proposed along the BRT corridor in Ahmedabad. But the LCMP team strongly recommended against higher FSIs on the BRT corridors, as it attracts real estate agents, depriving the urban poor and middle class from using the system.".

GIS expert Dr. Nitin Bhavsar from RUDA mentioned that autorickshaws in Rajkot are in the process of being converted from petrol to CNG, which is assumed to emit less carbon. Dr. Munshi responded that this is not the only solution, and that the corporation could consider other means stated in the report to get better results. The land use simulation conducted by the LCMP team was highly appreciated by the authorities, and ways of taking it further in the ongoing development plan were discussed. The traffic police, present in the workshop, were also given the responsibility by the higher authorities of managing traffic and creating a traffic plan for the city. The team further clarified that all the four strategies mentioned above needed to be worked upon in an integrated manner to ensure positive change. Regarding the finalisation of the project to be further detailed out by the team, Commissioner Ajay Bhadoo emphasised the non-motorised transport network, as RMC had begun trialling 30-seater mini buses on the roads of Rajkot. The team agreed to create a detailed project report for non-motorised transport, and submit both the reports to the Rajkot Municipal Corporation as soon as possible.

Table 7-5: List of workshop attendees

Sl.	Name	Designation	Organisation
1	Ajay Bhadoo	Commissioner	RMC
2	Alpana Mitra	A.S.D	RMC
3	J.A. Tank	AIMV	RTO, Rajkot
4	K.T. Sapariya	Administrative Head	RUDA
5	M.V. Dholariya	Assistant Manager	RUDA
6	Dr. Nitin Bhavsar	GIS Expert	RUDA
7	A.A. Borad	Town Planner	RUDA
8	Pradeep. P. Trivedi	President	ACCE, Rajkot
9	B.H. Rupani	Town Planning Officer	RMC
10	Bharat Kharecha	Committee Member	Rajkot Chamber
11	Hitenbhai Jasani	Committee Member	Rajkot Chamber
12	A.M. Herma	Police Sub-Inspector	Traffic Branch
13	Yash Dave	Planning Supervisor	RMC
14	Mitesh Chauhan	MIS	RMC
15	Utkarsh Shah	GIS Specialist	RMC
16	Chirag Joshi	–	RMC
17	Dr. Talat Munshi	Project Coordinator	CEPT
18	Suchita Vyas	Research Associate	CUE
19	Neha Bhatia	Research Associate	CUE
20	Kalgi Shah	Research Associate	CUE
21	Yogi Joseph	Research Associate	CUE
22	Deepali Advani	Research Associate	CUE
23	Vishal Darji	Research Associate	CUE
24	Tejas Patel	Research Assistant	CUE
25	Sayan Roy	Research Associate	CUE

7.4. Summary

The concept of the LCMP is to reduce emissions from the transport sector. It has been shown that this can be achieved by reducing trip lengths, reducing automobile dependence and promoting non-motorised modes of transport and public transit systems. To facilitate implementation, the projects are organised on the basis of different categories, such as the non-motorised transport plan, public transport plan, land use plan, safety, security and traffic management plan and road-network plan.

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